Comparing AV1, VP9, HEVC, and H.264

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My Focus

- Content publishers (not hardware developers)
  - Primary concern is content royalties decode royalties
- Mainstream codecs
  - There are business cases for V-Nova PERSEUS and RealMedia HD, but I won't discuss them here
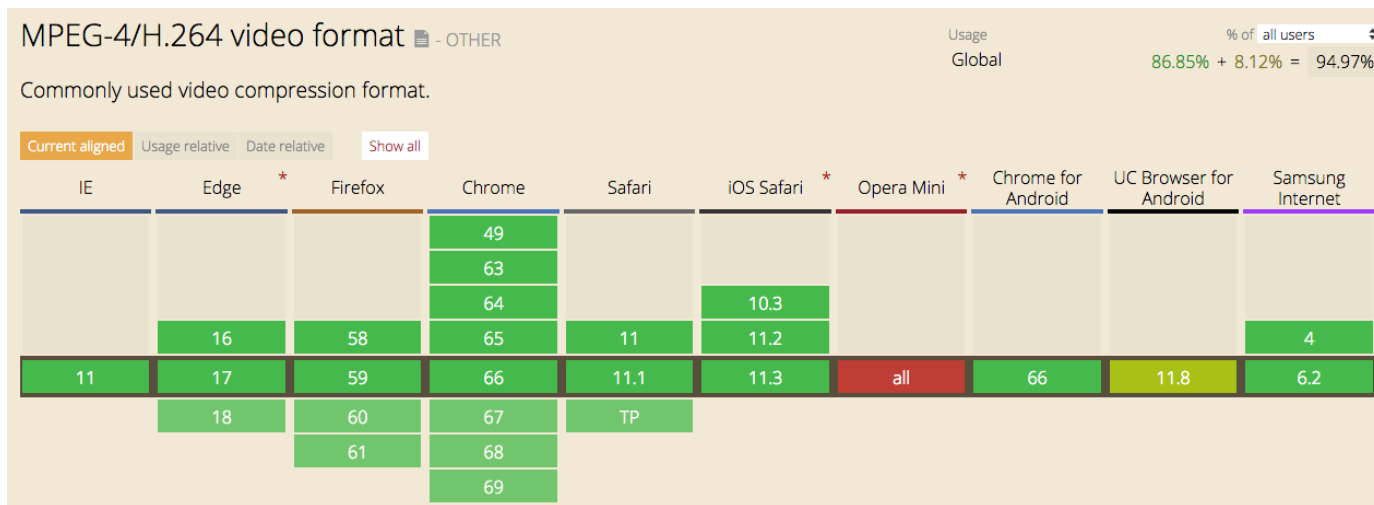
Agenda

- Why do we change codecs?

- To make money
  - Enter new markets (HDR, ultra-low bandwidth)
  - Improve QoE in existing markets
- Factors in decision
  - Codec reach
  - Codec features
  - Codec quality/bitrate

- To save money
  - Reduce bandwidth costs
- Factors:
  - Codec reach
  - Quality
  - Encoding cost
  - Other factors

H.264

- Reach
- Features
- Cost side

H.264: Computers and Mobile

- Near ubiquitous reach is H.264's strongest feature

https://caniuse.com/#search=H.264

H.264 OTT/Smart TV

OTT	H.264
Roku	Yes
Chromecast	Yes
FireTV	Yes
Apple TV	Yes
Smart TV	
Samsung	Yes
HbbTV	Yes
Smart TV Alliance	Yes

H.264:Live and Live Transcoding

- Ubiquitous live encoders in all shapes and forms
- Transcoding available from Wowza (right), Nimble Streamer, and many cloud, software, and appliance-based encoding vendors
- Very little 4K deployed in live, making H.264 a great option for most live events

Video Output	H.264
Adobe RTMP	✔
RTSP/RTP	✔
MPEG-TS	✔
Apple HLS	✔
MPEG-DASH	✔
Adobe HDS	✔
Microsoft Smooth Streaming	✔
WebRTC(Preview)	✔

H.264 and High Dynamic Range

- Technically feasible, but:
  - Virtually all HDR devices support HEVC
  - DolbyVision support is 8-bit, not 10-bit
  - 4K delivery costs would be excessive

Table 4: Constraints on codec level

Profile ID	Profile Name	BL/EL codec	BL:EL	Dolby Vision level (maximum)	BL/EL codec profile	BL codec level (maximum)	EL codec level (maximum)
4	dvhe.04	10-bit HEVC	1:¼	uhd60	H.265 main10	5.1	4.1
5	dvhe.05	10-bit HEVC	NA	uhd60	H.265 main10	5.1	NA
7	dvhe.07	10-bit HEVC	1:1	fhd60	H.265 main10	High Tier 5.1	High Tier 5.1
			1:¼	uhd60	H.265 main10	High Tier 5.1	High Tier 5.1
8	dvhe.08	10-bit HEVC	NA	uhd60	H.265 main10	5.1	NA
9	dvav.09	8-bit AVC	NA	fhd60	H.264 high	4.2	NA

📄 Note: Profiles 0–3 and 6 are not supported for new applications.

H.264 Cost Side

- Quality – it's the baseline
- Encoding time/cost – it's the baseline
- Storage – again, it's the baseline

H.264: Royalties

- Subscription
  - 100,000 or fewer subscribers/yr = no royalty;
  - 100,000 to 250,000 subscribers/yr = $25,000;
  - 250,000 to 500,000 subscribers/yr = $50,000;
  - 500,000 to 1M subscribers/yr = $75,000;
  - 1M subscribers/yr = $100,000
- Title-by-Title - 12 minutes or less = no royalty;
  - 12 minutes in length = lower of (a) 2% or (b) $0.02 per title •

H.264: What's it Cost You?

- Capacity - if delivering over fixed capacity infrastructures
  - According to Netflix: x265 and VP9 up to 40% more efficient, especially at higher resolutions. http://bit.ly/nf_codec
  - So: supporting either VP9, HEVC, or both will expand your capacity and potentially shave bandwidth costs

H.264: What's it Cost You? - QoE

Data Rate	H.264		HEVC		
	Rez	VMAF	Rez	VMAF	Delta
145	234p	21.50	432p	26.56	5.06
365	270p	52.52	540p	65.12	12.61
730	360p	69.10	720p	78.45	9.34
1100	432p	80.61	720p	87.32	6.72
2000	540p	88.02	1080p	92.94	4.92
3000	720p	92.89	1080p	95.86	2.97
4500	720p	95.06	1080p *	97.53	2.47
6000	1080p	96.99	1080p *	97.53	0.54
7800	1080p	97.71	1080p *	97.53	-0.18

- Mobile
  - 1.1 mbps - H.264 - 432p - 80.61 VMAF
  - 1.1 mbps stream HEVC/VP9 - 720p – 87.32 VMAF (noticeably higher quality)

