WEBINAR: CHOOSING A CODEC IN 2021 AND BEYOND

Jan Ozer
www.streaminglearningcenter.com
jozer@mindspring.com/
276-235-8542
@janozer

Agenda

- Where codecs come from and what they cost
- Hardware vs. software codecs
- Meet the codecs
  - Existing
  - New rules of codec integration
  - MPEG 2020
- Analyzing quality
  - Codec vs. encoder
  - Academic vs. real world trials
  - What BD-Rate doesn't tell you
- Performance results
  - LCEVC
  - VVC
- Codecs and the roles that they play (handicapping adoption)
- Question and answer

Where Codecs Come From and What They Cost

- Standards-based
- “Open-Source”

Standards Based

- Which codecs
  - MPEG-2, H.264, HEVC, VVC, EVC, and LCEVC
- How created
  - By committees that establish goals/targets
  - Multiple companies contribute (usually patented) encoding “tools” which are tested for effectiveness and either included or excluded
  - Very formal process with multiple test iterations
- How funded
  - Typically, via one or more “patent pools” (more later)
  - Companies are free to join or not join a pool
  - Companies who contribute to a standard often must pledge to make their standard-essential patents available either:
    - Royalty free or
    - “Fair, reasonable and non-discriminatory” (FRAND) royalties

Open Source

- Example
  - Ogg Theora / Xiph.org (home grown)
  - VP8/WebM
    - Google bought On2
    - Then open-sourced as WebM; later shipped VP9
  - AV1
    - Alliance for Open Media formed in 2015
    - Merged multiple open-source projects like VP9, Thor (Cisco), Daala (Xiph), plus IP from Microsoft, Intel and many others
    - AOM states that all contributes are vetted to ensure they don't use third-party IP

- AOMedia Royalty status (bit.ly/aom_royalty)
  - Established a royalty-free patent licensing commitment from all AOMedia members
  - Completed a comprehensive evaluation of the video codec patent landscape and performance of patent due diligence by world-class codec engineers and legal professionals during the development stage
  - Adopted the AOMedia Patent License 1.0, which gives all AV1 implementers, both AOMedia members and non-members, royalty-free patent rights to the AV1 codec in exchange for the same royalty-free patent commitment; and
  - Established the AOMedia patent defense program to help protect AV1 ecosystem participants in the event of patent claims.

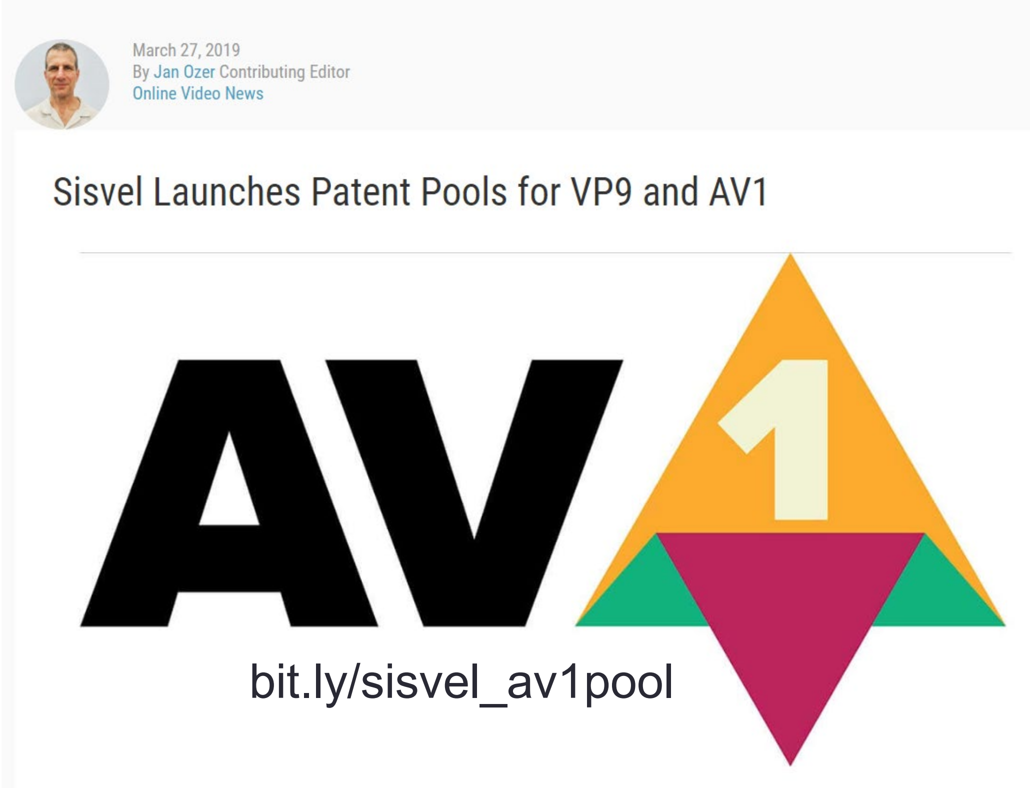
Royalty Free? – VP8

- VP8
  - Feb/2010 – On2 purchased by Google getting VPx codecs
  - May/2010 – VP8 open sourced as WebM
  - Feb/2011 – MPEG LA starts patent pool for VP8
  - March/2013 – Google signs license agreement with MPEG LA for "techniques that ***may be*** essential to VP8 and earlier-generation VPx video compression technologies under patents owned by 11 patent holders"
  - MPEG LA closes patent pool

- Terms not disclosed; strong assumption that substantial funds (cough, cough royalties) changed hands
- Google has claimed open-source = royalty free in the past; and (it looks like) they ended up paying royalties
- http://bit.ly/google_mpegla

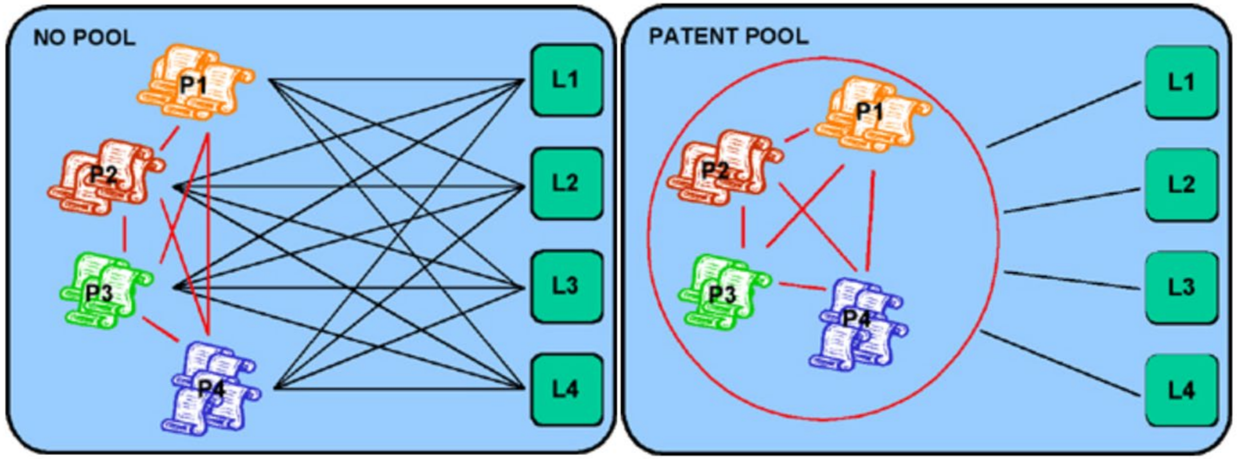
VP9/AV1: Sisvel Pools

- Sisvel patent pool for AV1/VP9 and threats from Velos
  - Consumer device only
  - No content
  - No cap
  - Software tbd
- Patents in pool
  - VP9 – 765 (to date; more coming)
  - AV1 – 1461 (to date; more coming)
  - Members include Dolby, Ericsson, GE, Philips, NTT Docomo, Orange, Toshiba
- Full disclosure – I consult with Sisvel on marketing matters



bit.ly/sisvel_av1pool

A Quick Primer on Patent Pools



- Courts frown on pooling of interests (anti-trust violation)
- Patent pools allowed (in part) because dramatic savings in administrative costs
- On left
  - No pool – each licensee needs separate agreement with each patent owner
  - So do patent owners
- On right
  - Each licensor has one agreement with pool
- Big But – DOJ (and global equivalents) strongly suggest that pools evaluate each included patent for "essentiality" to the covered technology
  - This gets very expensive

Measuring Costs and Benefits of Patent Pools

Table 1: *Costs of Establishing the MPEG Audio Patent Pool*

Expenses (over a two-year period)	Costs to Via Licensing	Costs to 14 Licensors
Employee Salaries	$385,000	$1,120,000
Travel & Lodging (13 meetings)	$104,000	$728,000
Patent Evaluation Fees	$5,250,000	
IT and Administrative Costs	$200,000	
Subtotals	$5,939,000	$1,848,000
Total Estimated Costs	$7,787,000	

https://bit.ly/pool_benes

Description of Transaction Costs	MPEG Audio Standard
Transaction Costs Devoted to Search and Negotiations in Absence of Patent Pool	$635,880,000
Transaction Costs Associated with Establishing Patent Pool	$7,787,000
Transaction Costs Conserved	$628,093,000

- Law Journal article modeling benefit of a patent pool
- VIA MPEG-audio pool
  - $5.25 million for MPEG Audio Pool (700 patents @ $7,500/ analysis)
  - ~ $8 million total startup

- Total transaction costs if licensed separately (805 licensees)
  - $636 million
  - Less costs
  - $628 transaction costs conserved

Key Points

- Patent pools are subject to legal scrutiny
- Third-party examiners are almost always used to analyze essentially (with antitrust litigation as the potential stick)
- You don't just "throw a patent pool together"
  - It's very, very expensive and time consuming
- Does this mean that AV1/VP9 are not royalty-free?
  - No: Google/AOM can argue
    - Patents invalid
    - Third-party examiners wrong
    - VP9 – 765 (to date; more coming)
    - AV1 – 1461 (to date; more coming)
- But it does mean that open-source does NOT equal royalty-free
  - Determined on a case-by-case basis

Hardware vs. Software Codecs

- Software codecs
  - Can be played in software without performance issues or significantly shortening a device's battery life
  - Can be deployed immediately
    - PCs – best if supported by browsers, but otherwise implementors can achieve compatibility by using a specific player (like Bitmovin, JWPlayer, or THEOPlayer)
      - May give rise to a royalty
    - Mobile devices – can be deployed within apps
    - Smart TV/OTT/STB – may be supportable by apps; device dependent

- Hardware codecs
  - Too complex for real time playback on many current computers and/or will overconsume battery life on devices
  - Can't be deployed until hardware decode is available
    - Typically, a 2-year cycle after standard finalization (and royalty setting)
    - Plus, the time it takes for the codec to achieve a critical mass in relevant target markets (maybe another 2-3 years?)

Meet The Codecs

- H.264
- VP9
- HEVC
- AV1
- MPEG Codecs 2020
  - Versatile Video Coding (VVC)
  - Essential Video Coding (EVC)
  - Low-Complexity Enhancement Video Coding (LCEVC)

Current Codec Overview

	H.264
Heritage	Standards-based
Patent pool(s)	MPEG LA
Royalties on paid content	Subscription/PPV
Royalties on free internet video	No
Royalty on hardware enc/dec	Yes
Royalty on software enc/dec	Yes
Max annual known royalty	MPEG LA - $9.75M
Hardware or software	Software

New Rules of Codec Deployments

- Impact of the HEVC Royalty Imbroglio
- Impact of the Alliance for Open Media

The Impact of the HEVC Royalty Imbroglio

1/2013 1/2014 1/2015 1/2016 1/2017 1/2018 1/2019 1/2020 1/2020

MPEG
FDIS

1/2014
MPEGLA

-$0.20/unit
- $25 mill cap
- no content royalties

7/2015
HEVCAdvance

- up to $1.50/unit
- No cap (added later)
- Content royalties (.005% revenue dropped later)

3/2017
VELOS media

- Doesn't specify terms
- Doesn't rule out content royalty (to this day!)

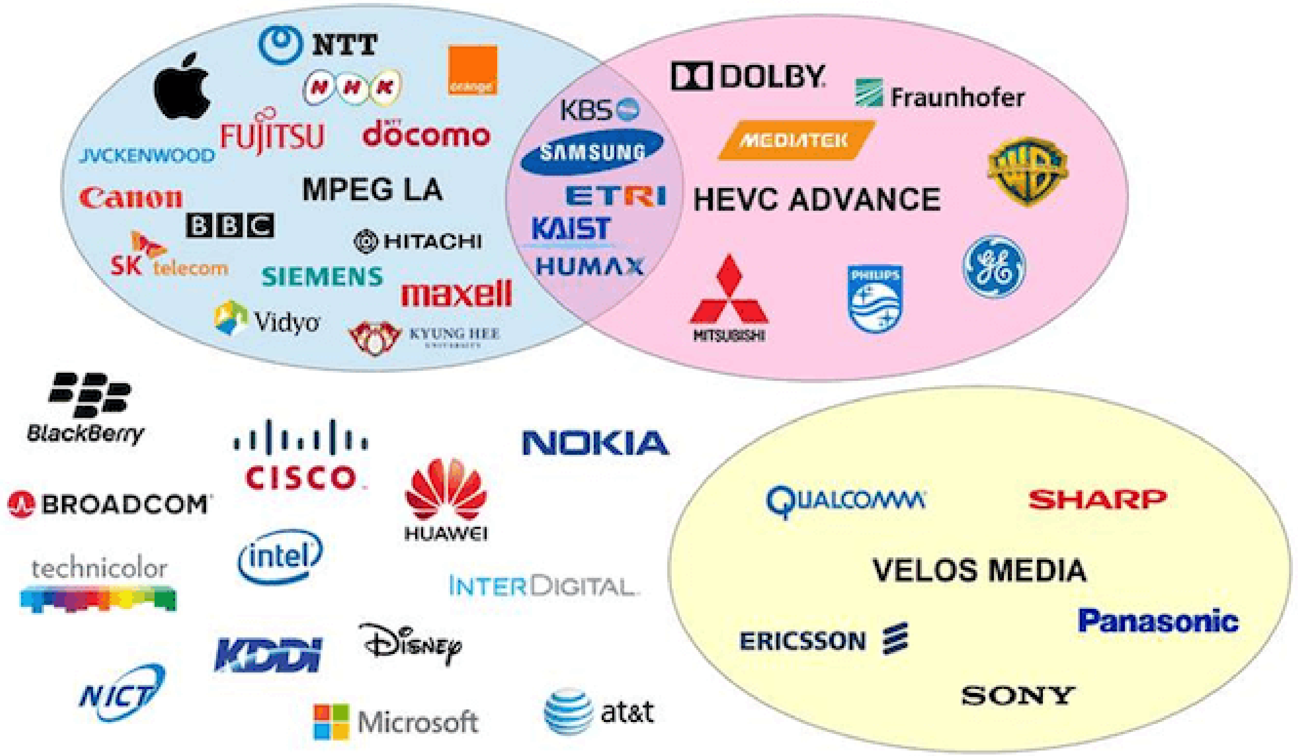
One year

2.5 years

4.25 years

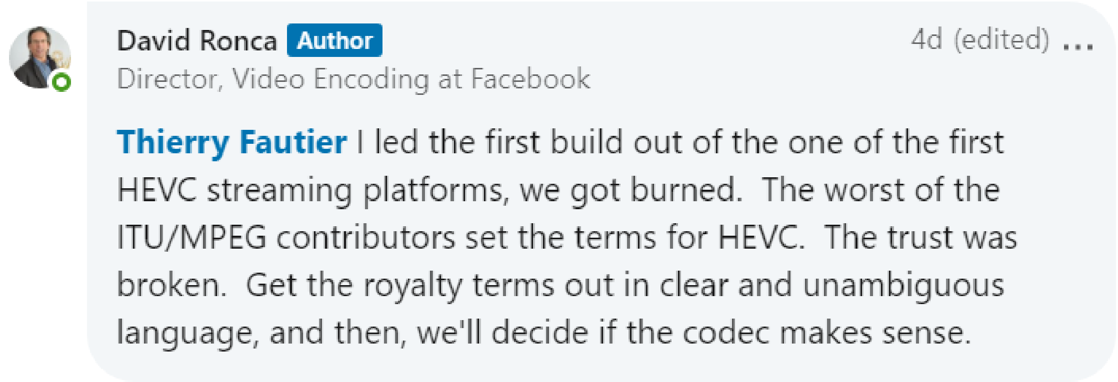
Picture of Disarray (HEVC Patent Ownership 2017)

- Created by Jonatan Samuelsson of Divideon in 2017
  - Now with Apple
- Three pools with substantial companies outside of any pool (and some in two)



Caused Delay in Technology Adoption

- With MPEG-2, H.264, and HEVC, many companies started integrating the technologies before the royalty structure was final
- Post HEVC, that's much less likely to happen
  - Many (if not most) of large integrators (TV, phone, OTT, STB, CPU, GPU, SoC) won't decide to integrate a new technology until the royalty structure is known
  - This delays potential integrations



David Ronca Author 4d (edited) ...
Director, Video Encoding at Facebook

Thierry Fautier I led the first build out of the one of the first HEVC streaming platforms, we got burned. The worst of the ITU/MPEG contributors set the terms for HEVC. The trust was broken. Get the royalty terms out in clear and unambiguous language, and then, we'll decide if the codec makes sense.

