PER-TITLE ENCODING

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Agenda

- What is per-title encoding
 - Why is it important
 - Universe of features

Our contestants

- Capped Constant Rate Factor (CRF)
- Capella Systems Source Adaptive Bitrate Ladder (SABL)
- Brightcove Context Aware Encoding
- EuclidIQ Rithm
- Our tests
- Our results

What is Per-Title Encoding

- Customizing encoding for each file
- First implemented by Netflix and YouTube
- First encoder implementation Capella Systems Cambria Encoder
- Can be implemented vis capped CRF

Why is Optimizing the Bitrate Critical?

Consumer Side

- Reduced bandwidth cost (consumer/corporate)
 - Home
 - Mobile
- More efficient on networks
- Better quality of experience
 - Higher rez stream to mobile

Producer Side

- Lower bandwidth costs
- Lower storage costs
- Lower encoding costs
- More video through fixed pipes
- Better reach to consumers on edge of networks
- More competitive because of consumer-side benefits
- More competitive because a feature in competitive products and services

When	Prior to 2015
What	Optimization
Who	Beamr/Euclid/ CRF
Operation	Frame by frame
Overall bitrate control	No
Change GOP/Segment	No



Video – 30 seconds talking head/ 30 seconds ballet – repeat 8x

No bitrate control except cap

When	Prior to 2015	Late 2015
What	Optimization	Per-Title Encoding
Who	Beamr/Euclid	Netflix
Operation	Frame by frame	Gauge complexity/ Choose bitrate ladder
Overall bitrate control	No	Yes; CBR/VBR
Change GOP/Segment	No	No





When	Prior to 2015	Late 2015	2016-2017
What	Optimization	Per-Title Encoding	Commercial Per-title
Who	Beamr/Euclid/ Capped CRF	Netflix	Capella Systems
Operation	Frame by frame	Gauge video complexity/ encode traditionally	Gauge video complexity/ encode traditionally
Overall bitrate control	No	Yes	CBR/VBR
Change GOP/Segment	No	No	No







When	Prior to 2015	Late 2015	2016-2017	Late 2017	2018
What	Optimization	Per-Title Encoding	Commercial Per-title	Segment- based encoding	Shot-based encoding
Who	Beamr/Euclid/ Capped CRF	Netflix	Capella Systems, BC, others	Euclid, others	Netflix
Operation	Frame by frame	Gauge video complexity/ encode traditionally	Gauge video complexity/ encode traditionally	Gauge complexity for each segment; encode segment	Divide each video into shots; encode separately
Overall bitrate control	No	Yes	CBR/VBR	Cap, but no CBR	Probably cap only
Change GOP/Segment	No	No	No	No	Yes

Why Shot-Based Encoding Make Sense

- Key frames at scene changes and not at regular intervals
 - Switching preserved because all iterations encoded the same way
- Major encoding changes up and down at scene changes (so not noticeable)
- Rate control not critical because most scenes are relatively homogenous (minimal capping which can degrade quality)
- Seeking via I-frames are all at scene changes



http://bit.ly/nf_shot

Why Shot-Based Encoding Make Sense

Significant data rate reductions

TITLE	Best fixed-Q	P encoding	Dynamic Optimizer @ same quality	Dynamic Optimizer @ same bitrate	
	Bitrate (kbps)	HVMAF (0-100)	Bitrate savings (%)	Delta HVMAF (0-100)	
Bloodline	245	86.6	-15%	+2.0	
BoJack	230	95.5	-14%	+1.1	
Breaking Bad	251	91.8	-16%	+1.7	
Marvel's Daredevil	247	92.0	-21%	+1.9	
El Fuente	262	36.1	-38%	+21.8	
House of Cards	213	92.3	-17%	+1.3	
Meridian	259	96.0	-13%	+0.6	
Orange is the new black	256	86.2	-11%	+1.6	
The Avengers	278	82.0	-18%	+3.4	
Wet Hot American Summer	231	78.7	-8%	+1.6	
AVERAGE	247	83.7	-17.1%	+3.7	

http://bit.ly/nf_shot

Why Shot-Based Encoding Make Sense

- Benefits are very significant
- Not codec-dependent



http://bit.ly/nf_shot

Issues:

- Traditional rate control may not be available
 - Assume capping
 - But, if this bitrate pattern gives you nightmares, per-shot encoding is probably not for you
- You can't have it
 - Closest I looked at was segment-based optimization (from Euclid)
 - Assume it's coming from some third party vendors, but it is technically complex