- Living room
  - 4.5 mbps - H.264 - 720p ~ 95.06 VMAF
  - 4.5 mbps - HEVC/VP9 - 1080p – 97.41 VMAF (may be noticeable)

H.264 Scorecard

- Great for reach and features
  - Clearly best codec for legacy viewers
  - Not optimal for HDR
- Cost side
  - Low quality means:
    - high bandwidth costs
    - Limited access to low-bandwidth markets
  - Content royalties an accepted reality

	H.264
Revenue Side	
Reach	
Computers	100%
Mobile with hardware	100%
OTT/Smart TV	100%
Features	
Live	100%
Live transcode	100%
Low latency	100%
HDR	Not optimal (reach of 10-bit AVC unknown)
Cost Side	
Quality	1 - lowest of the bunch
Encoding time	1
Content royalty cost	PPV/Subscripion
FUD Factor	Nokia/Motorola

H.264: The Big Question

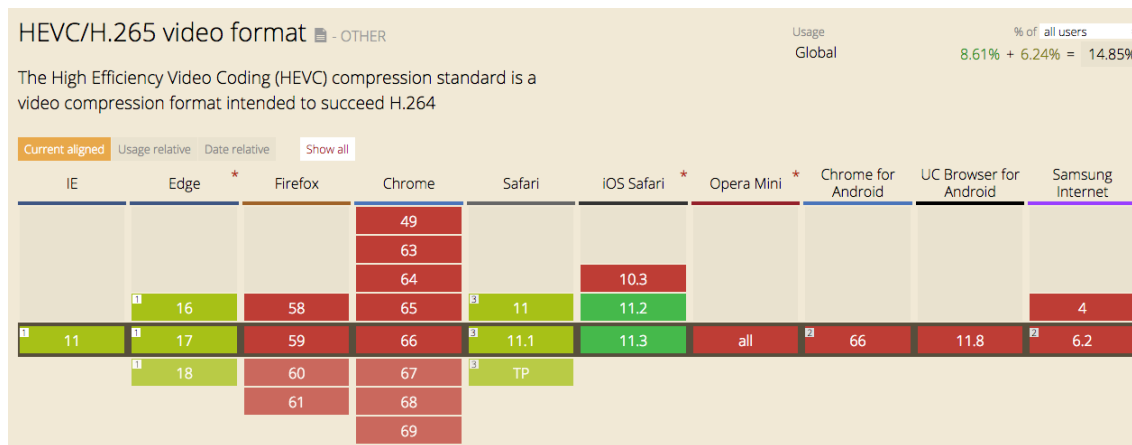- How much longer will you be encoding H.264?

H.264: The Big Question

- How much longer will you be encoding H.264?
  - Forever

HEVC

- Reach
- Features
- Cost side

HEVC: Computers and Mobile

https://caniuse.com/#search=HEVC

- Windows 10
  - Computers with HEVC hardware decode
  - Not HLS
- MacOS - High Sierra
- iOS – 11/Android 5.0 (not HLS)

- No support
  - Computer - Chrome and Firefox
  - Pre MacOS/iOS 11
  - Pre-Windows 10

HEVC OTT/Smart TV

OTT	HEVC	HEVC
Roku	Yes	4K capable
Chromecast	Yes	Ultra
FireTV	Yes	2nd Gen
Apple TV	Yes	4K
Smart TV		
Samsung	Yes	2015+
HbbTV	Yes	Yes
Smart TV Alliance	Yes	Yes

HEVC:Live and Live Transcoding

- Some live encoders in all shapes and forms
- Transcoding available from Wowza (right), Nimble Streamer, and many cloud, software, and appliance-based encoding vendors

Video Output	H.265	H.264
Adobe RTMP	✓	✓
RTSP/RTP	✓	✓
MPEG-TS	✓	✓
Apple HLS	✓	✓
MPEG-DASH	✓	✓
Adobe HDS		✓
Microsoft Smooth Streaming		✓
WebRTC(Preview)		✓

HEVC and High Dynamic Range

- Technology of choice at this point

Table 4: Constraints on codec level

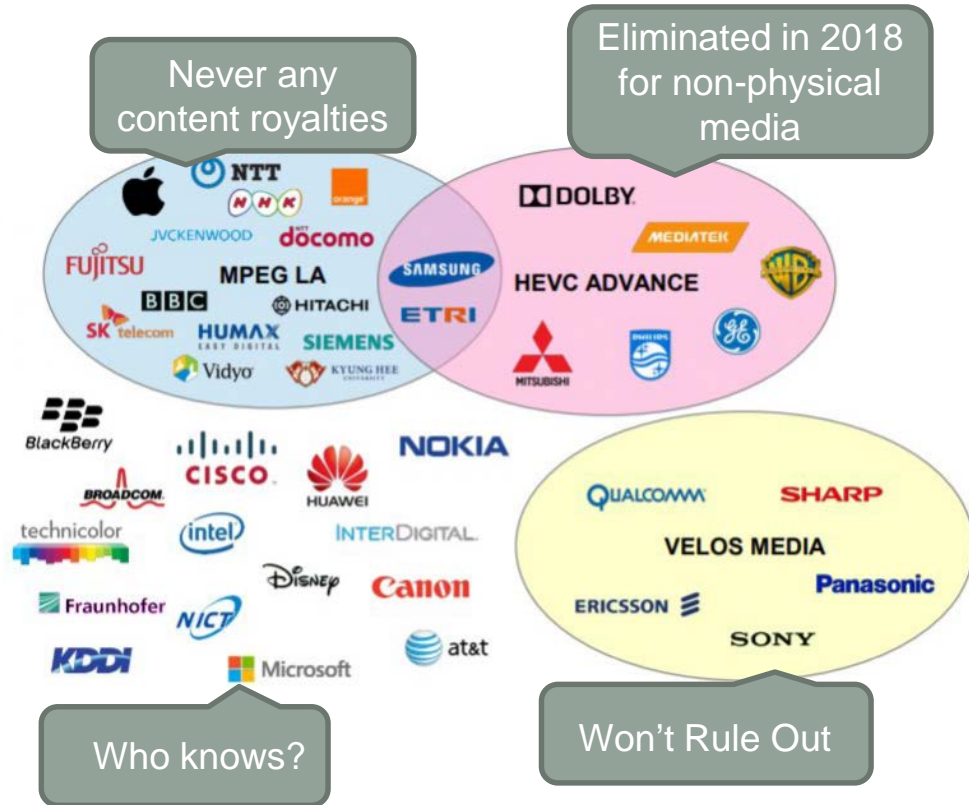| Profile ID	Profile Name	BL/EL codec	BL:EL	Dolby Vision level (maximum)	BL/EL codec profile	BL codec level (maximum)	EL codec level (maximum)
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Note: Profiles 0–3 and 6 are not supported for new applications.