David Ronca Author 4d ...
Director, Video Encoding at Facebook

Thierry Fautier When EVC and/or VVC have clear royalty terms, they may be interesting codecs. In the mean time, don't be surprised if there are few companies willing to jump on the "deploy our codec now, and trust us for fair and clear royalty terms" train. We did that in 2014. Didn't go so well.

http://bit.ly/VVC_timing

The Impact of The Alliance for Open Media (and AV1)

- Prominent members include:
  - Desktop and mobile OS – Apple, Microsoft, Google
  - Device – Apple, Google, Samsung, Amazon
  - Component – Intel, NVIDIA, ARM, Ittiam
  - Content – YouTube, Netflix, Amazon, Facebook, Hulu,
  - Infrastructure – Bitmovin, Ateme, AWS Elemental

Control Desktop OS

Windows 10 Mac OS

Control Mobile OS/hardware

android iOS

Control Browsers

Control Components

intel AMD NVIDIA

Control Infrastructure Adoption

BITMOVIN VIDEO INFRASTRUCTURE FOR THE WEB ateme aws elemental

Dominate Content

NETFLIX YouTube hulu prime video vimeo

Other Content Viewing Platforms

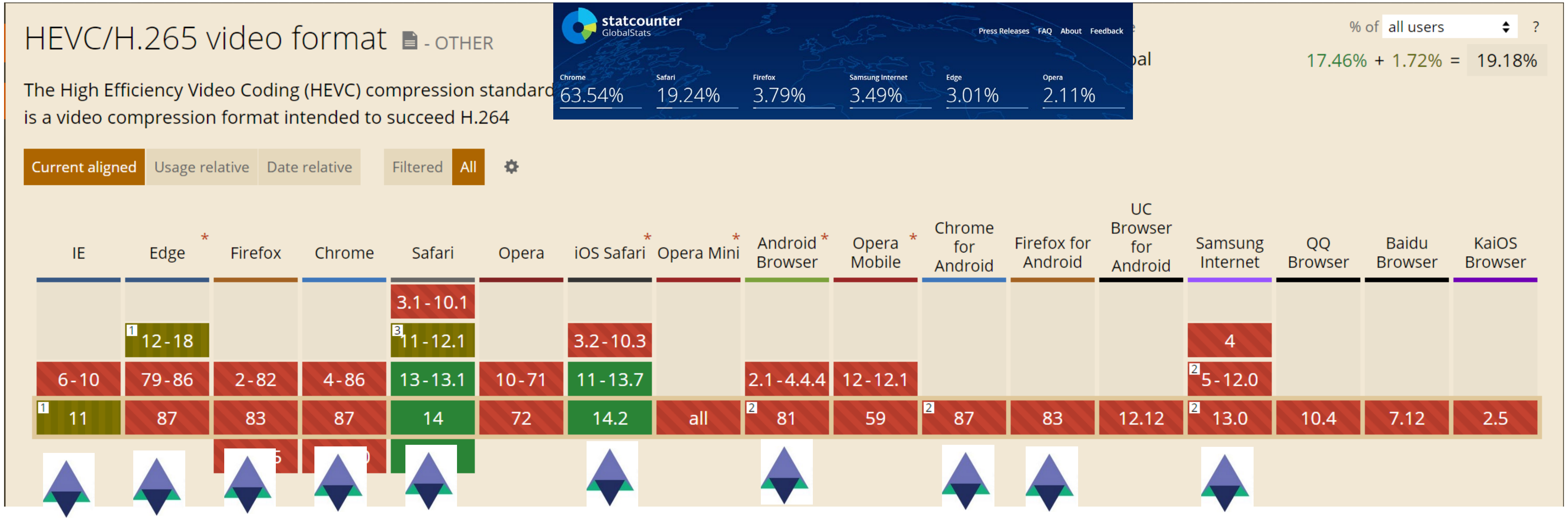
SAMSUNG tv chromecast amazon fireTV

AOM Members Won't Support HEVC Even When Free

- Browsers usually can support codecs supported by the OS without incurring a royalty charge
  - That's initially how Firefox supported H.264 on mobile platforms
- So, in theory, Google/Mozilla could support HEVC on:
  - MacOS
  - iOS
  - Android OS
  - Many Windows PCs
- By leveraging OS support, which they haven't

- This complicates using HEVC for publishers targeting native browser-based playback
- Because royalties likely not involved, this is more of a strategic decision than a financial decision

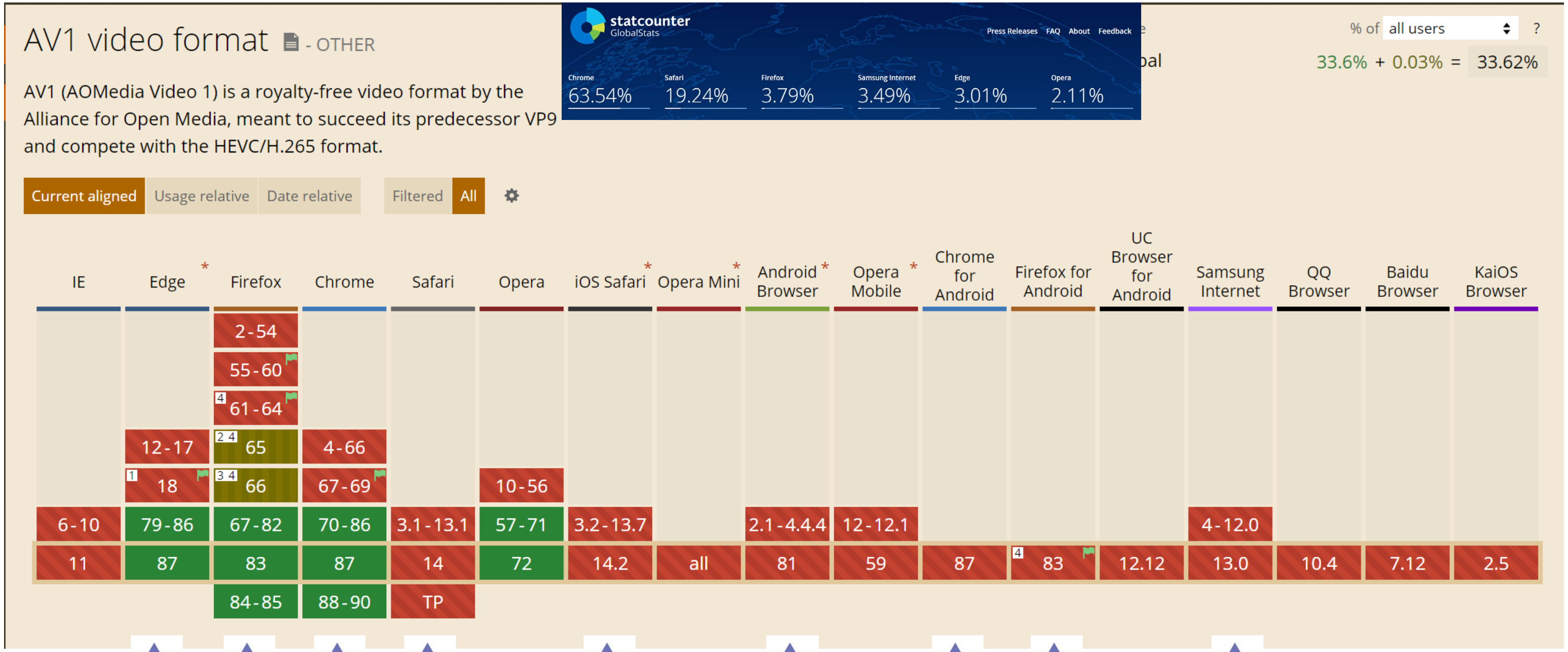
Browser Support HEVC – Finalized 1/2013



19.18%

- Not supported in Chrome/Firefox/Edge/Samsung (~74%)
- Supported by Apple OS/iOS (19%)

Browser Support AV1 – Finalized 4/2018 (5 Years Later)



33.62%

- Supported in Edge/Firefox/Chrome (~70%)
- Not supported by Apple OS/iOS (19%)
  - May be soon – Apple recently added VP9 support for 4K YouTube Videos
- Not yet supported in mobile browsers but supported in apps from some AOM members

The Bottom Line

- AOMedia members can slow or block the deployment of standard-based codecs in:
  - Browsers (already doing)
  - Desktop OS
  - Smart TVs, dongles, STBs
  - Cloud encoding facilities
  - Content encoding and delivery for major content sources
- Software codecs can workaround on computers by using a third-party player
  - V-Nova Perseus/LCEVC with THEOPlayer (bit.ly/PERSEUS_THEO)
  - May trigger a royalty obligation
- Will hinder deployment on:
  - Mobile devices due to battery life issues
  - Non-computer devices (STBs, SmartTVs, dongles) due to limited power and programmability

Lesson: MPEG Codecs 2020

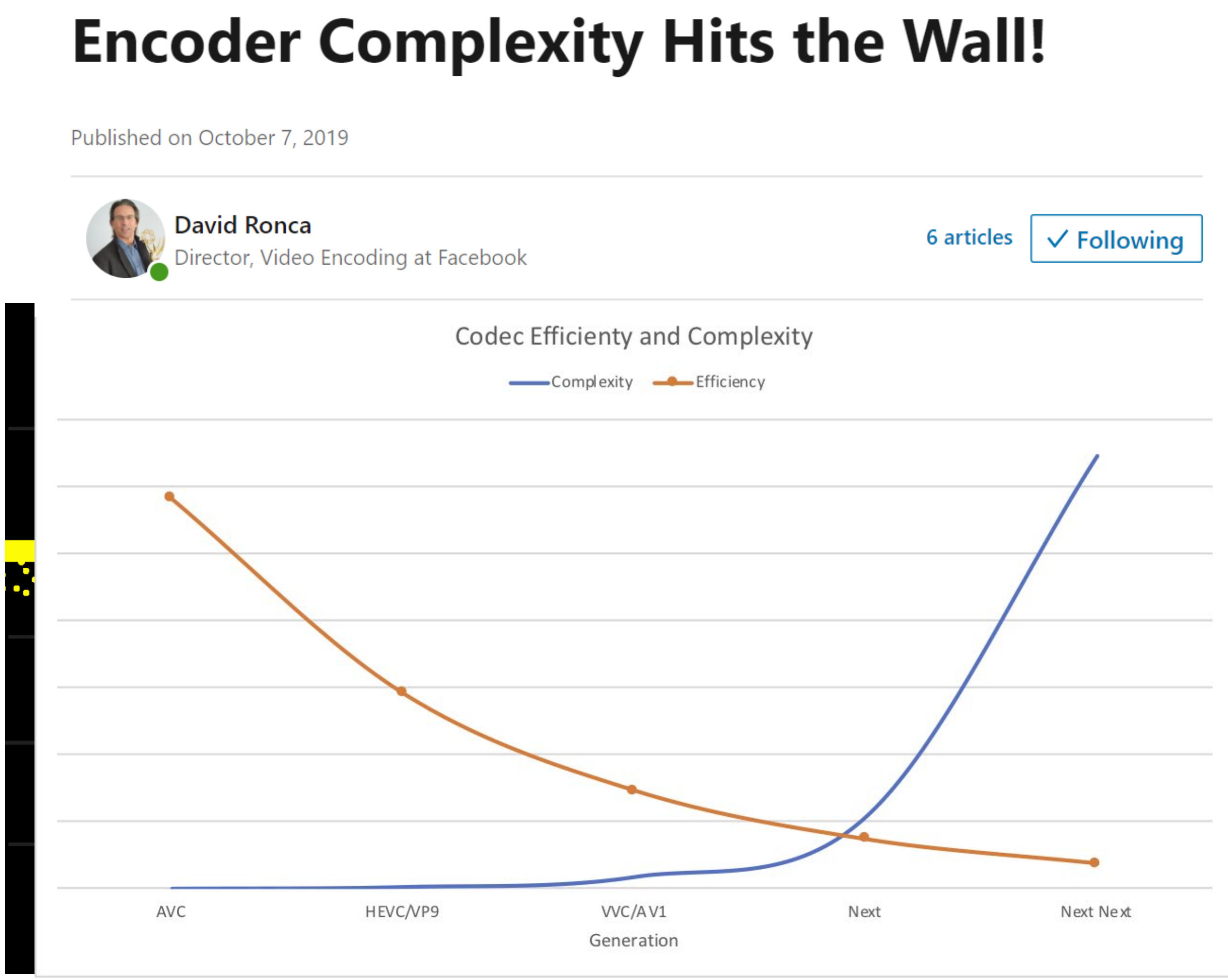
- Overview and goals
- Versatile Video Coding (VVC)
- Essential Video Coding (EVC)
- Low Complexity Enhancement Video Coding (LCEVC)
- Accomplishing MPEG’s goals

Overview

- MPEG is “Moving Pictures Experts Group”
- Standards body that created MPEG-2
- Along with the ITU (International Telecommunications Union), responsible for
  - H.264/AVC
  - H.265/HEVC

Overview

- Perspective
  - 10-year gap between MPEG-2/H.264 and H.264/HEVC
- Three motivations to accelerate new standards
  - 1. HEVC royalty disaster
  - 2. AV1 codec is an alluring alternative to MPEG codecs (though may not be royalty free)
  - 3. Encoding complexity is driving up encoding costs

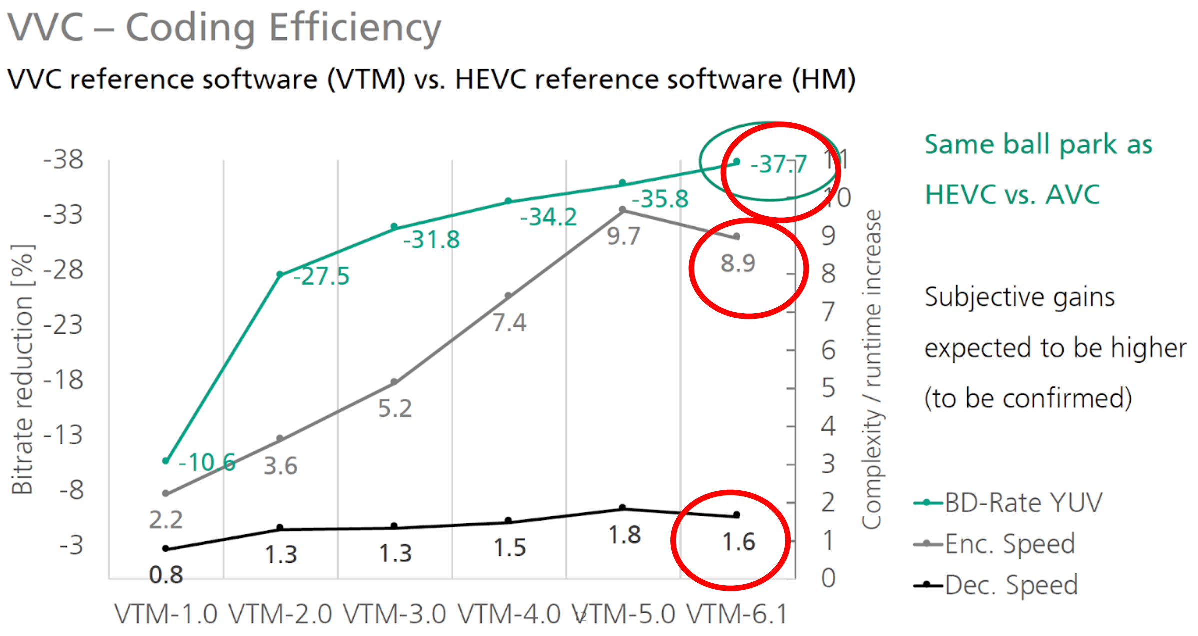


MPEG Needed

- Rational royalty policy
- Technologies to compete with AV1
- A CPU-efficient alternative