HEVC Cost Side

- Quality
  - Assume same quality as H.264 at 60% of the data rate (save 40%)
- Encoding time/cost
  - Assume 4x H.264, 8x for UHD streams
    - Much less if running your own encoding farm
    - More if you're paying retail by the GB or minute
- Storage – assume 60% the cost of H.264 quality

HEVC: Content Royalties

- Three patent groups
  - MPEG LA
  - HEVC Advance
  - Velos – Hoping you get hooked so they can come back and charge you royalties later (and retroactively)
    - Joking, but why not say?
- Non-affiliated

Never any content royalties

Eliminated in 2018 for non-physical media

Who knows?

Won't Rule Out

Image by Jonatan Samuelsson, Divideon

Please Tweet (and Attribute to Jan Ozer)

- By refusing to definitively eliminate content royalties, HEVC IP owners, particularly those in the Velos Media Pool, have created the worst case of self-inflicted FUD in the history of technology
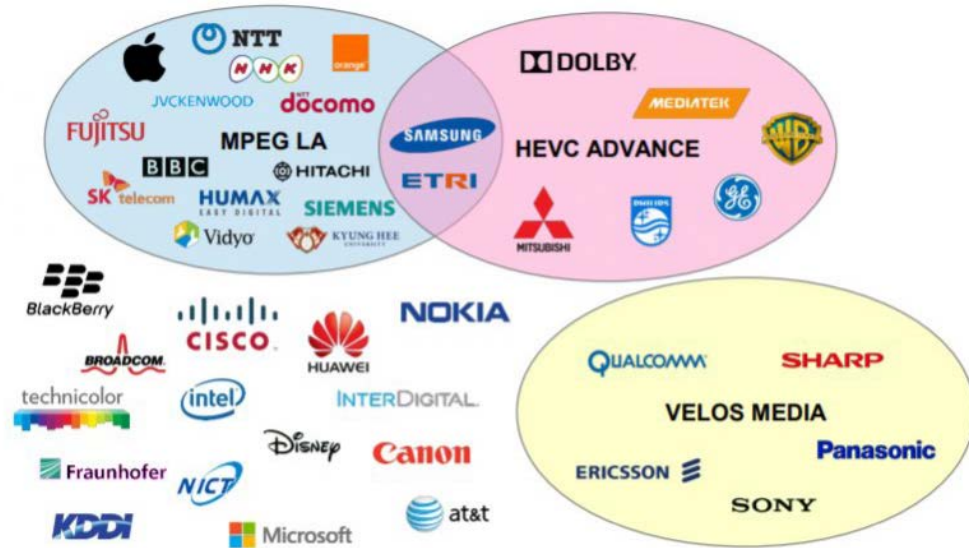
What do Steely-Eyed CFOs Hate More than Anything?

HEVC in HLS?

- Two reasons
  - Improved QoE
  - Bandwidth savings
- Bandwidth savings
  - Explored before – higher quality at all bitrates
  - Most noticeable for mobile

Data Rate	H.264		HEVC		
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7800	1080p	97.71	1080p *	97.53	-0.18

Bandwidth Savings Breakeven Analysis

- ## Cost –
  - Fixed – player cost – should be minimal
  - Variable – additional encoding/storage
- ## Savings
  - Reduced bandwidth costs
  - What are bandwidth savings?
    - Just because HEVC enables same quality as H.264 at 60% of data rate doesn't mean you save 40% of bandwidth

$$\frac{\text{Fixed + Variable Costs}}{\text{Savings/hour}} = \text{Viewing hours to Breakeven}$$

Netflix ISP Index

- Averages 4.06 Mbps during primetime viewing

RANK	ISP	SPEED Mbps		PREVIOUS Mbps
1	Comcast	4.06		4.00
2	Verizon - FiOS	4.04		3.97
3	Cox	4.02		3.95
4	Optimum	3.98		3.92
5	Spectrum	3.98		3.90
6	Mediacom	3.94		3.87
7	AT&T - U-verse	3.92		3.87
8	Suddenlink	3.84		3.76
9	Frontier	3.36		3.31
10	CenturyLink	3.36		3.29
11	Windstream	3.30		3.21
12	Verizon - DSL	3.16		3.22
13	AT&T - DSL	2.86		2.87

ISP LEADERBOARD - MARCH 2018

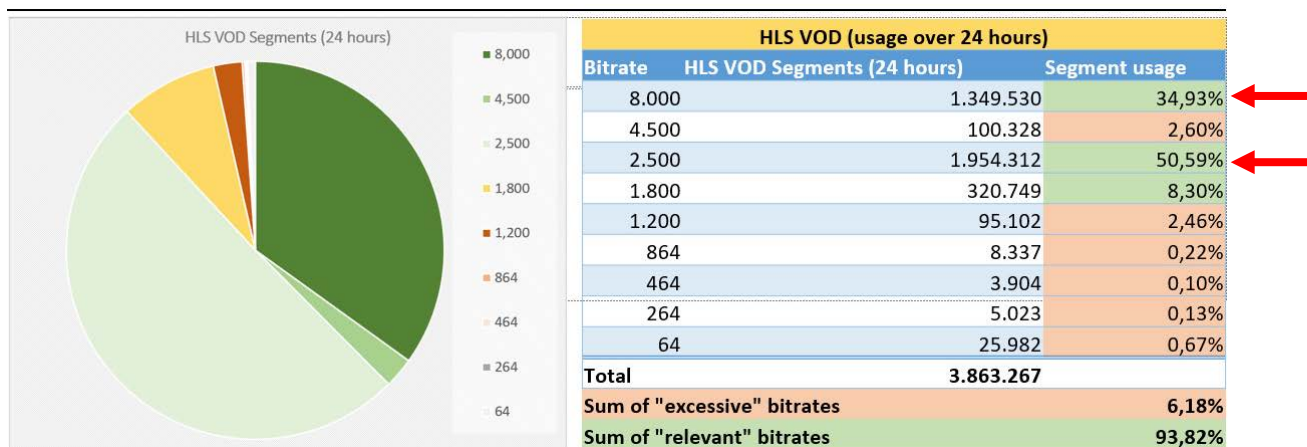https://ispspeedindex.netflix.com/country/us/

How ABR Works

- Netflix averages 4 Mbps in the US during primetime hours
- Assume you can push through 4.5 Mbps
- H.264 would be this stream
- HEVC would be this stream
- No bandwidth savings
- Clearly – just because HEVC cuts bitrates by 50% doesn't mean you cut bandwidth costs by 50%

Data Rate	H.264 Rez	HEVC Rez
145	234p	432p
365	270p	540p
730	360p	720p
1100	432p	720p
2000	540p	1080p
3000	720p	1080p
4500	720p	1080p *
6000	1080p	1080p *
7800	1080p	1080p *

How Can You Assess Potential Savings?

HLS VOD Segments (24 hours)

Legend: 8,000 · 4,500 · 2,500 · 1,800 · 1,200 · 864 · 464 · 264 · 64

HLS VOD (usage over 24 hours)		
Bitrate	**HLS VOD Segments (24 hours)**	**Segment usage**
8.000	1.349.530	34,93%
4.500	100.328	2,60%
2.500	1.954.312	50,59%
1.800	320.749	8,30%
1.200	95.102	2,46%
864	8.337	0,22%
464	3.904	0,10%
264	5.023	0,13%
64	25.982	0,67%
Total	**3.863.267**	
Sum of "excessive" bitrates		**6,18%**
Sum of "relevant" bitrates		**93,82%**

- Is your average 4 Mbps because of bandwidth restrictions or because of a mix of SD and HD and UHD?
- Check your log files

- 85% of this client's distribution were the highest quality SD &HD streams
- HEVC/VP9/AV-1 should lead to very significant bandwidth savings

•https://www.linkedin.com/pulse/check-your-dang-log-files-jan-ozer/

HEVC in HLS?

Encoding Cost/video hour	Bandwidth Cost (per GB)							
	$0.085	$0.08	$0.06	$0.04	$0.03	$0.03	$0.02	$0.01
$3	49	52	69	104	139	167	208	417
$5	82	87	116	174	231	278	347	694
$10	163	174	231	347	463	556	694	1,389
$15	245	260	347	521	694	833	1,042	2,083
$20	327	347	463	694	926	1,111	1,389	2,778
$25	408	434	579	868	1,157	1,389	1,736	3,472
$30	490	521	694	1,042	1,389	1,667	2,083	4,167

- Assumptions
  - H.264 @ 4 Mbps/HEVC @ 2.4 MB
  - Storage not included (~ $1.20/hr for 5 years)
  - No player dev cost (native playback)
- Simple math exercise
  -

Seems Logical; on the Radar Screen

- Streaming Media survey sponsored by Harmonic; published in January 2018
  - 437 *Streaming Media* readers responded
- Substantial interest in supporting HEVC in HLS, particularly in mid-to-late 2018.
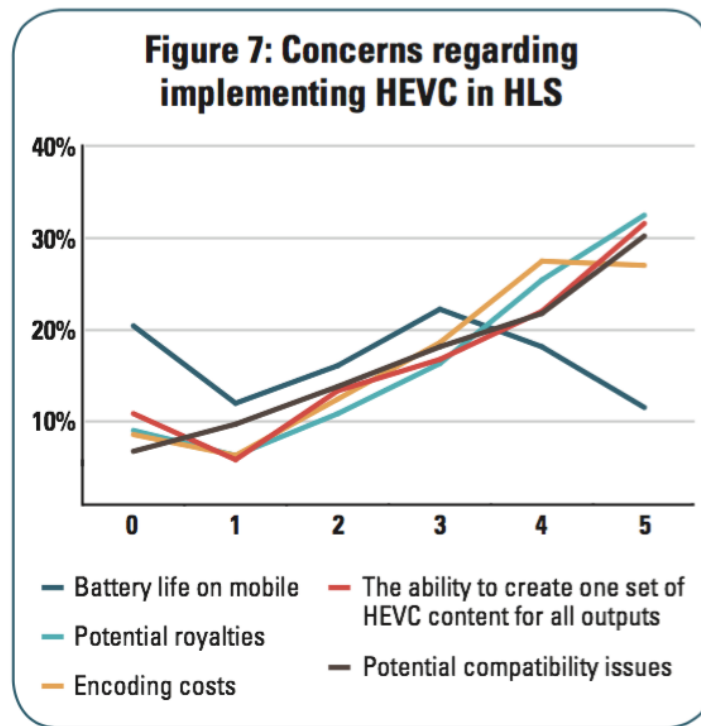

Figure 6: The soonest respondents plan to deploy HEVC in HLS
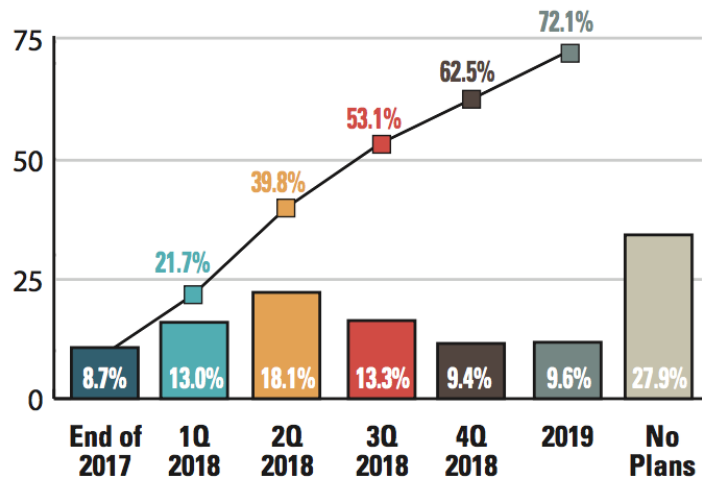
http://bit.ly/HEVC_HLS_Survey

Seems Logical; on the Radar Screen

- Nor surprisingly, royalties were the most significant concern
  - 30% rated this concern a 5, which was the strongest

Figure 7: Concerns regarding implementing HEVC in HLS

Legend:
- Battery life on mobile
- Potential royalties
- Encoding costs
- The ability to create one set of HEVC content for all outputs
- Potential compatibility issues

http://bit.ly/HEVC_HLS_Survey

HEVC Scorecard

- Potential for content royalty continues to be a huge wet blanket
- Non-starter for browser-based distribution on computers
- Best option for HDR to Smart TVs
  - No brainer
- What about HEVC/HLS?
  - Let's take a look

	H.264	HEVC
Revenue Side		
Reach		
Computers	100%	Safari/Edge
Mobile with hardware	100%	100%
OTT/Smart TV	100%	100%
Features		
Live	100%	Many options
Live transcode	100%	Many options
Low latency	100%	Some options
HDR	Not optimal (reach of 10-bit AVC unknown)	100%
Cost Side		
Quality	1 - lowest of the bunch	H.264 @ 60%
Encoding time	1	~ 4x H.264
Content royalty cost	PPV/Subscripion	Velos?
FUD Factor	Nokia/Motorola	Others not in pool

VP9

- Reach
- Features
- Cost side

VP9 Browser and Mobile (www.caniuse.com)

Supported Platforms
- Windows
  - All but IE
- Android - 4.2 +

No support
- Mac Safari
- iOS
- IE (which means lots of pre-Windows 10)

IE	Edge *	Firefox	Chrome	Safari	iOS Safari *	Opera Mini *	Chrome for Android	UC Browser for Android	Samsung Internet
			49						
			63						
			64		10.3				
	16	58	65	11	11.2				4
11	17	59	66	11.1	11.3	all	66	11.8	6.2
	18	60	67	TP					
		61	68						
			69						