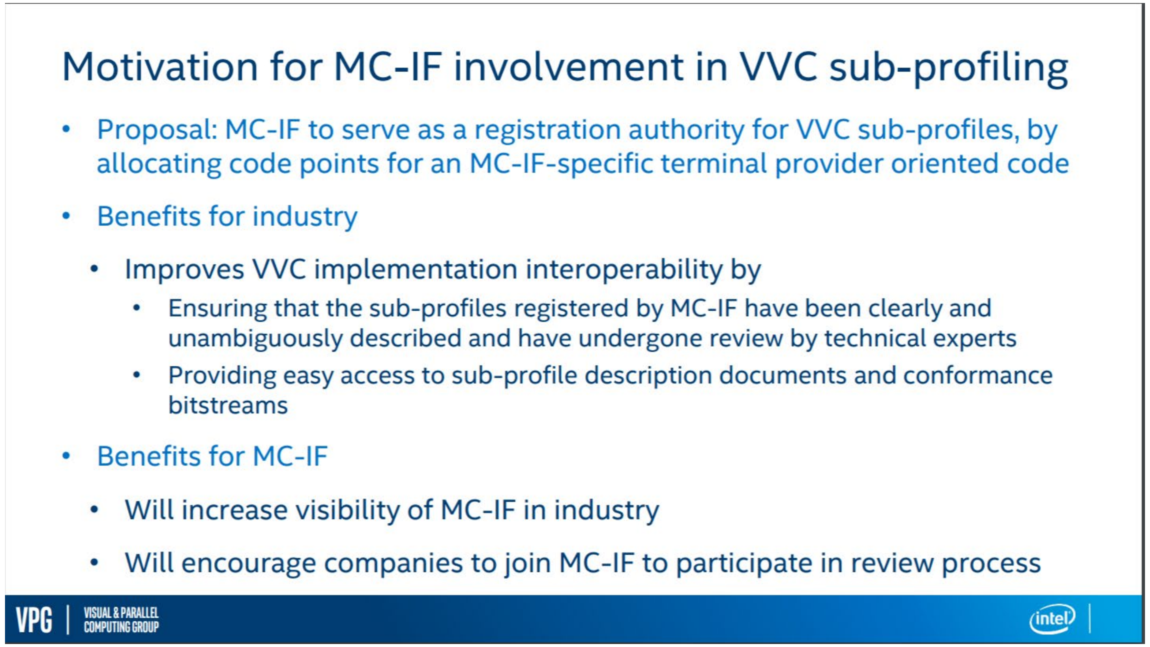
Versatile Video Coding

- **What:** Typical MPEG codec
- **Status:** Finalized July 2020
- **Quality:** between 30% - 50% more efficient than HEVC
- **Encoding complexity:** ~10x HEVC encode (8.9 shown)
- **Decoding complexity:** 1.6x shown
- Test results shared later



Versatile Video Coding

- **Control royalties:** Media Coding-Industry Forum (MC-IF)
  - Register sub-profiles that can exclude specific tools from recalcitrant vendors
    - If royalty claims unreasonable, can exclude technology – but this may dilute performance
  - Patent owners agreed to patent-pool fostering and are interviewing patent pool administers in December 2020 timeframe
    - Goal is to select pool administrator by Q1 2021
    - Then comes due diligence for included patents, and internal pricing discussions. Could easily be 2022 before royalty is finalized
- **When relevant?** Hardware decode required so launch +2 years



VVC Summary

- Ability to exclude technologies based on profiles may speed licensing progress, but limits our ability to predict how VVC will perform
  - We can’t tell at this point what tools will be included in the different profiles
- The licensing process is uncertain; HEVC Advance (now Access Advanced) has already proposed their own joint HEVC/VVC pool
- Though some disagree, VVC is likely a “hardware codec” which means that it will take 2 years before consumer-level products appear
  - And another 2-3 years before addressable critical mass is available

HEVC Advance Releases Draft VVC Licensing Program Overview – includes a Joint VVC and HEVC License

NEWS,PATENTS,PRESS-RELEASE,TECHNOLOGY 08/20/2020

http://bit.ly/aa_pool

Accomplishing MPEG's Goals

	Rational Royalty Policy	Compete against AV1	Reduce Complexity
VVC	MC-IF	Nothing	No
EVC			
LCEVC			

Essential Video Coding

- **What:** Two profiles;
  - Baseline – royalty-free
  - Main – controlled by 3 companies
- **Performance:**
  - Baseline ~ 31% more efficient than H.264
  - Main - 27% more efficient than HEVC
- **Complexity:**
  - Baseline ~42% > H.264 encode/116% decode
  - Main – 4.5x > HEVC encode/154% decode
- **October 2020 results (Main profile compared to HEVC)**
  - 4K – EVC bitrate savings = 36%
  - 2K - EVC bitrate savings = 35%
  - mpeg.chiariglione.org/meetings/127

Coding performance of EVC Baseline profile

- **Testing condition**
  - EVC Baseline profile, ETM3.0
  - Anchor: H.264/AVC (JM19.0)
- **Coding performance**

	Over JM19.0 (Random Access)					Over JM19.0 (Low Delay)				
	Y	U	V	EncT	DecT	Y	U	V	EncT	DecT
Class A	-38.0%	-33.7%	-38.4%	46%	117%					
Class B	-24.8%	-27.8%	-26.9%	39%	114%	-25.4%	-21.4%	-21.5%	24%	122%
Class E						-30.9%	-34.0%	-34.9%	25%	163%
Overall	**-31.4%**	**-30.8%**	**-32.7%**	**42%**	**116%**	**-27.5%**	**-26.1%**	**-26.5%**	**24%**	**136%**

Coding performance of EVC Main profile

- **Testing condition**
  - EVC Main profile, ETM3.0
  - Anchor: HEVC (HM16.6)
- **Coding performance**

	Over HM16.6 (Random Access)					Over HM16.6 (Low Delay)				
	Y	U	V	EncT	DecT	Y	U	V	EncT	DecT
Class A	-30.0%	-27.4%	-26.7%	413%	167%					
Class B	-23.1%	-23.8%	-21.2%	491%	142%	-17.5%	-13.7%	-11.0%	627%	127%
Class E						-15.1%	-9.5%	-11.7%	283%	108%
Overall	**-26.5%**	**-25.6%**	**-23.9%**	**450%**	**154%**	**-16.6%**	**-12.1%**	**-11.3%**	**465%**	**119%**

EVC

EVC uses a novel profile structure

Baseline profile

- Includes only technologies that are more than 20 years old or that were submitted with a royalty-free declaration

Main profile

- Adds a small number of additional tools that each provide a significant improvement in terms of compression performance
- Each additional Main profile tool is isolated so that it can be switched off independently of other tools with limited loss of performance
- Contributors were encouraged to submit voluntary declarations on the timely publication of licensing terms

XXX company may have current or pending patent rights relating to the technology described in this contribution and, conditioned on reciprocity, is prepared to grant licenses under reasonable and non-discriminatory terms as necessary for implementation of the resulting ITU-T Recommendation | ISO/IEC International Standard. **Furthermore, XXX company is prepared to make the timely publication of applicable licensing terms within 2 years of FDIS stage either individually or as part of a patent pool.**

http://bit.ly/evc_preso

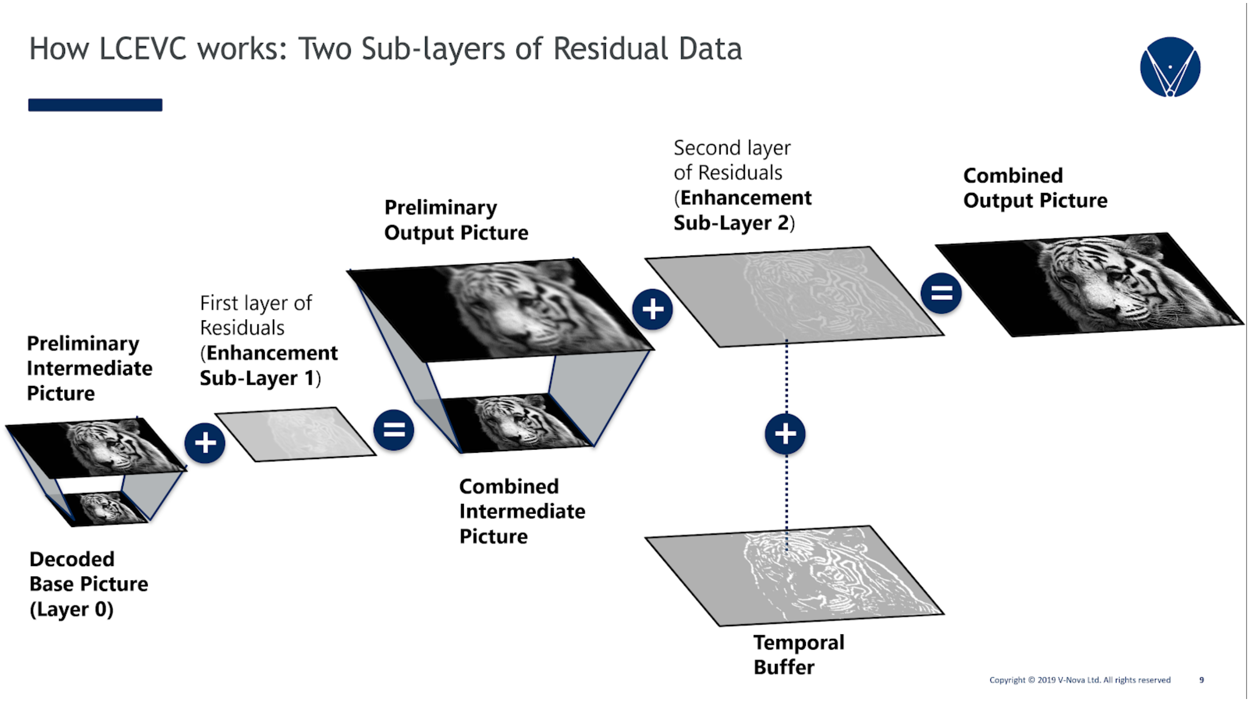
- **Control royalties:**
  - IP mostly from 3 companies (Samsung, Huawei, and Qualcomm)
  - This should simplify licensing structure
- But: Goal is to publish royalty policies within 2 years of FDIS (First Draft International Standard)!
  - Not yet FDIS, so could be as late as early 2023 before royalty policies are know
  - Hopefully, will be sooner, but lack of royalty structure may slow interest in EVC

Accomplishing MPEG's Goals

	Rational Royalty Policy	Compete against AV1	Reduce Complexity
VVC	MC-IF	Nothing	No
EVC	Limited group/2-year policy	Royalty-free baseline profile	Baseline yes/Main No
LCEVC			

Low Complexity Enhancement Video Coding

- **What:** Standardization of V-NOVA Perseus Technology
  - Enhancement layer over baseline codec
  - Backwards compatible for baseline
  - Software decode for enhancement layer
- **Will show performance later in session**
- **Control royalties:**
  - One company controls IP so should be simple
- **When relevant?** Shipping today as V-NOVA technology
  - Will look at performance results later



Accomplishing MPEG's Goals

	Rational Royalty Policy	Compete against AV1	Reduce Complexity
VVC	MC-IF	Nothing	No
EVC	Limited group/2-year policy	Royalty-free baseline profile	Baseline yes/Main No
LCEVC	Single IP owner	Royalty should be low with much lower complexity	Yes, and therefor the only "software" coded

Analyzing Quality

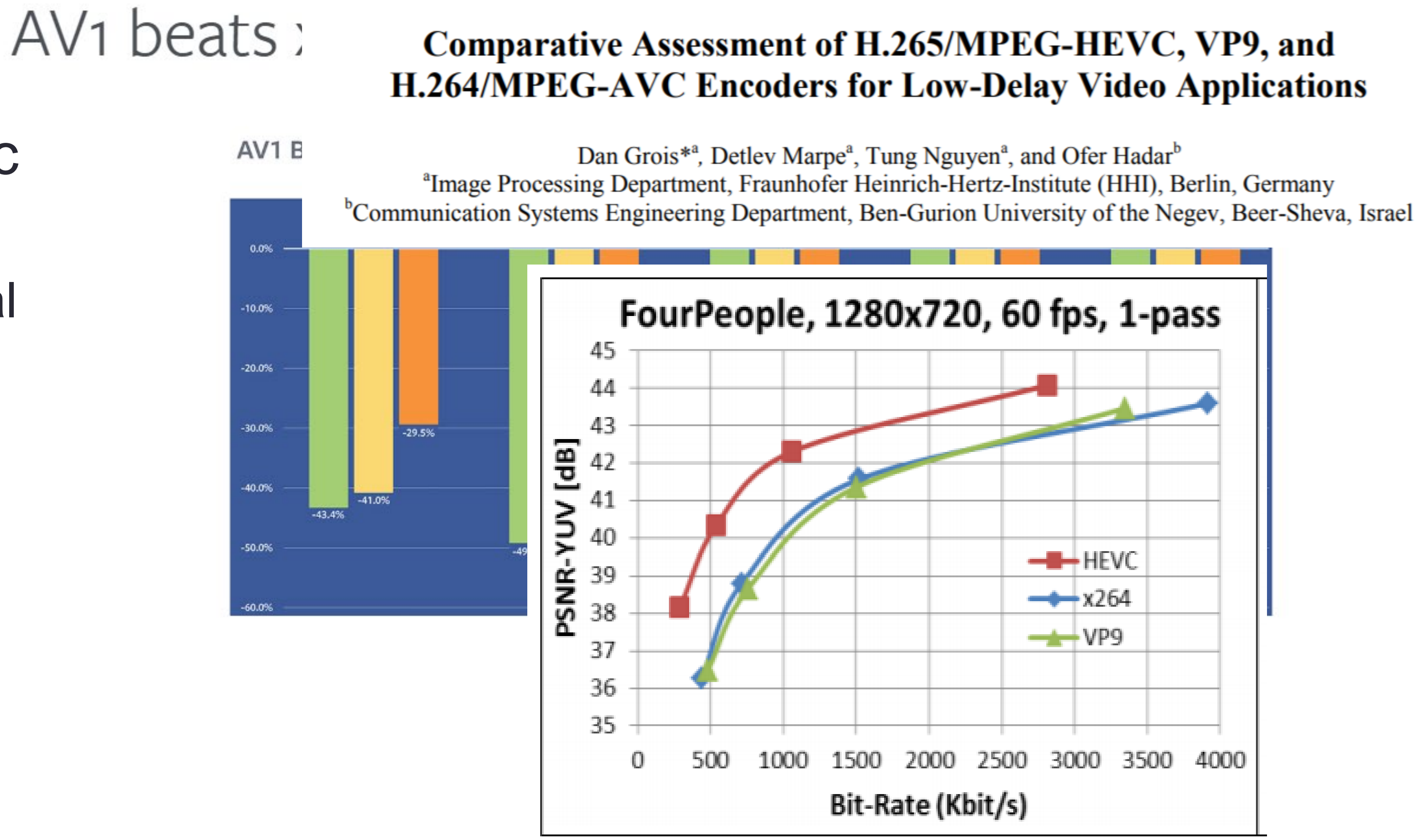
- Rate-distortion curves
- BD-Rate functions

Lesson: Rate Distortion Curves and BD-Rate Functions

- What they are, what they mean, and how they are used
- How to produce
- Rate distortion curves
- BD-Rate functions

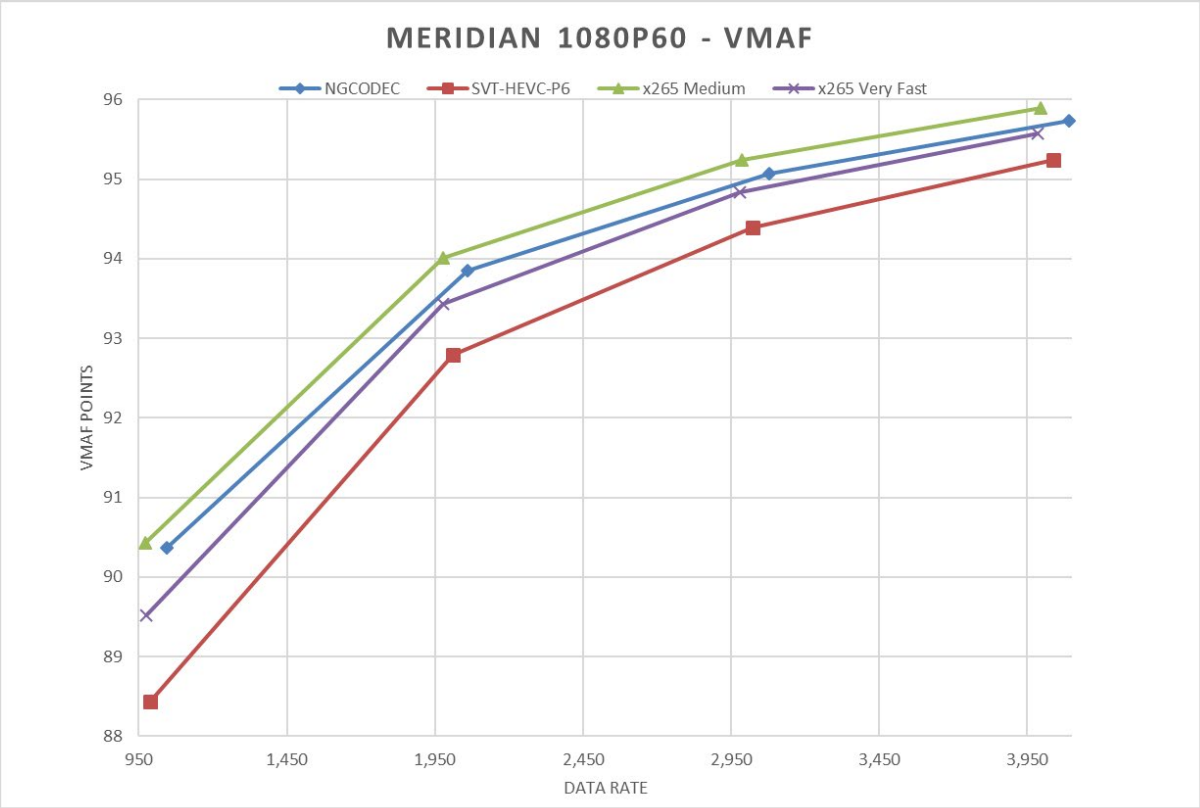
What They Are

- Represent how one codec compares to another
  - Rate distortion curve – visual
  - BD-Rate – numerical



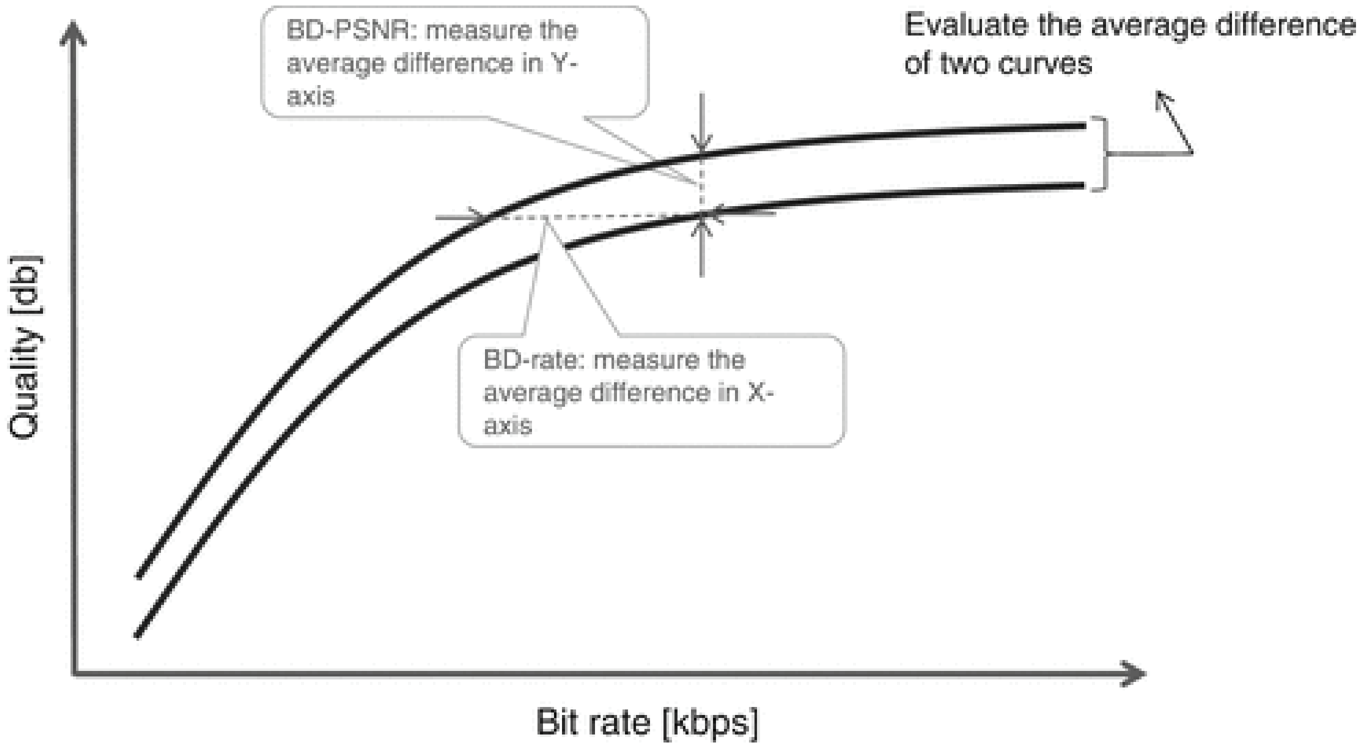
How to Produce

- Process
  - Encode test clip(s) to at least four encoding points
    - Data rate (1-4 Mbps)
    - CRF (23, 25, 27, 29)
    - Plug into Excel scatter graph
  - Meant to represent typical operating range of codec
    - Say, 80 – 95 VMAF



Bjontegaard Functions

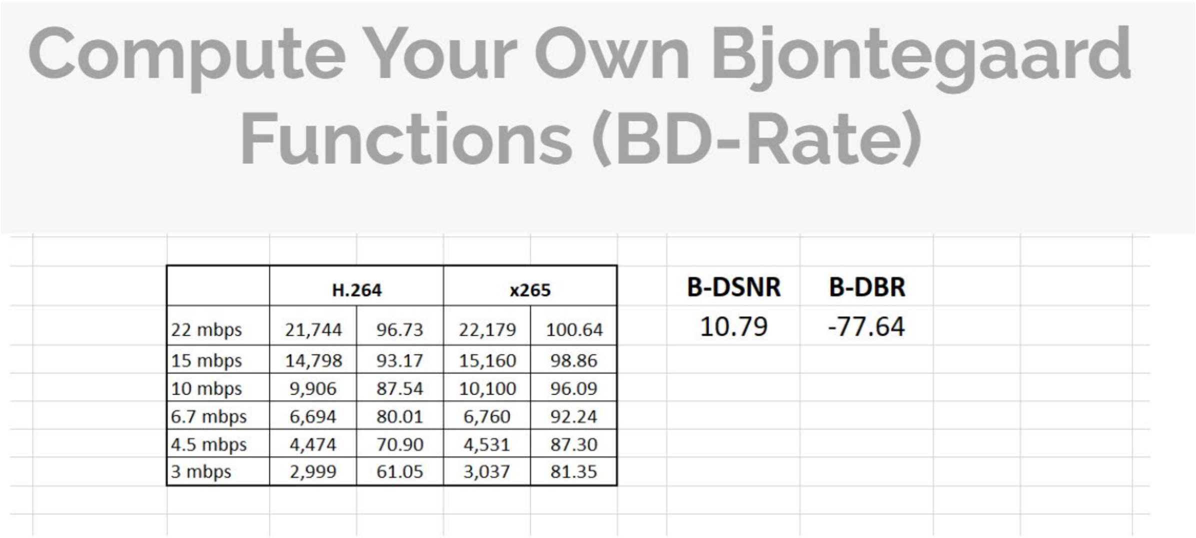
- Quantifies differences between two curves
  - BD-Rate – data rate saving for the **same quality**
  - BD-PSNR – quality disparity for same **bitrate**
    - Can use with any metric



http://bit.ly/BDRPSNR

How to Compute BD-Rate Functions

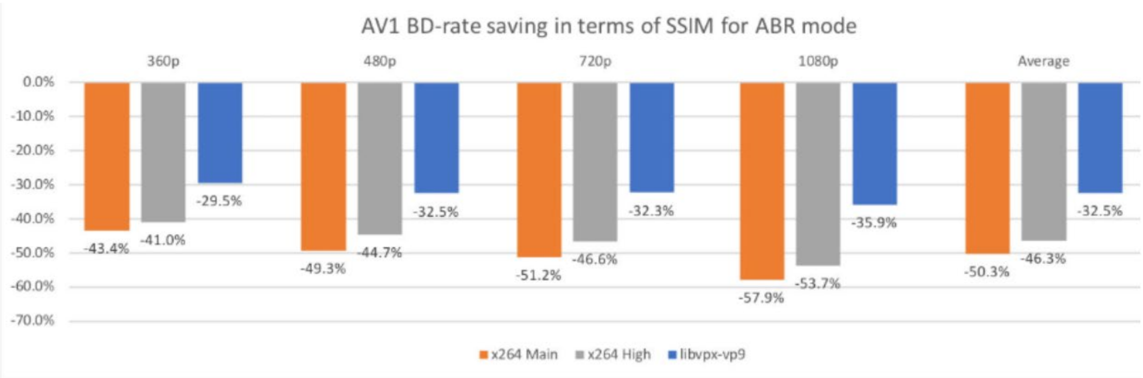
- Free Excel macro
  - Plug in numbers, apply macro
- Documented in my article
  - http://bit.ly/BD_functions



Compute Your Own Bjontegaard Functions (BD-Rate)

	H.264		x265	
22 mbps	21,744	96.73	22,179	100.64
15 mbps	14,798	93.17	15,160	98.86
10 mbps	9,906	87.54	10,100	96.09
6.7 mbps	6,694	80.01	6,760	92.24
4.5 mbps	4,474	70.90	4,531	87.30
3 mbps	2,999	61.05	3,037	81.35

B-DSNR	B-DBR
10.79	-77.64



Issues with BD-RATE Computations

- Academic vs. real-world comparisons
- Actual profile usage

Academic vs. Real World Comparisons

Comparing VVC, HEVC and AV1 using Objective and Subjective Assessments

Fan Zhang, *Member, IEEE*, Angeliki V. Katsenou, *Member, IEEE*, Mariana Afonso, *Member, IEEE*, Goce Dimitrov, and David R. Bull, *Fellow, IEEE*

https://arxiv.org/pdf/2003.10282.pdf

MSU Codec Comparison 2019

Part II: FullHD Content, Subjective Evaluation

Graphics & Media Lab Video Group

http://bit.ly/MSU_2019_sub

- Conclusion: “For the tested versions there is no significant difference between AV1 and HEVC”

- AV1 is:
  - 22% more effective than best HEVC codec
  - 32% more efficient than x265

Codec vs. Encoder

- Codec
  - Compression technology capable of outputting a compressed bitstream
  - Must be tested within an "encoder" but typically academics use "reference encoders" or "test models" that:
    - Provide access to all features of a codec, even those that may not be implemented in a commercial encoder
      - Licensing issues (VVC/EVC)
      - Too slow
    - Don't provide a relevant range of encoding controls, like 2-pass VBR
    - Not commercially usable

- Encoder
  - Provides access to different codecs
  - Enables a full range of encoding controls relevant to a typical production environment

Academic vs. Real World Comparisons

Comparing VVC, HEVC and AV1 using Objective and Subjective Assessments

Fan Zhang, *Member, IEEE*, Angeliki V. Katsenou, *Member, IEEE*, Mariana Afonso, *Member, IEEE*, Goce Dimitrov, and David R. Bull, *Fellow, IEEE*

- **Goal:** Benchmark theoretical codec performance
- **Encoder:** Reference encoder providing access to all codec features;
- **Settings:** CQ-based encoding (because no effective bitrate control in reference encoder)
- **Test clips:** Limited set of 10-second clips in YUV format used exclusively for testing

MSU Codec Comparison 2019

Part II: FullHD Content, Subjective Evaluation

Graphics & Media Lab Video Group

- **Goal:** Benchmark real-world codec/encoding performance
- **Encoder:** Real-world encoders
- **Settings:** Bitrate-based
- **Test clips:** Usually a diverse set of real-world clips at realistic source bitrates

In Essense

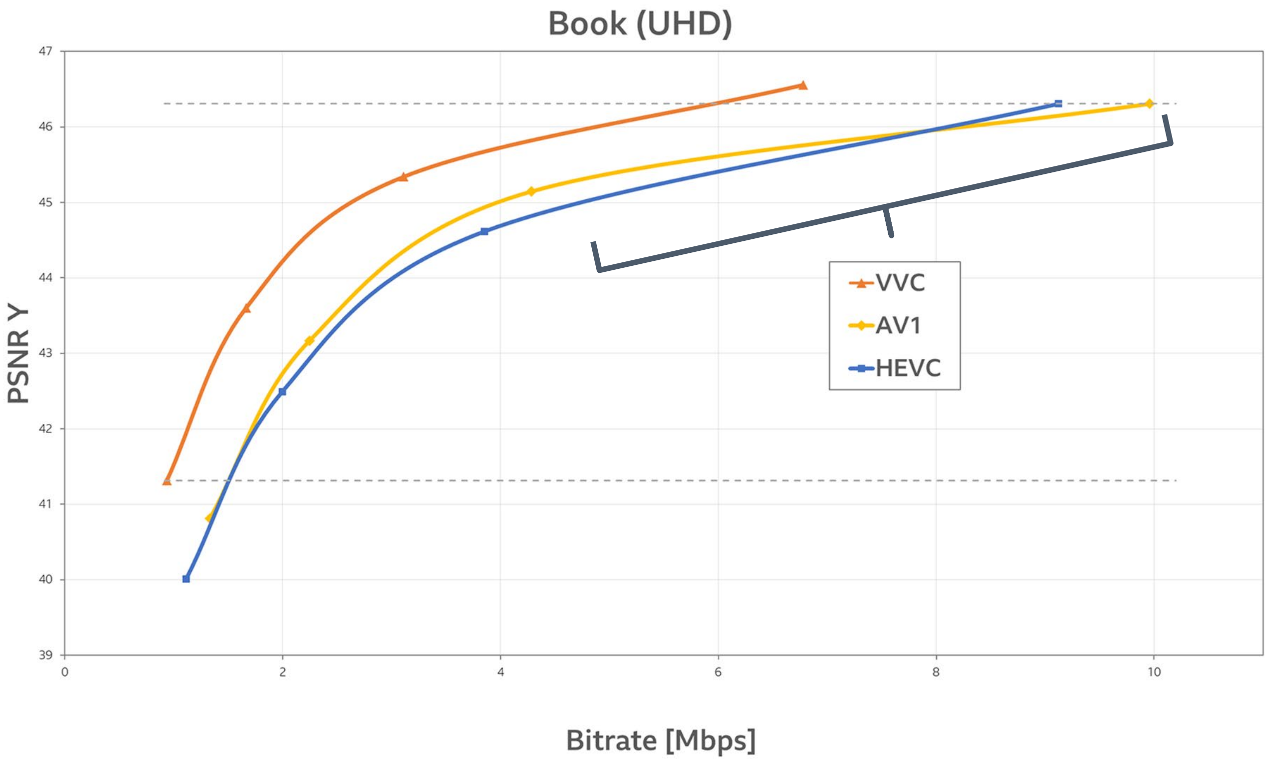
- Academics test:
  - Encoders no producer will ever use
  - Using settings no producer will ever use
  - With raw test clips unlike those transcoded by most producers and
  - Videos that few consumers have ever watched
- To gauge theoretical performance

- Real-world trials test:
  - Commercially available encoders
  - Using actual production settings
  - With clips formatted like those they typically transcode (10 – 50 Mbps)
  - From multiple sources representing broad-based relevant content
    - MSU uses Vimeo clips
    - Facebook used their own library
    - Netflix uses their library
- To gauge real-world performance

Bottom Line

- Academic comparisons are valid tools for benchmarking theoretical codec performance
- But
  - If they use reference coders, and/or
  - CQ-based encoding (as opposed to bitrate)
  - The results probably don't reflect real world performance.