VP9 Compatibility Matrix

OTT	H.264	HEVC	VP9
Roku	Yes	4K capable	4K capable
Chromecast	Yes	Ultra	Ultra
FireTV	Yes	2nd Gen	2nd Gen
Apple TV	Yes	4K	**No**
Smart TV			
Samsung	Yes	**2015+**	2015+
HbbTV	Yes	**Yes**	**No**
Smart TV Alliance	Yes	**Yes**	**No**

VP9:Live Transcoding - Available for DASH

- Very few live encoding devices (most H.264/HEVC)
- Decent transcoding support from services
- Not so much from traditional encoders

Video Output	H.263	VP9
Adobe RTMP		
RTSP/RTP		
MPEG-TS		
Apple HLS		
MPEG-DASH		✔
Adobe HDS		
Microsoft Smooth Streaming		
WebRTC(Preview)		✔

VP9 and High Dynamic Range

- Technically feasible (10-bit+ available)
- Not included in DolbyVision spec
- Not included in Apple HLS spec

Table 4: Constraints on codec level

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			1:¼	uhd60	H.265 main10	High Tier 5.1	High Tier 5.1
8	dvhe.08	10-bit HEVC	NA	uhd60	H.265 main10	5.1	NA
9	dvav.09	8-bit AVC	NA	fhd60	H.264 high	4.2	NA

Note: Profiles 0–3 and 6 are not supported for new applications.

VP9: What's it Cost You?

- Royalty free, but no indemnifications from Google
  - Google insists they performed full IP review before buying ON2 and hadn't infringed since, but
  - Velos Media - "As it relates to royalties, we know that VP9 incorporates patented technologies, including some of the patents being licensed by Velos Media for HEVC" (http://velosmedia.com/technology/q-and-a/)
    - Sowing Fear, Uncertainty, and Doubt (FUD) or a shot across the bow?
    - Hard to assume that Google didn't do their due diligence when buying On2 and during subsequent development of VP9
  - Given that VP9 was never highly utilized and is about to be supplanted, an infringement suit seems unlikely
    - That said, an AV1 suit would probably include VP9 as well
- Same storage costs at origin as HEVC

VP9: When to Support VP9 in the Browser?

- Same QoE and bandwidth saving analysis
  - Player development cost needs to be considered
  - Encoding cost should be about 2x H.264
- Penetration to date
  - Some uptake
  - Encoding.com's VP9 production down from 11%
  - Feels like the market will wait for AV1

https://bitmovin.com/whitepapers/Bitmovin-Developer-Survey.pdf

https://www.encoding.com/files/2018-Global-Media-Formats-Report.pdf
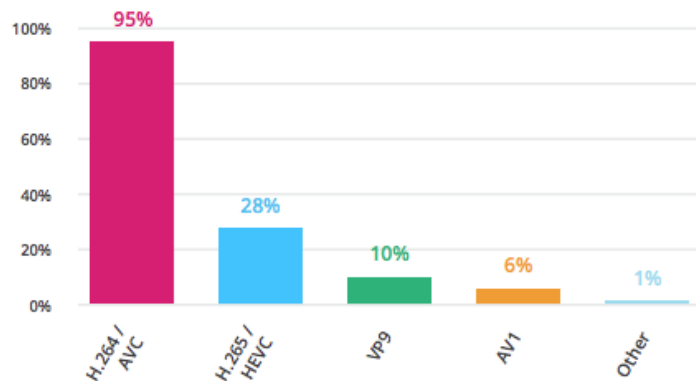
What About the Survey?

- Substantial interest in VP9

Figure 11: Codecs respondents plan to add in 2017 and beyond

(Multiple Responses Possible)

Codec	Percentage
AV1	33.0%
VP9	27.3%
V-NOVA PERSEUS	5.8%
Divideon xvc	3.0%
RealNetworks RealMedia HD	4.4%
Not planning on adding any codecs at this time	53.8%
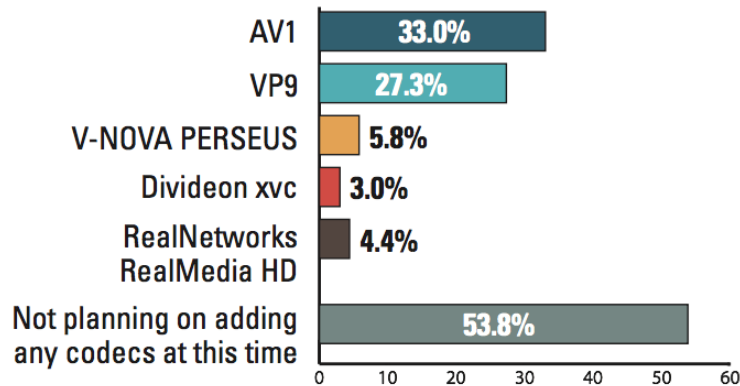
http://bit.ly/HEVC_HLS_Survey

VP9 Scorecard

- Great browser support
- Preferred for Android
- Limited features

|	H.264	HEVC	VP9
Revenue Side			
Reach			
Computers	100%	Safari/Edge	95%
Mobile with hardware	100%	100%	50%
OTT/Smart TV	100%	100%	75%
Features			
Live	100%	Many options	Little support
Live transcode	100%	Many options	Wowza & Nimble
Low latency	100%	Some options	unknown
HDR	Not optimal (reach of 10-bit AVC unknown)	100%	No std. support
Cost Side			
Quality	1 - lowest of the bunch	H.264 @ 60%	H.264 @ 60%
Encoding time	1	~ 4x H.264	~2X H.264
Content royalty cost	PPV/Subscripion	Velos?	None
FUD Factor	Nokia/Motorola	Others not in pool	Feels low risk

What About HEVC vs. VP9 Quality?