Bottom Line



- When assessing results, go beneath the numbers
  - Make sure the tests incorporate a relevant range of quality
    - VMAF – 85 – 95
    - Anything beyond 45 PSNR is typically not perceivable by the viewer
- When creating your own tests, use bitrates that represent the relevant range of codec usage

Actual Savings Depend Upon Your Usage

- How much bandwidth do you save delivering HEVC to mobile viewers in ladder A rather than H.264?
  - None:
    - H.264 might be 3.29 Mbps 720p stream
    - HEVC would be 3.29 Mbps 1080p stream
    - Quality higher, but no bitrate savings
- How much bandwidth do you save delivering HEVC to TV viewers in ladder B rather than H.264?
  - The difference between the bitrates of of the top rung
    - Which is where most savings typically are

Ladder A: Mobile

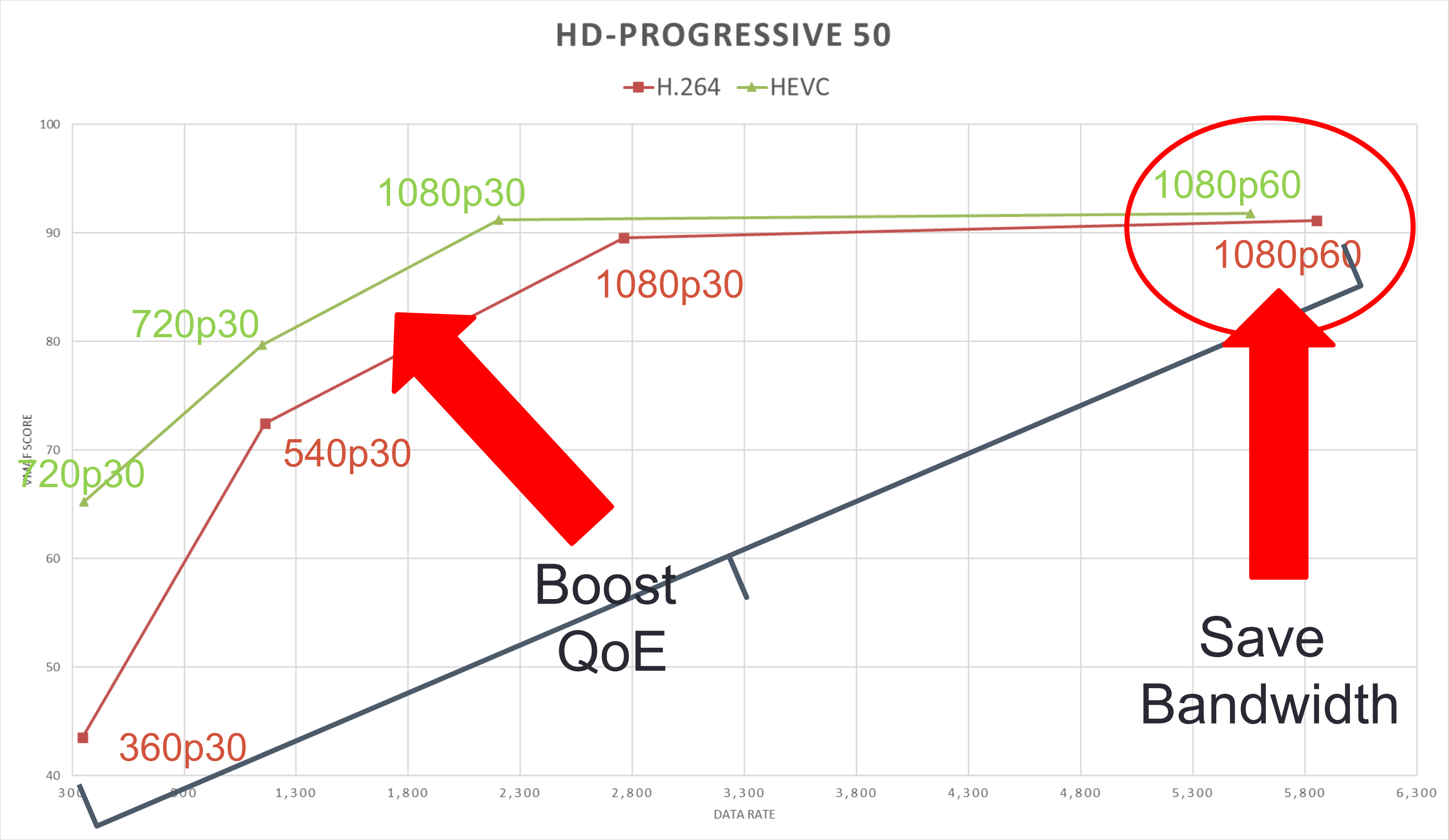
Device type	Usage [%]	Average bandwidth [Mbps]
PC	0.004	7.5654
Mobile	94.321	3.2916
Tablet	5.514	3.8922
TV	0.161	5.4374
All devices	**100**	**3.3283**

Ladder B: IPTV

Device type	Usage [%]	Average bandwidth [Mbps]
PC	0.0	N/A
Mobile	0.0	N/A
Tablet	0.0	N/A
TV	100	35.7736
All devices	100	35.7736

Recent Consulting Project (Live, 25i to 50p)

- Live scenario, converting 30i to 60p for top rung
  - Created two separate ladders
    - Top rate for HEVC had to match H.264
    - Then extend down to ensure jump between rungs of 1.5x – 2x lower data rate
  - Overall, HEVC delivered about a 37% savings over H.264
  - Great quality boost at lower bitrates
  - But, 96% of streams delivered were the top-quality stream, where savings were modest
    - Do you deploy a new codec to boost QoE of those connecting on lower connections?
    - Maybe, but you're not going to achieve 37% savings
- Most first-world countries
  - Bandwidth saving here
  - Improve QoE here



Suggested Approach

Compute average delivery bitrate and average VMAF score using actual usage stats with current codec

H.264	Bitrate	VMAF	Usage	Weighted Bitrate	Weighted VMAF
	145,000	21.50	2%	2,900	0.43
	365,000	52.52	3%	10,950	1.58
	730,000	69.10	5%	36,500	3.46
	1,100,000	80.61	5%	55,000	4.03
	2,000,000	88.02	5%	100,000	4.40
	3,000,000	92.89	10%	300,000	9.29
	4,500,000	95.06	10%	450,000	9.51
	6,000,000	96.99	20%	1,200,000	19.40
	7,800,000	97.71	40%	3,120,000	39.09
Average			**100%**	**5,275,350**	**91.17**

Compute average delivery bitrate and average VMAF score using actual usage stats with new codec

HEVC	Bitrate	VMAF	Usage	Weighted Bitrate	Weighted VMAF
	145,000	26.56	2%	2,900	0.53
	365,000	65.12	3%	10,950	1.95
	730,000	78.45	5%	36,500	3.92
	1,100,000	87.32	5%	55,000	4.37
	2,000,000	92.94	5%	100,000	4.65
	3,000,000	95.86	10%	300,000	9.59
	4,500,000	97.53	10%	450,000	9.75
	4,500,000	97.53	20%	900,000	19.51
	4,500,000	97.53	40%	1,800,000	39.01
Average			**100%**	**3,655,350**	**93.28**
				30.71%	**2.11**

Bitrate savings

VMAF boost

Though VMAF and SSIMPLUS continually improve, you should perform subjective trials if at all possible and perform the anaylsy with MOS scores

VVC Trials

- Tested Fraunhofer’s VVC encoder VVenC v0.1.0.1.
- Compared with
  - X264 – FFmpeg - git-2020-08-09-6e951d0
  - X265 – FFmpeg - git-2020-08-09-6e951d0
  - Aomenc - aomenc v2.0.0
    - AOMedia’s standalone encoder
- Encoding strings available when article posts to Streaming Media website
  - Should be this week

Five Test Clips

- **Crowd Run** - the well-known test clip of the start of a road race, encoded from 3.75 Mbps to 9 Mbps.
- **Elektra** - a slow-motion, talking head sequence from the Jennifer Garner movie encoded from 200 kbps to 1 Mbps.
- **EuroTruckSimulator2** - a snippet from the challenging Twitch eGames test clip encoded between 2 - 7 Mbps.
- **Football** - the Harmonic test clip of a college bowl game filmed at the Dallas Cowboy stadium and encoded from 2 to 4 Mbps.
- **Sintel** - a snippet from the well-known animation encoded between 1,200 and 2,800 kbps.

Encoding Time

Codec	Encoding Time	Times Real Time	Times x264
x264	0:04:03	1.74	NA
x265	0:10:24	4.46	2.57
Aomenc	1:05:29	28.07	16.17
VVenC	2:05:09	53.64	30.90

- Encoded three clips to identical target and timed encoding
- Spec – 10x HEVC – here, about 12x, so on track
- About 2X AV1

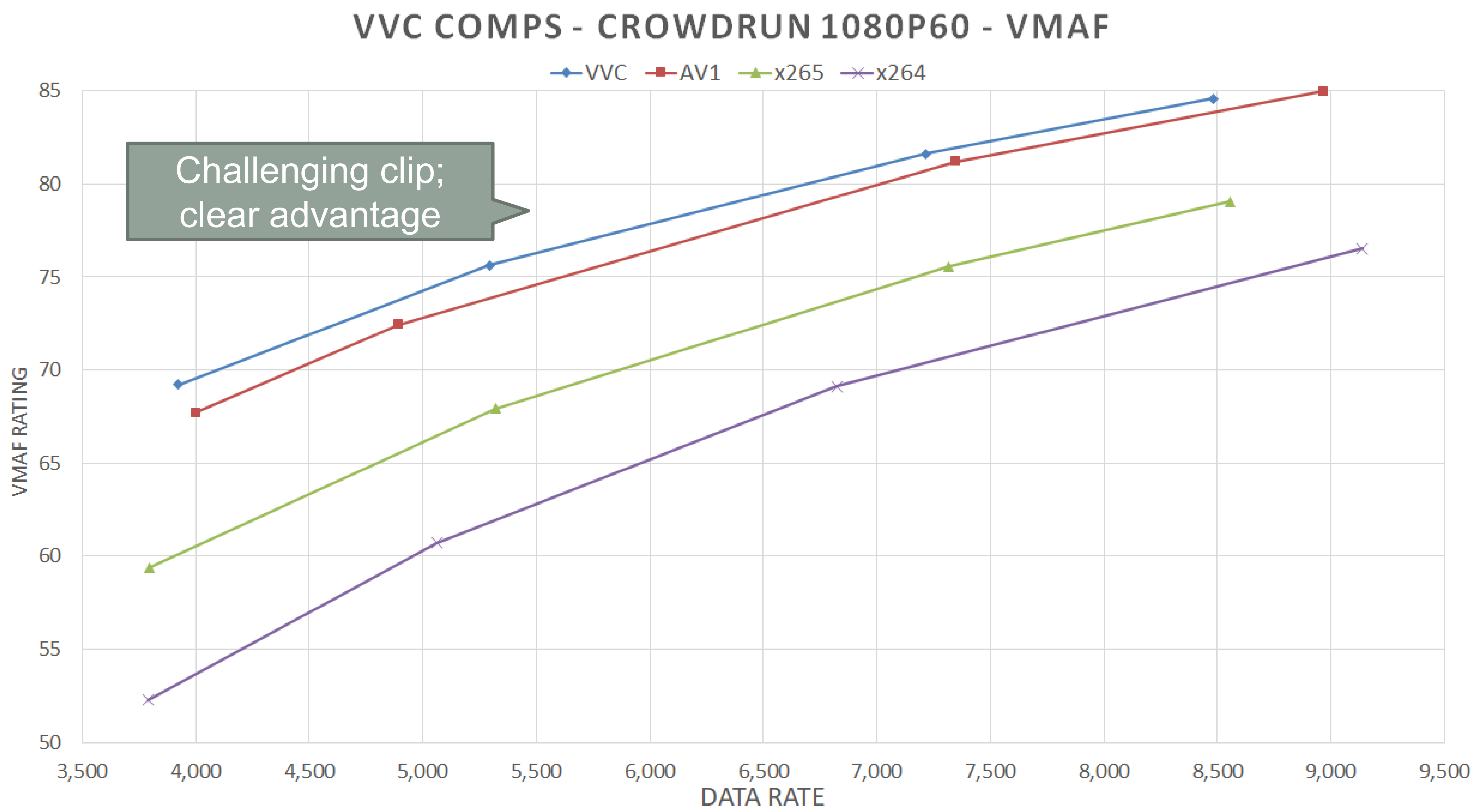
BD-Rate (non-Weighted Average)