- Moscow State University
- Most likely use case – very close according to SSIM
- AV1 produces same quality as x264 @ 55% of the data rate
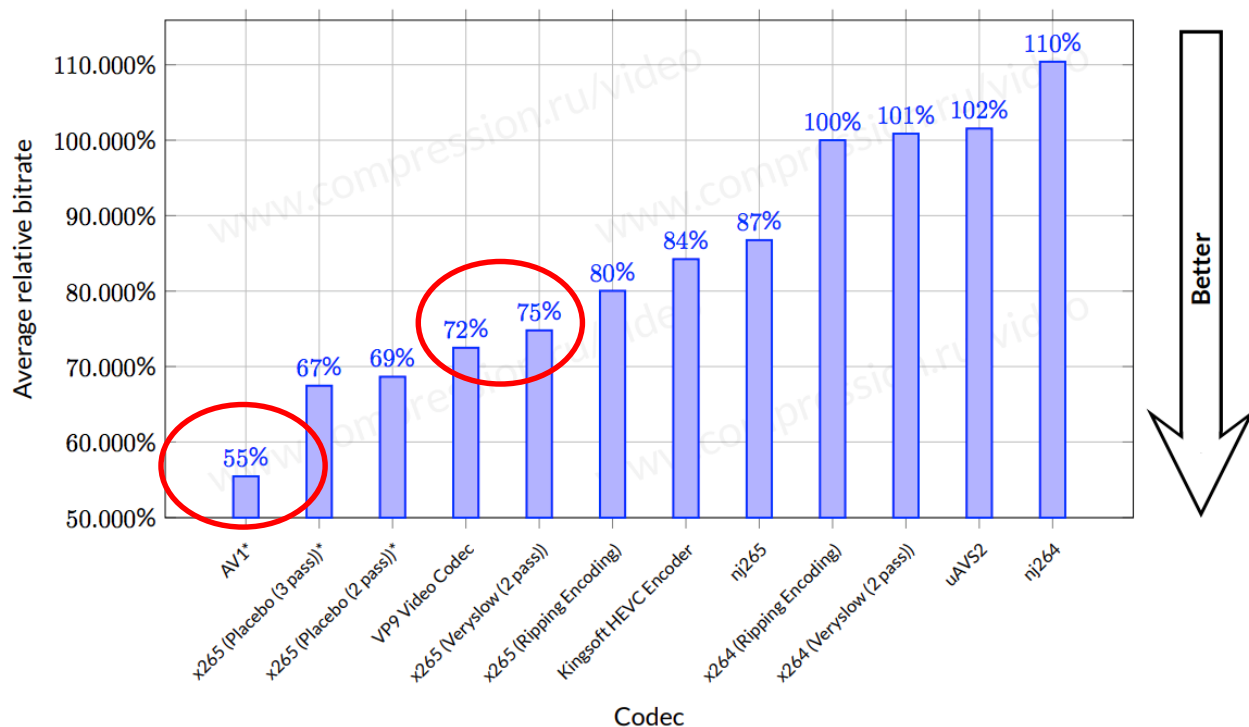
New Subjective Comparisons

- Subjectify.us – cloud-sourced viewing:
  - https://youtu.be/ftSbNUM1yMA
- VP9 slightly better than best HEVC alternative

http://www.compression.ru/video/
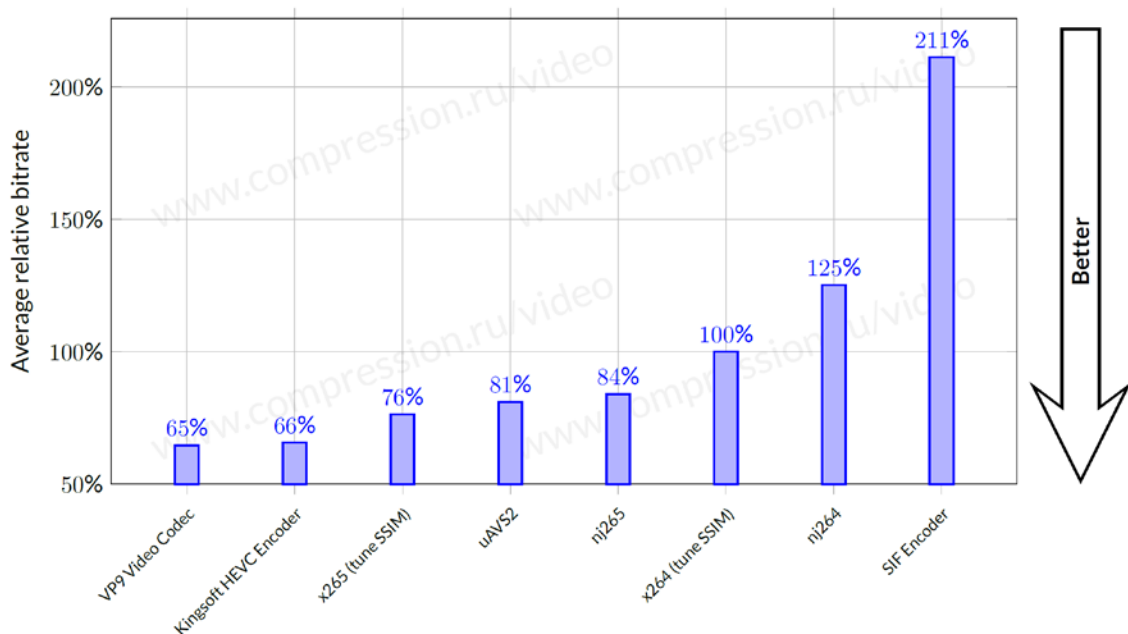
Alliance for Open Media AV1

- What is it?
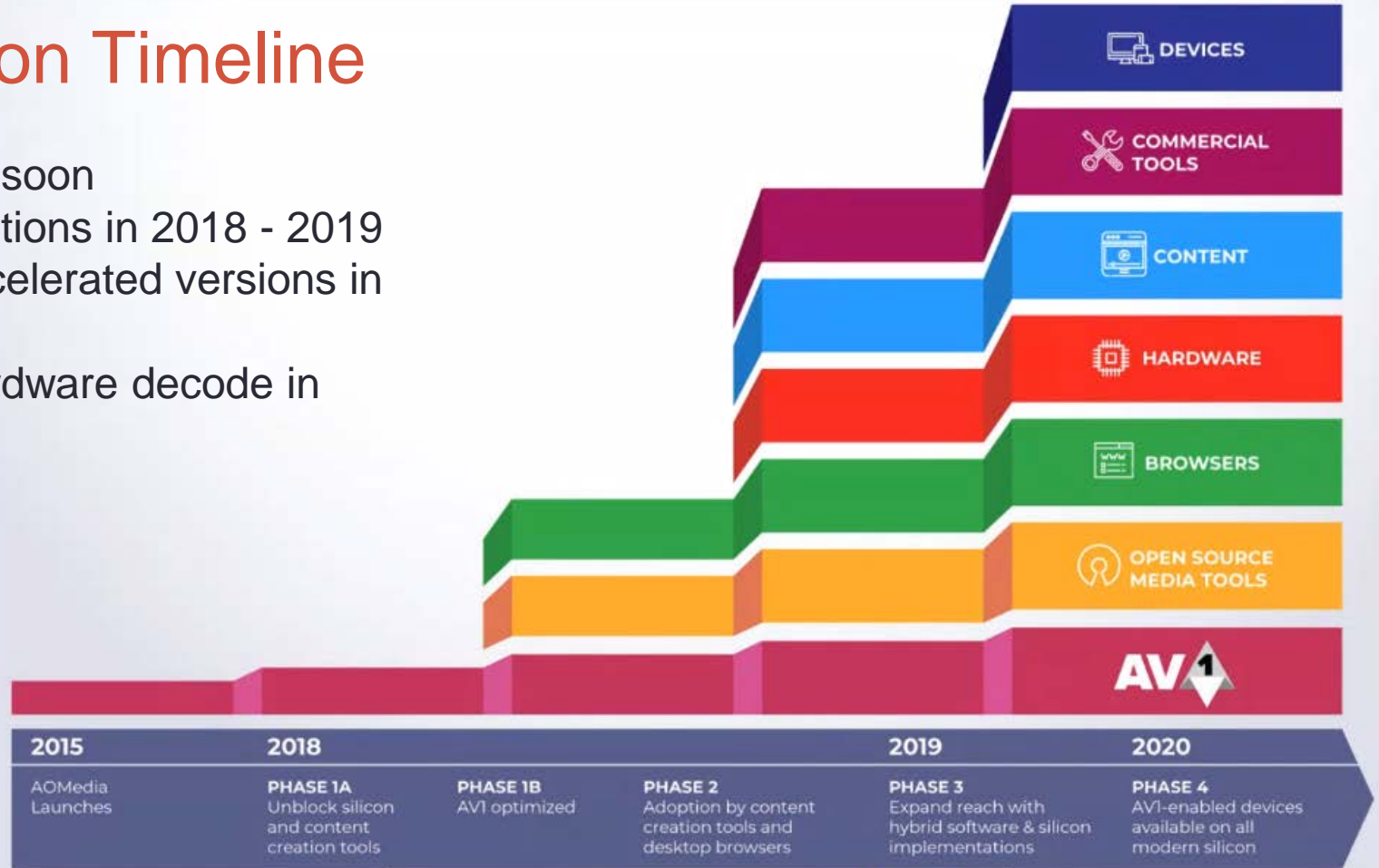- Reach
- Features
- Cost side

What is AV1?

- Codec produced by the Alliance for Open Media (AOM)
- Prominent members include:
  - Codec vendors – Google, Microsoft, Mozilla, Cisco
  - Hardware – Intel, NVIDIA, ARM, Broadcom, Ittiam
  - Content – YouTube, Netflix, Amazon, Facebook, Hulu, BBC
  - Infrastructure – Bitmovin, Ateme, IBM
  - Technically sophisticated group (hold that thought)
- Bitstream almost frozen at NAB; should be frozen soon

Reach

- Looks pretty certain: Members include:
  - Apple (Safari, iOS, MacOS, tvOS)
  - Google (Android, Chrome)
  - Microsoft (Edge, Windows)
  - Mozilla (Firefox)
  - So, both major computer OS, both major mobile OS and all four major browers
- Working in versions of Chrome and Firefox at NAB
- Major unknown:
  - CPU horsepower required to play AV1
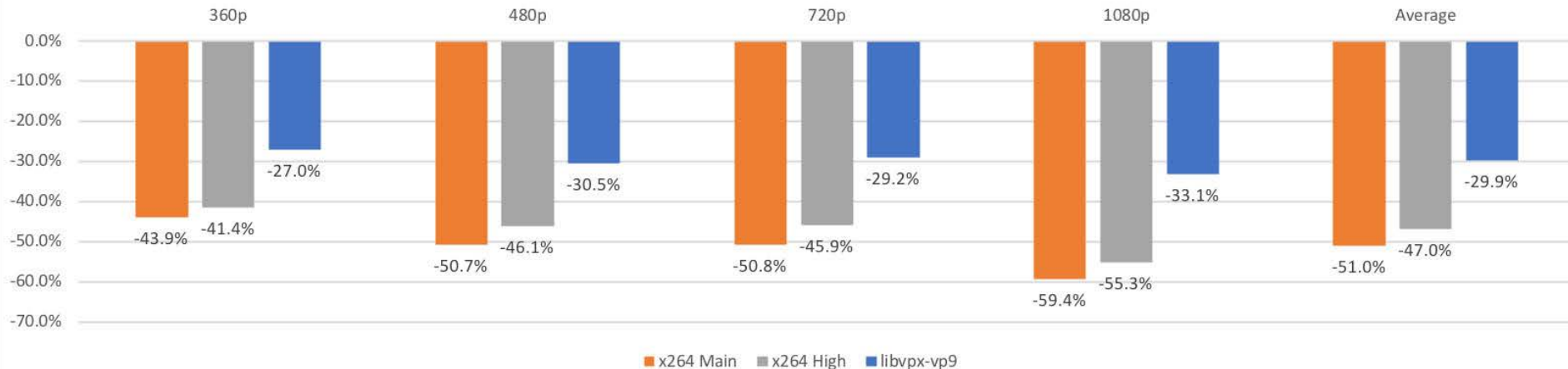 - Will slower machines be excluded (not yet tested)

Adoption Timeline

- Browser soon
- Optimizations in 2018 - 2019
- GPU-accelerated versions in 2019
- Total hardware decode in 2020
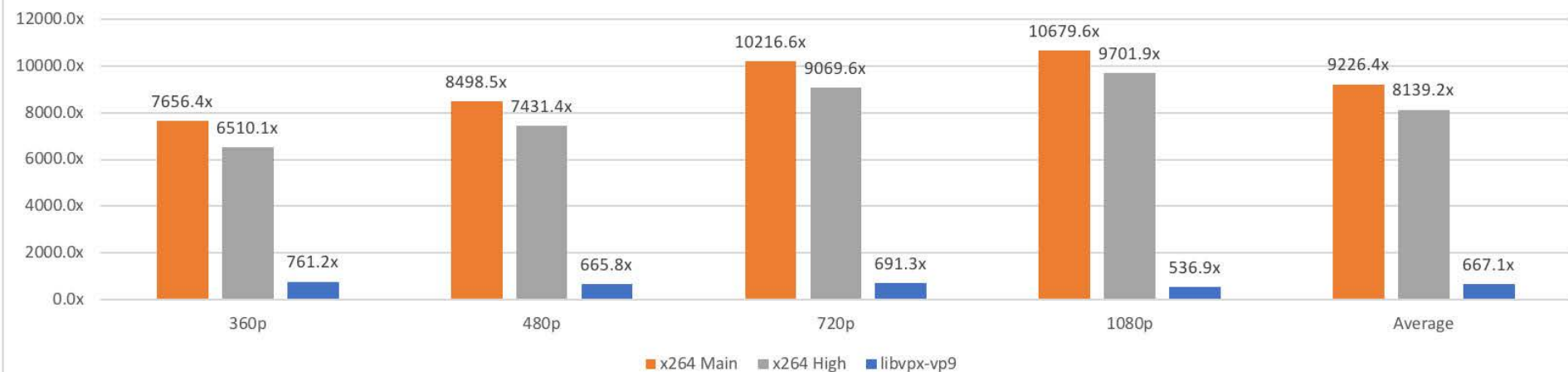
AV1: What's it Give You?

AV1 BD-rate saving in terms of PSNR for ABR mode

	360p	480p	720p	1080p	Average
x264 Main	-43.9%	-50.7%	-50.8%	-59.4%	-51.0%
x264 High	-41.4%	-46.1%	-45.9%	-55.3%	-47.0%
libvpx-vp9	-27.0%	-30.5%	-29.2%	-33.1%	-29.9%

- Same quality as VP9 at 70% the bandwidth

What's the Catch?