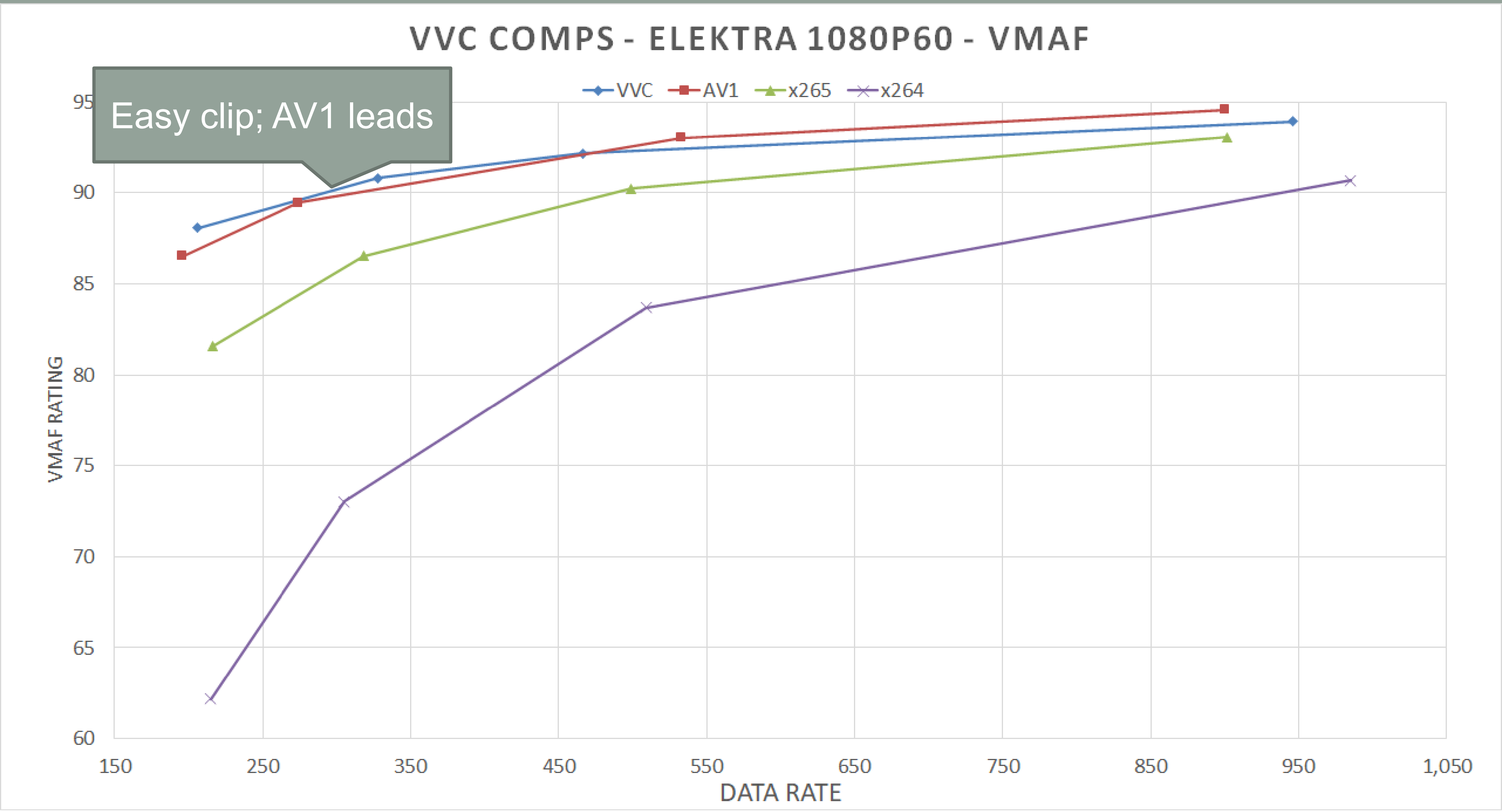
11% more efficient than Aomenc

39% more efficient than x265

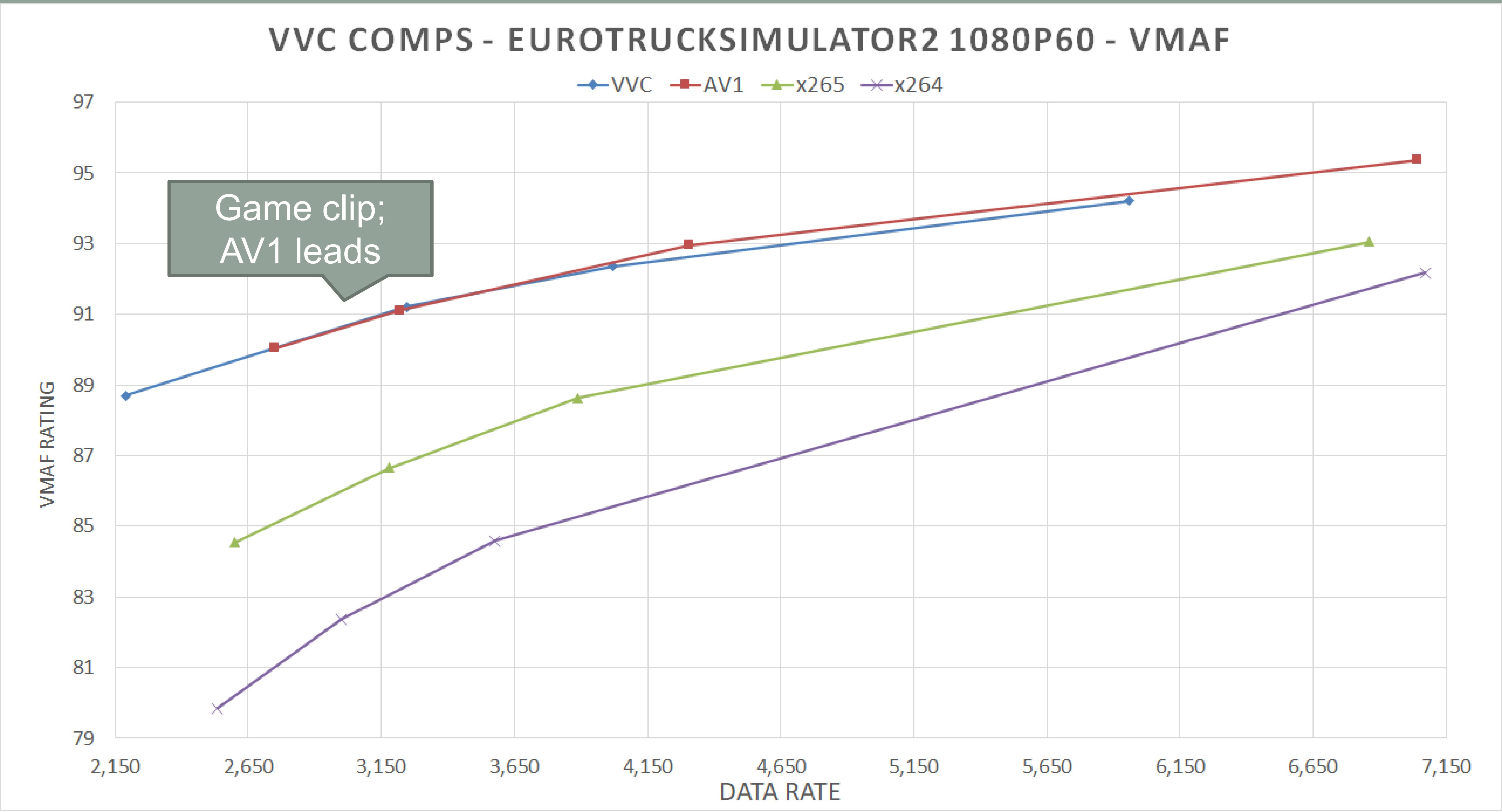
All	Aomenc	AV1	x265	x264
VVenC	X	-11%	-39%	-58%
Aomenc	12%	X	-28%	-49%
x265	63%	40%	X	-30%
x264	137%	96%	43%	X

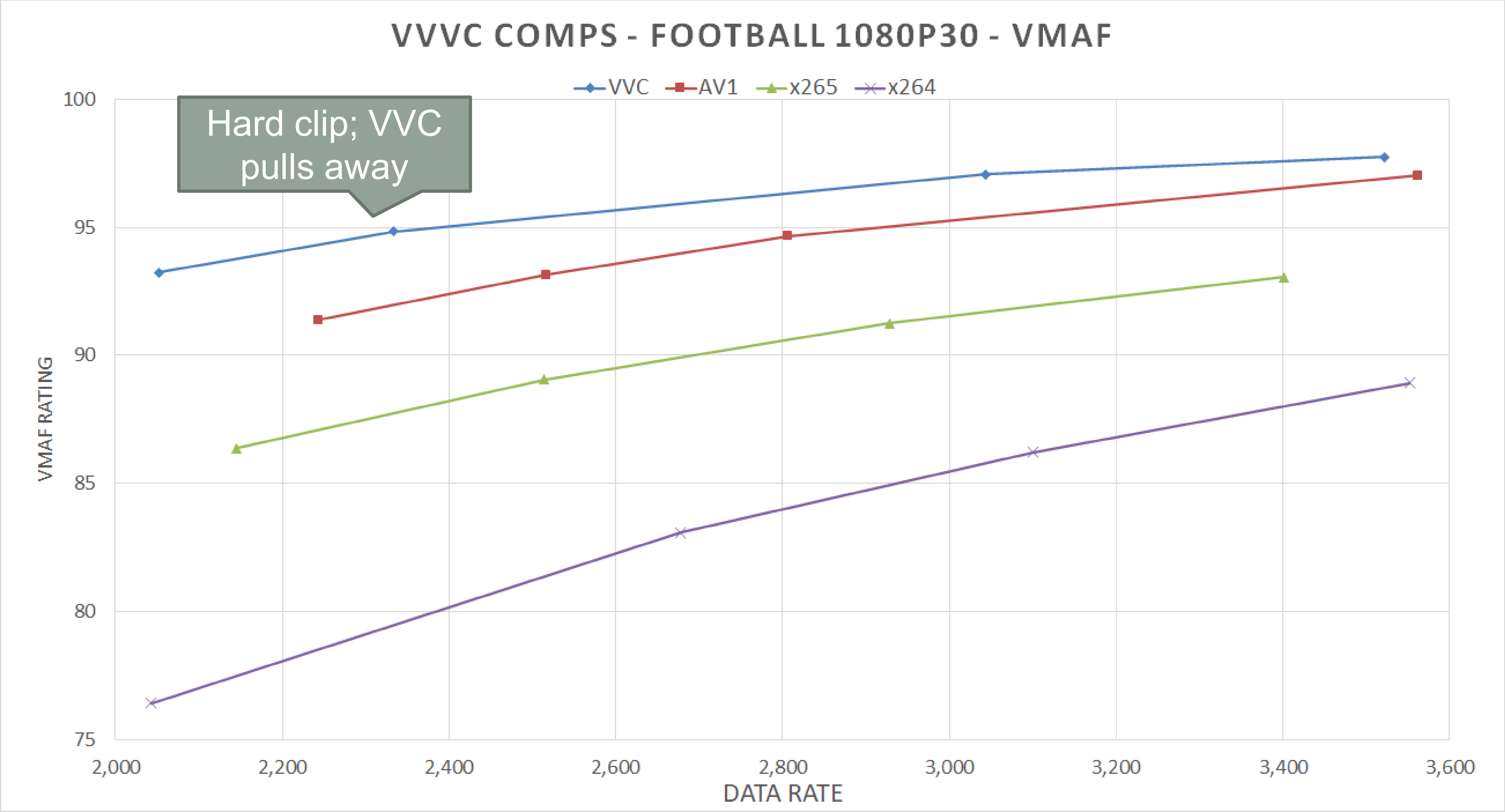
58% more efficient than x264

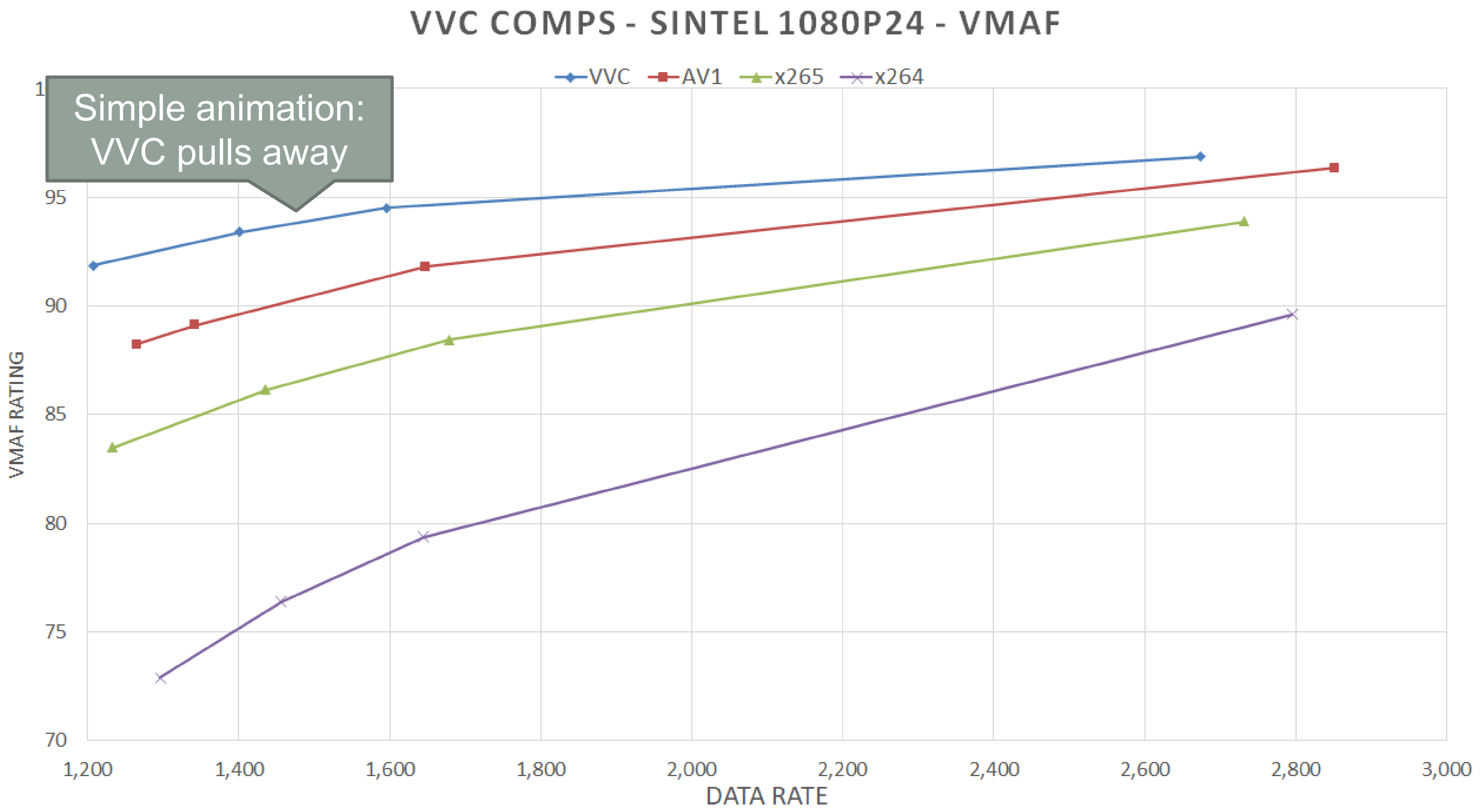

VVC COMPS - CROWDRUN 1080P60 - VMAF
VVC
AV1
x265
x264
Challenging clip; clear advantage
VMAF RATING
85
80
75
70
65
60
55
50
3,500
4,000
4,500
5,000
5,500
6,000
6,500
7,000
7,500
8,000
8,500
9,000
9,500
DATA RATE



VVC COMPS - ELEKTRA 1080P60 - VMAF
Easy clip; AV1 leads
VVC
AV1
x265
x264
VMAF RATING
95
90
85
80
75
70
65
60
150
250
350
450
550
650
750
850
950
1,050
DATA RATE


VVC COMPS - EUROTRUCKSIMULATOR2 1080P60 - VMAF
VVC
AV1
x265
x264
Game clip; AV1 leads
VMAF RATING
97
95
93
91
89
87
85
83
81
79
2,150
2,650
3,150
3,650
4,150
4,650
5,150
5,650
6,150
6,650
7,150
DATA RATE


VVVC COMPS - FOOTBALL 1080P30 - VMAF
VVC
AV1
x265
x264
Hard clip; VVC pulls away
VMAF RATING
100
95
90
85
80
75
2,000
2,200
2,400
2,600
2,800
3,000
3,200
3,400
3,600
DATA RATE

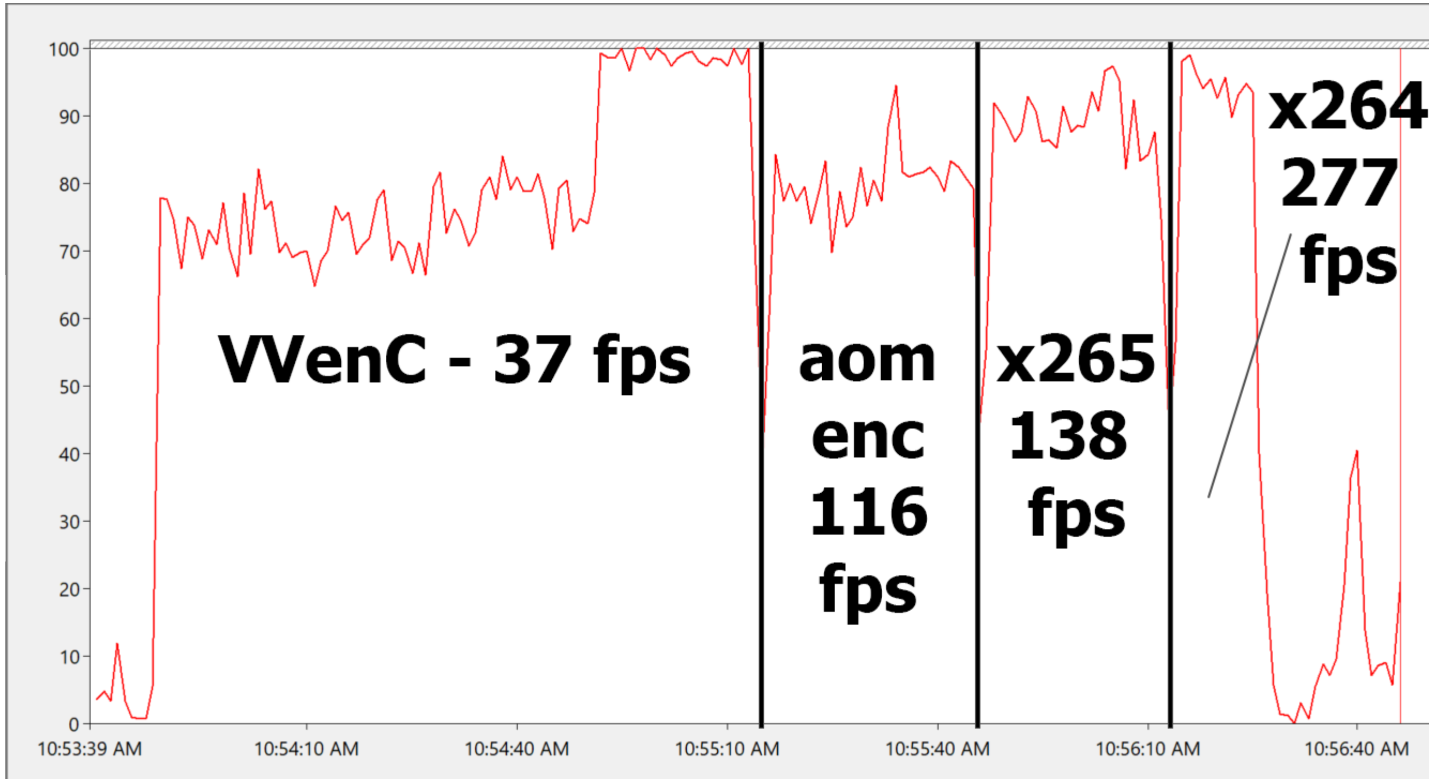


VVC COMPS - SINTEL 1080P24 - VMAF
VVC
AV1
x265
x264
Simple animation: VVC pulls away
VMAF RATING
95
90
85
80
75
70
1,200
1,400
1,600
1,800
2,000
2,200
2,400
2,600
2,800
3,000
DATA RATE

Decoding Speed

HP ZBook Studio G3

Device name	DESKTOP-0F3TKDV
Processor	Intel(R) Xeon(R) CPU E3-1505M v5 @ 2.80GHz 2.81 GHz
Installed RAM	32.0 GB (31.9 GB usable)



- Decode on notebook, converting to YUV files and stored on a RAM drive

- Roughly 3.7x complexity of HEVC (which is a hardware codec for mobile/devices)
  - About double what was predicted
- VVC almost certainly a “hardware codec”

Summary

- Fraunhofer implementation is polished and easy to use, though still lacking bitrate control and other features
- VVC quality is getting close to the targeted range (50% more efficient than HEVC)
- Encode performance on track; decode a little high but should come around
- Need royalty data to predict success

All	Aomenc	AV1	x265	x264
VVenC	X	-11%	-39%	-58%
Aomenc	12%	X	-28%	-49%
x265	63%	40%	X	-30%
x264	137%	96%	43%	X

LCEVC Testing

- Live transcoding use cases
  - Convert file to full encoding ladder
  - LCEVC with x264 as a base layer vs. x264
- Two use cases; eGames and sports
  - 8 eGames clips (1080p60)
  - 12 sports clips (1080p30)
- Tests
  - Objective: VMAF (0-100)
  - Subjective: Double Stimulus Impairment Scale (DSIS) with MOS scoring from 1-10

- Report to be published this week
- Full disclosure: I consult with V-Nova on testing and quality evaluations

Creating the LCEVC Ladder

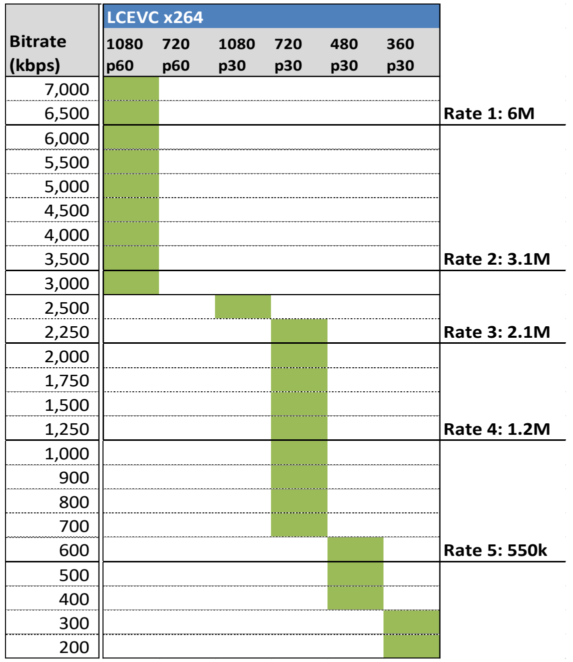
1. To create the LCEVC ladder, we started with a basic encoding ladder for H.264 (example on the right)

Profiles	Bitrate (kbps)	Resolution
#1	6,000	1080p
#2	3,500	720p
#3	2,000	540p
#4	1,100	432p
#5	730	432p
#6	365	360p
#7	145	234p

2. Top rung – bitrate that matched the VMAF quality score for the top H.264 profile

3. Computed lower bitrates to preserve the 1.5x – 2x data rate increase recommended by Apple

3. At each rung, tested at multiple resolutions to find the highest quality rung (see: http://bit.ly/NF_chull)



4. This analysis produced two different LCEVC x264 ABR ladders: one for eGames and one for sports

eGames ladder

Weighted average analysis

Measured impact on complete encoding ladders

x264	Bitrate (kbps)	Rez	Fps	Estimated usage	Bitrate/ second
Profile 1	6,000	1080p	60	60.0%	3,600
Profile 2	3,100	720p	60	15.0%	465
Profile 3	2,100	720p	30	10.0%	210
Profile 4	1,200	480p	30	8.0%	96
Profile 5	550	360p	30	7.0%	39
	12,950				**4,410**

LCEVC x264	Bitrate (kbps)	Rez	Fps	Estimated usage	Bitrate/ second
Profile 1	4,500	1080p	60	67.5%	3,038
Profile 2	2,700	1080p	60	12.5%	338
Profile 3	1,500	720p	30	8.5%	128
Profile 4	800	720p	30	6.0%	48
Profile 5	450	480p	30	5.5%	25
	9,950				**3,575**

-25%

-23%

-19%

LCEVC saving on total bitrate

LCEVC saving on average streamed bitrate

Sports ladder

x264	Bitrate (kbps)	Rez	Fps	Estimated usage	Bitrate/ second
Profile 1	6,000	1080p	30	71.6%	4,296
Profile 2	3,500	720p	30	13.5%	473
Profile 3	2,000	540p	30	9.5%	190
Profile 4	1,100	432p	30	3.2%	35
Profile 5	730	432p	30	1.2%	9
Profile 6	365	360p	30	0.6%	2
Profile 7	145	234p	30	0.4%	1
	13,840				**5,005**

LCEVC ENHANCED

LCEVC x264	Bitrate (kbps)	Rez	Fps	Estimated usage	Bitrate/ second
Profile 1	4,500	1080p	30	77.0%	3,465
Profile 2	2,700	1080p	30	11.0%	297
Profile 3	1,500	720p	30	8.0%	120
Profile 4	800	720p	30	2.5%	20
Profile 5	400	480p	30	1.0%	4
Profile 6	145	360p	30	0.5%	1
Profile 7					
	10,045				**3,907**

-25%

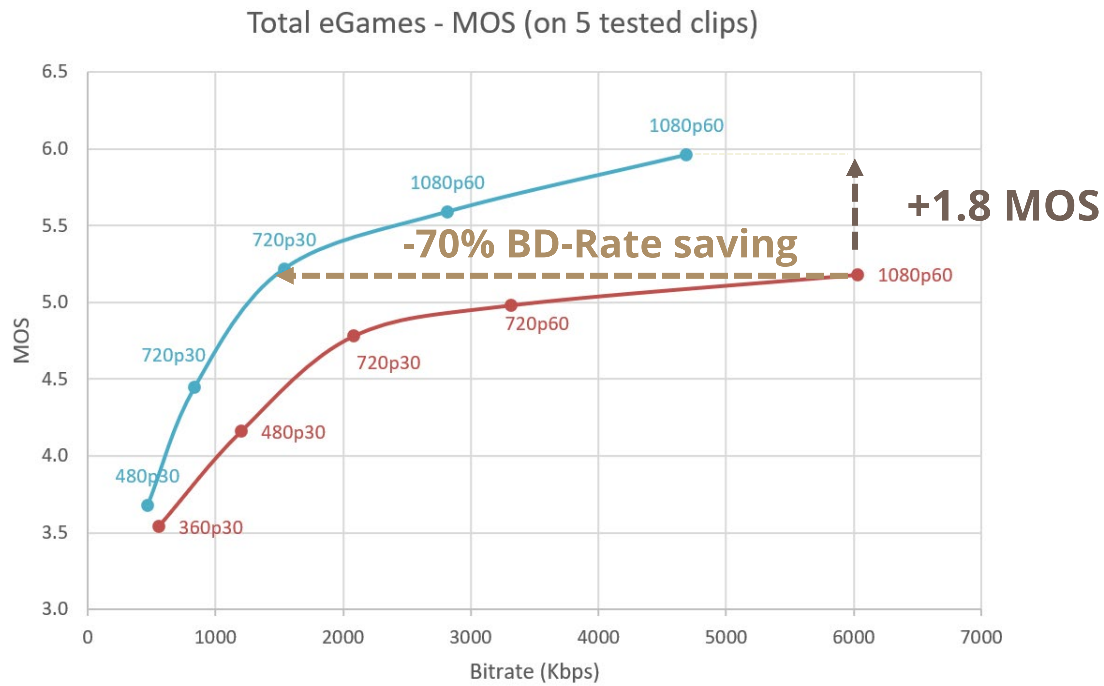
-27%

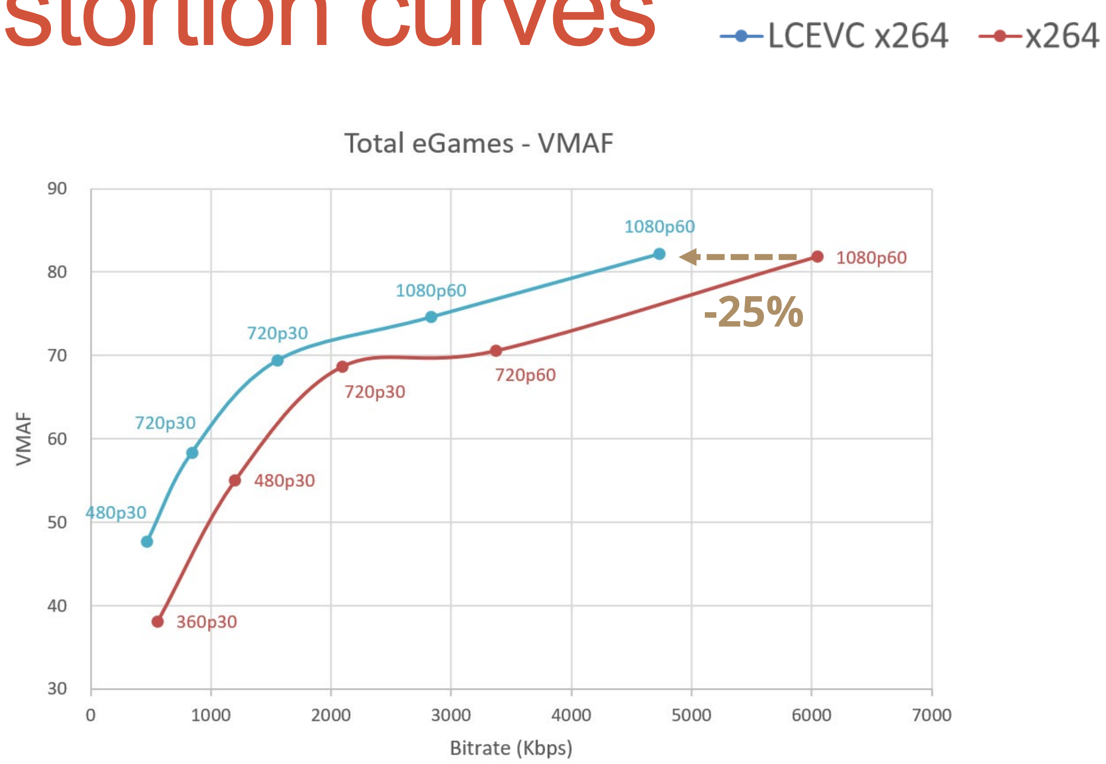
LCEVC saving on total bitrate

-22%

LCEVC saving on average streamed bitrate

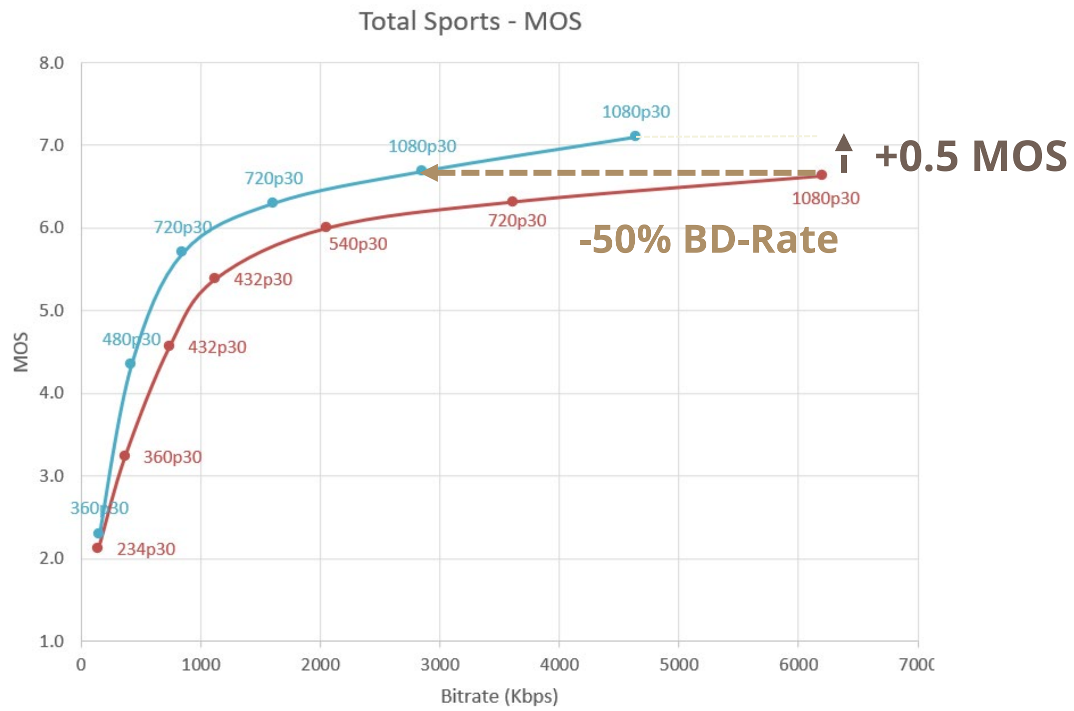
eGames: MOS & VMAF Rate distortion curves

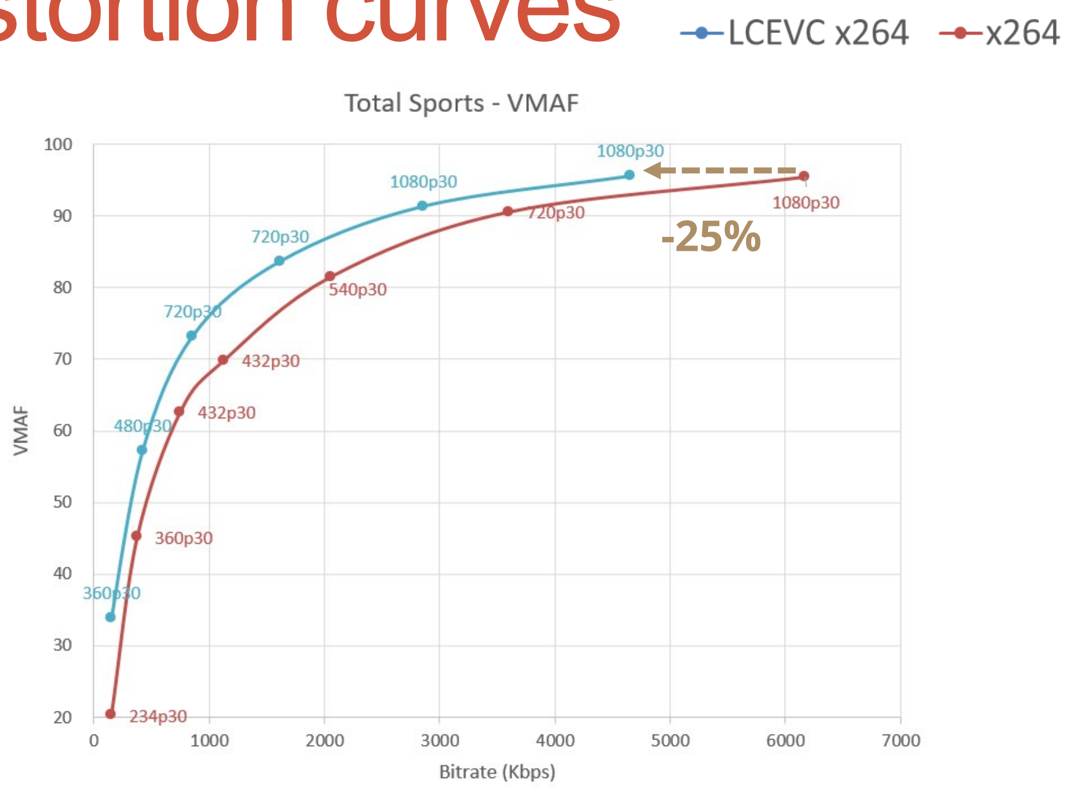




- MOS:
  - MOS – 70% BD-Rate savings
  - Increase MOS by 1.8 in top rung (with 25% savings)
  - Better quality throughout
- VMAF:
  - 25% savings in top rung
  - Better quality throughout