AV1 encoding time increase ratio for ABR mode

- As much as 10,000 times slower than H.264

Encoding Cost/Breakeven

Encoding Cost/video hour	Bandwidth Cost (per GB)							
	$0.085	$0.08	$0.06	$0.04	$0.03	$0.03	$0.02	$0.01
$3	49	52	69	104	139	167	208	417
$5	82	87	116	174	231	278	347	694
$10	163	174	231	347	463	556	694	1,389
$15	245	260	347	521	694	833	1,042	2,083
$20	327	347	463	694	926	1,111	1,389	2,778
$25	408	434	579	868	1,157	1,389	1,736	3,472
$30	490	521	694	1,042	1,389	1,667	2,083	4,167
$30,000	490,196	520,833	694,444	1,041,667	1,388,889	1,666,667	2,083,333	4,166,667

- Makes sense for producers with millions of views, which includes members like Amazon, Google, Facebook, Netflix
- But only publishers distributing at that volume

Is 30% Superior Quality Real?

- Much ado about encoding quality comparison between HEVC and AV1
- Anyone who cares at this point is performing their own analysis
- There are no production encoders, or commercially reasonable encoders to test
- Let's give it 12 months
  - Playback scenario set
  - Commercial encoders available
  - Encoding time should be ~ 20 – 30 x VP9

Besides Encoding Time, What Does AV1 Cost?

- Royalty free, but no indemnifications from AOMedia
- Velos Media - "And, while AV1 has not yet been publicly released, it may also incorporate patented technology from many parties." (http://velosmedia.com/technology/q-and-a/)
  - Sowing Fear, Uncertainty, and Doubt (FUD) or a shot across the bow?
  - Can we assume that Alliance Members are naïve regarding technology IP?

You Sure You Want to Sue AOM?

- Established defense fund for anyone sued for infringment
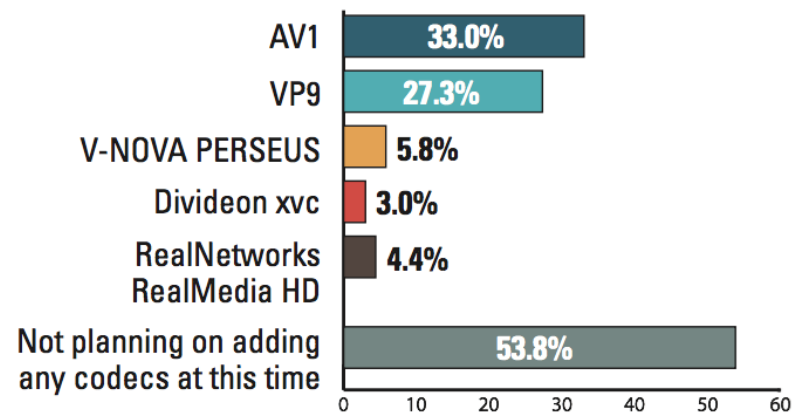- That said, Nokia recently won $2 billion from Apple, which is quite a war chest

Survey Respondents on AV1

- Lots of interest

Figure 11: Codecs respondents plan to add in 2017 and beyond
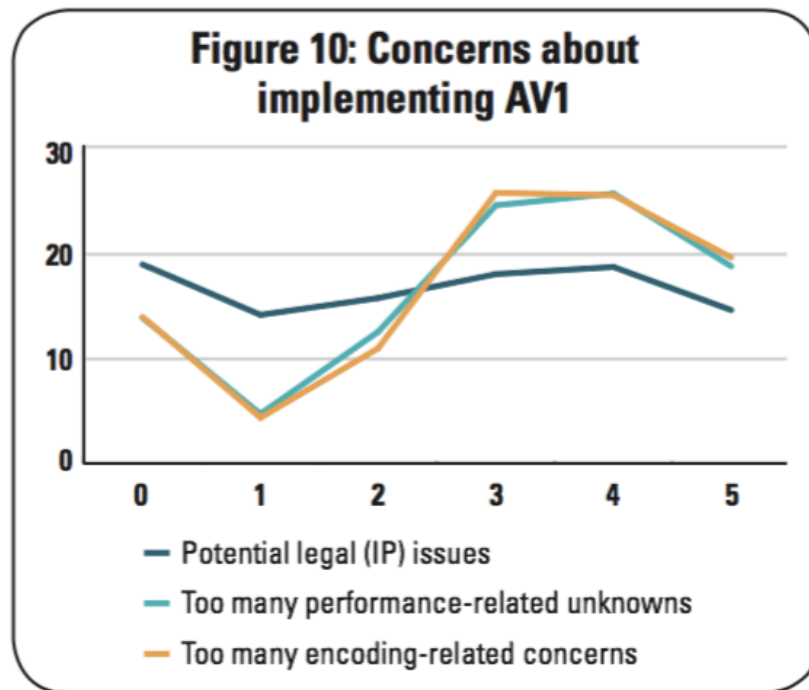### (Multiple Responses Possible)

Codec	Percentage
AV1	33.0%
VP9	27.3%
V-NOVA PERSEUS	5.8%
Divideon xvc	3.0%
RealNetworks RealMedia HD	4.4%
Not planning on adding any codecs at this time	53.8%

http://bit.ly/HEVC_HLS_Survey

Survey Respondents on AV1

- Legal issues not a major concern
- Encoding-related and performance-related concerns were more serious
  - Most of these issues should resolve in the next twelve months or so

Figure 10: Concerns about implementing AV1

- Potential legal (IP) issues
- Too many performance-related unknowns
- Too many encoding-related concerns

http://bit.ly/HEVC_HLS_Survey

AV1 Scorecard:

-- If you're not one of the companies on the front panel of most smart TVs - AV1 won't be relevant through the end of 2018 or later

	H.264	HEVC	VP9	AV1
Revenue Side				
Reach				
Computers	100%	Safari/Edge	95%	80% in 6 months/CPU not yet known
Mobile with hardware	100%	100%	50%	2 years
OTT/Smart TV	100%	100%	75%	2 years
Features				
Live	100%	Many options	Little support	Challenging
Live transcode	100%	Many options	Wowza & Nimble	Challenging
Low latency	100%	Some options	unknown	Challenging
HDR	Not optimal (reach of 10-bit AVC unknown)	100%	No std. support	2 years
Cost Side				
Quality	1 - lowest of the bunch	H.264 @ 60%	H.264 @ 60%	HEVC @ 70%
Encoding time	1	~ 4x H.264	~2X H.264	1000+ x VP9
Content royalty cost	PPV/Subscripion	Velos?	None	None
FUD Factor	Nokia/Motorola	Others not in pool	Feels low risk	Some risk

Questions