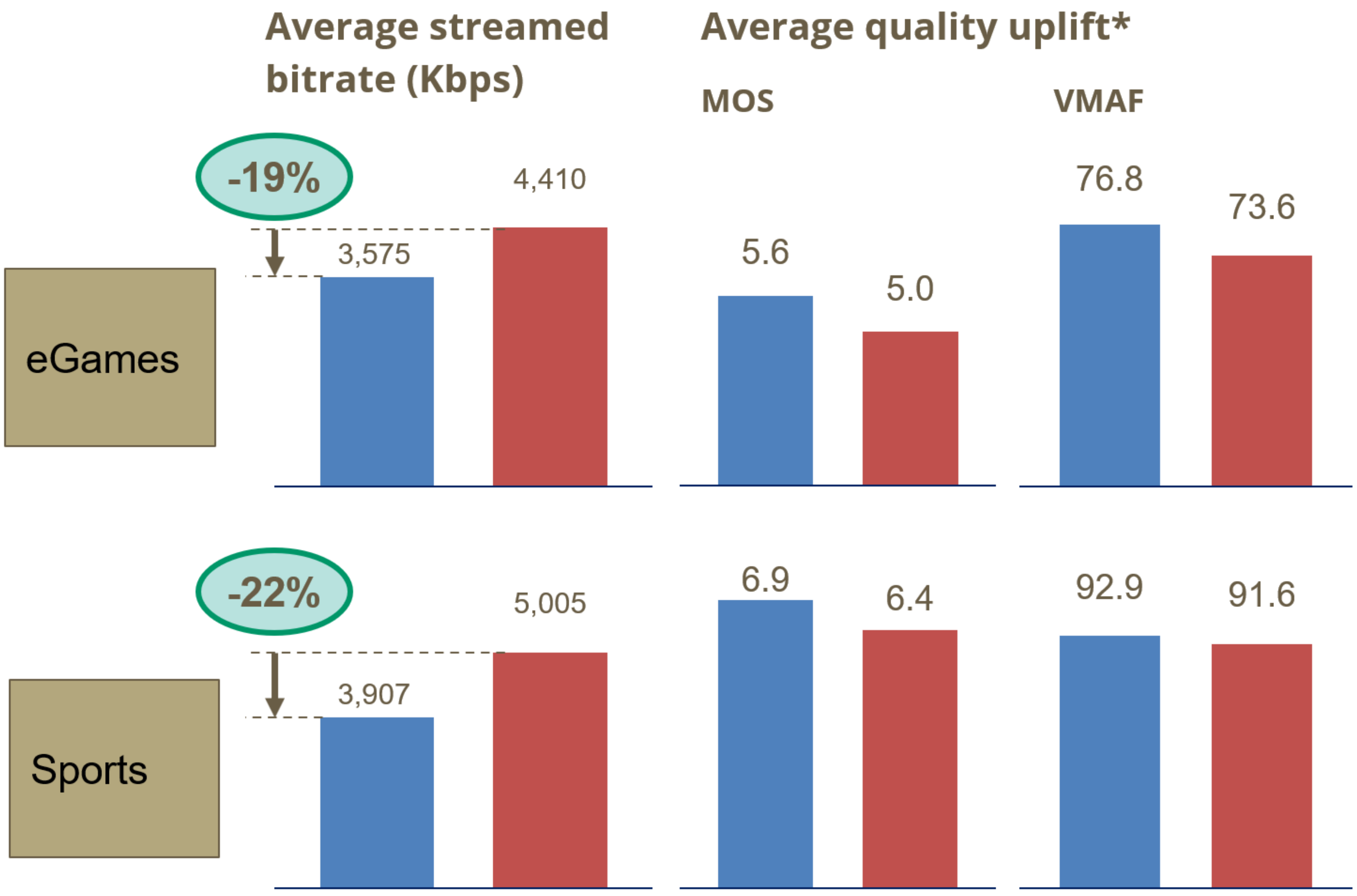
Sports MOS and VMAF Rate distortion curves





- MOS:
    - MOS – 50% BD-Rate savings
    - Increase MOS by .5 in top rung (with 25% savings)
    - Better quality throughout
- VMAF:
    - 25% savings in top rung
    - Better quality throughout

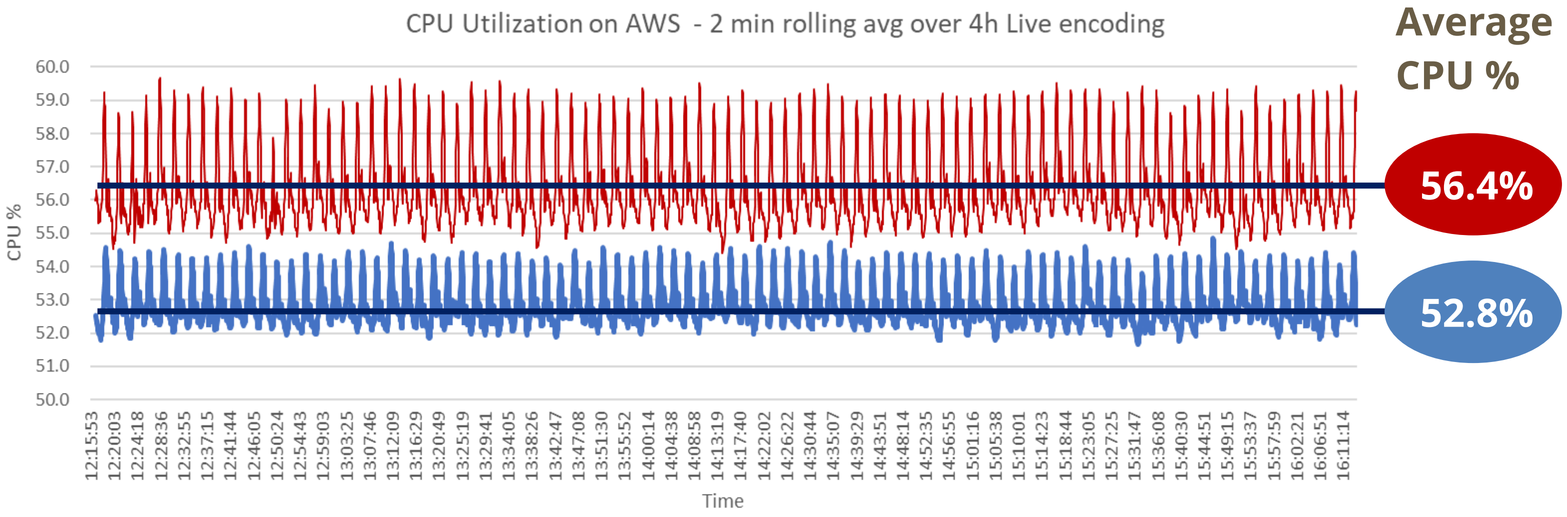
Key results: 20% bitrate savings + higher quality



- We computed the bitrate savings in a previous slide, which showed a **19-22% reduction of** average streamed bitrates, driven by reduction of top profile, enabling **reduction of CDN streaming costs**
- We computed the quality impact on the respective encoding ladders using the same procedure shown for bitrate savings; substituting VMAF/MOS values for data rate and using the same usage statistics to compute overall MOS and VMAF for the x264 and LCEVC x264 ladders.
- These results showed a **quality uplift,** across all profiles: subjectively **+0.5-0.6 incremental MOS,** confirmed by slight VMAF improvement

Encoding Requirements– eGames Example

LCEVC ladder
Native x264 ladder

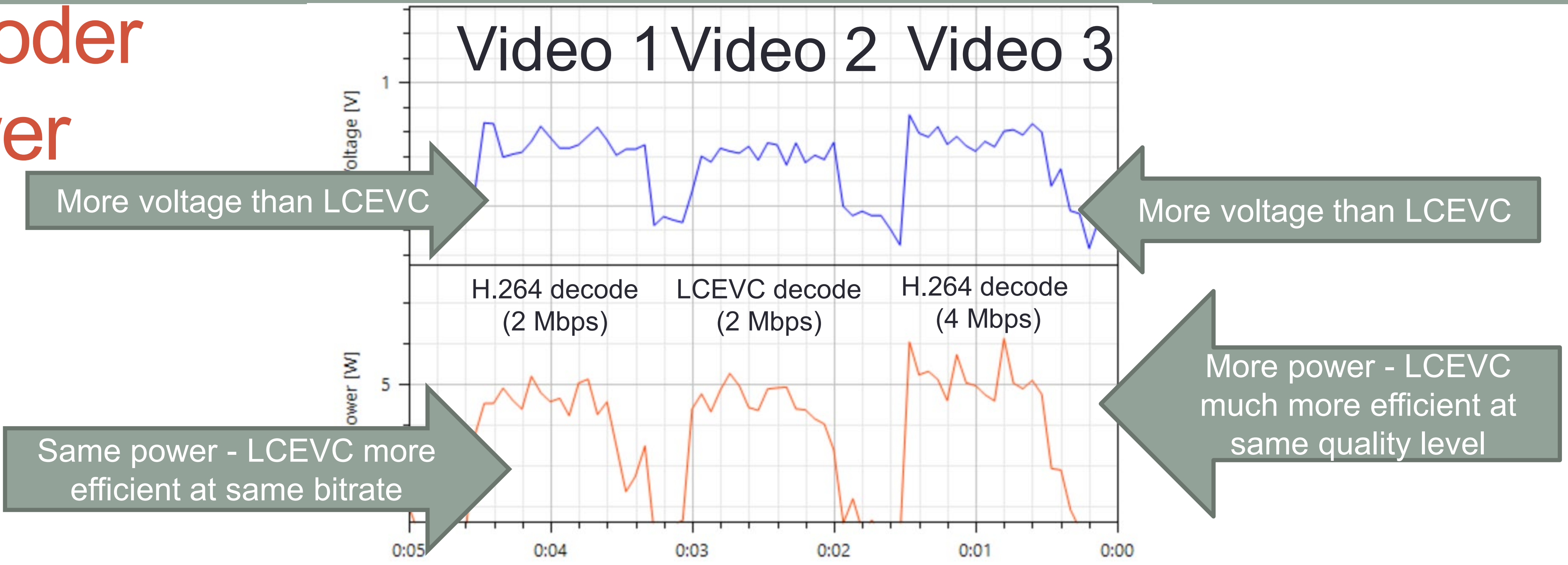


Methodology

- AWS instance: C5.9x Large (36 vcpu, 18 cores)
- LCEVC ABR ladder included: 2x 1080p60 profiles, 2x 720p30, 1x 480p30
- X264 ladder included: 1x 1080p60 profile, 1x 720p60, 1x 720p30, 1x 480p30, 1x 360p30
- No frames dropped

Key finding: LCEVC x264 consumed 6% less CPU than x264 despite 1.4x more encoded pixels and higher quality

Decoder Power



- Video 1 – H.264 @ 2 Mbps
- Video 2 – LCEVC @ 2 Mbps
- Video 3 – H.264 @ 4 Mbps (to match LCEVC quality)

Test bed: Zotac Zbox-EN72080v computer with a six-core I7-9750H running Windows 10. Measured voltage and power consumed with the Open Hardware Monitor utility (https://openhardwaremonitor.org/).

As you can see, compared to the 2 Mbps H.264 file, **LCEVC decode consumes lower voltage and about the same power**, so overall, LCEVC decode consumes less battery power. Compared to the 4 Mbps H.264 file, which is the **same approximate quality** as the LCEVC file, **LCEVC playback is more efficient in both power and voltage**.

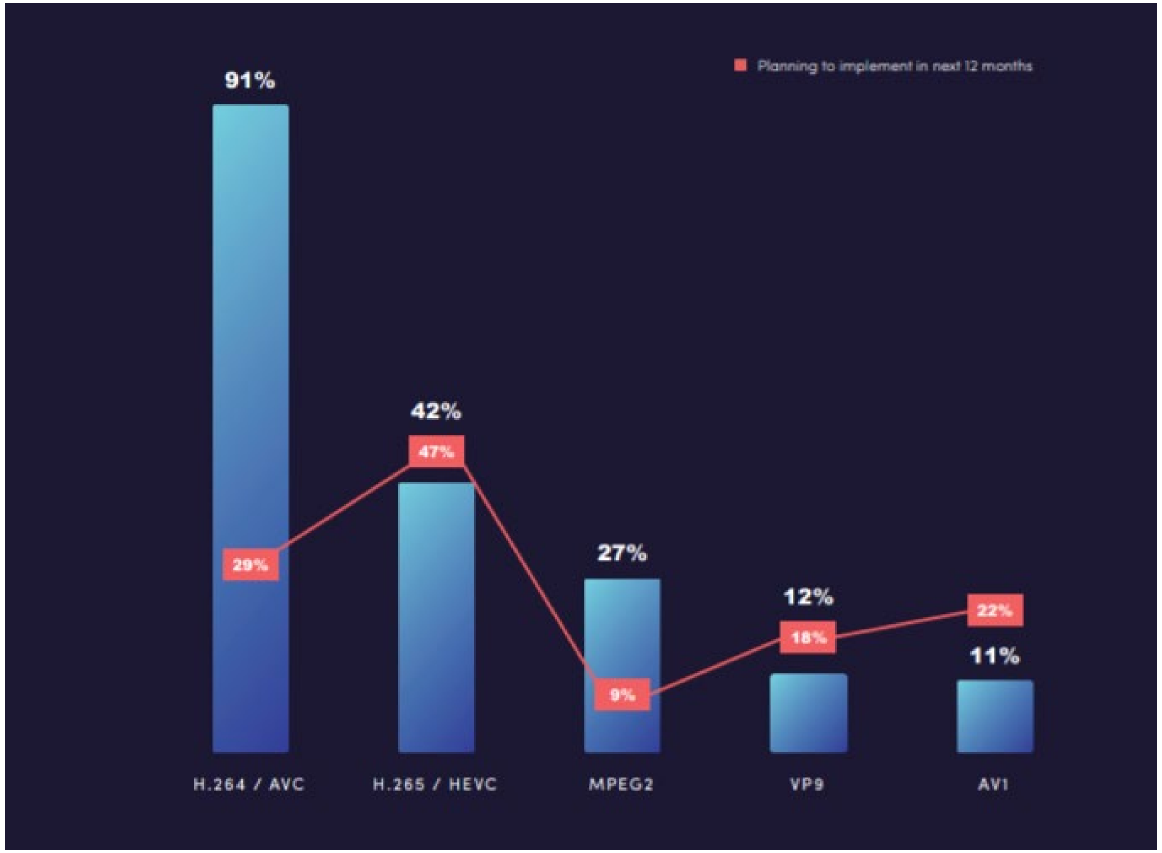
So, **despite the lack of hardware acceleration for the decode of the enhancement layer, LCEVC playback is slightly more efficient than H.264 playback**.

LCEVC Summary

- LCEVC is currently shipping as licensed by V-Nova
- It's the only "software" codec capable of being deployed today
- Royalty structure is relatively advanced and should be announced in early 2021

Reality Check: Where we Are

- Bitmovin 2020 Video Developer Report
  - H.264 at 91% (29% will implement in next 12 months
  - HEVC at 42% (47%)
  - VP9 at 12% (18%)
  - AV1 at 11% (22%)



http://bit.ly/bm_vd_2020

HEVC

	1/2021	1/2022	1/2023	1/2024	1/2025	1/2026	1/2027
Known royalty	Mostly Now						
Silicon	Now						
Devices	Now						
Market share worth chasing	Now						
In browser	You're joking right?						
Live contribution	Now						
Live transcoding – hardware	Now						
Live transcoding – software	Now						
Low latency		1/2022					
HDR	Now						

VP9

1/2021 | 1/2022 | 1/2023 | 1/2024 | 1/2025 | 1/2026 | 1/2027

Known royalty	?
Silicon	Some
Devices	Most non-Apple
Market share worth chasing	Now
In browser	Now
Live contribution	Few options
Live transcoding – hardware	Few options
Live transcoding – software	6/23
Low latency	Now (WebRTC)
HDR	HLG

AV1

1/2021 | 1/2022 | 1/2023 | 1/2024 | 1/2025 | 1/2026 | 1/2027

Known royalty	?
Silicon	Some
Devices	Some
Market share worth chasing	Now – because of browser and software decode on devices
In browser	Most
Live contribution	6/2021
Live transcoding – hardware	6/2022
Live transcoding – software	6/2026
Low latency	WebRTC
HDR	6/2021

VVC/EVC

1/2021 1/2022 1/2023 1/2024 1/2025 1/2026 1/2027

Known royalty	6/2021
Silicon	6/2022
Devices	6/2023
Market share worth chasing	6/2024
In browser	You're joking right?
Live contribution	1/2023
Live transcoding – hardware	6/2023
Live transcoding – software	6/2026
Low latency	6/2023
HDR	6/2023

VVC gets interesting for hardware developers

VVC gets interesting for publishers

LCEVC

1/2021 1/2022 1/2023 1/2024 1/2025 1/2026 1/2027

Known royalty	1/2021
Silicon	6/2022
Devices	6/2023
Market share worth chasing	Now
In browser	1/2021 – via player
Live contribution	1/2021
Live transcoding – hardware	6/2021
Live transcoding - software	6/2021
Low latency	6/2021
HDR	1/2022