Understanding Per-Title Techniques

Feature	Netflix	YouTube
Core	Brute force/CRF encodes/VMAF	Neural Network
Adjust data rate	Yes	Yes
Change number of files in ladder	Yes	Yes
Adjust resolution	Yes	Yes
Customizability	Presume yes	Presume yes
Bitrate control (CBR/VBR)	Presume yes	Presume yes
Post-encode quality check	Presume yes	Presume yes

• Universe of features

Our Contestants

Capped CRF

- Used by some OVPs (JW Player); available using FFmpeg and multiple encoders
- Capella Systems
 - Source Adaptive Bitrate Ladder (SABL)
 - Standard feature of Cambria FTC encoder
 - Review here http://bit.ly/cambria_pt

Brightcove

- Context Aware Encoding
- Standard feature for end-to-end Brightcove OVP offering
 - Premium for Brighcove encoder-only customers (pricing not set)
- EuclidIQ a preview
 - Rithm Signal-Adaptive Bit Rate Estimation (SABRE) and Perceptual Quality Optimization (PQO).

How We Tested

Title	Genre
Elektra (2 minutes)	Movie
El Ultimo (1 minutes)	Simple animated movie
Epiphan screencam (4:22)	Mixed screencam and real world video
Freedom (4:25)	Music video
Haunted (2 minutes)	Movie like video
Ironman preview (1:52)	Animated movie
New (92 seconds)	Test cliop
Screencam (2 minutes)	Screencam only
Sintel (2 minutes)	Animated movie
Sponge Bob preview (2:17)	Animated movie
Tears of Steel (2 minutes)	Movie with computer generated content
Test (8 minutes)	Mixed talking head and ballet
TalkingHead (2 minutes)	Simple talking head
Tutorial (2 minutes)	Mixed PowerPoint and small video
Zoolander (5 minutes)	Movie footage

- These videos
- To that ladder (as a baseline)
- Then encode using per-title technique

Width	Height	Profile	Preset	FPS	Data Rate
1920	1080	High	Medium	Native	4500
1280	720	High	Medium	Native	2700
960	540	High	Medium	Native	1900
852	480	High	Medium	Native	1350
640	360	High	Medium	Native	900
480	272	High	Medium	Native	500
320	180	High	Medium	Native	250

- Baseline encode
 - 200% constrained VBR
 - 2 second GOP
 - High profile
- Per-title
 - 2 second GOP
 - High profile
 - 150% upwards
 - Unlimited downwards

Compare Baseline to Per-Title for Each Vendor

		Data								Data				
Width	Height	Rate	Jump	PSNR	SSIM	VMAF		Width	Height	Rate	Jump	PSNR	SSIM	VMAF
1920	1080	4,461	1.66	34.84	0.97	95.39	4500	1920	1080	2,235	1.67	34.71	0.96	93.86
1280	720	2,684	1.42	34.53	0.96	91.42	2700	1600	900	1,339	1.42	34.60	0.96	91.25
960	<mark>5</mark> 40	1,893	1.41	34.32	0.96	86.10	1900	1200	674	941	1.42	34.31	0.96	87.75
852	480	1,340	1.51	34.29	0.96	84.32	1350	1064	600	665	1.52	34.21	0.96	85.53
<mark>64</mark> 0	360	889	1.83	34.24	0.95	78.31	900	800	450	437	1.85	33.84	0.95	78.67
480	272	485	2.04	33.36	0.94	61.47	500	600	336	236		33.45	0.94	65.80
320	180	238		32.19	0.92	28.54	250							

- Didn't compare encoder vs. encoder
- Each encoder's baseline vs. per-title

Interpreting VMAF Metrics

- Use VMAF as primary scoring mechanism:
 - CRF 22 @ 1080 maps to 100
 - CRF 28 @ 240 maps to 20
 - Anything in between is mapped in the middle (for example, SD encode at 480 is typically mapped to 40 ~ 70)
 - +/- 6 points ~ Just Noticeable Difference
- Overall scores for PSNR and SSIM as well

Huge Shoutout to Hybrik

- Cloud encoder with outstanding analysis tools
 - Bulk load (up to 20)
 - Bulk export (unlimited)
 - Metrics include VMAF, SSIM, PSNR and others
 - Analyzed over 750 encodes over three day period
- Alternative?
 - MSU 750 command lines to write
 - 750 results six data points each to copy and paste
- If you're doing large scale analysis work, check out Hybrik

Hybrik	ر ا	=	JOBS / COM	MPLETED			
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Jan Ozer			Job ID 👙	Media		Job Nan	1e ≑
			3148690	Media	Analyze Ba	ckground Task - el_ult	imo_460p_CVE
월 Dashboard			3148689	Media	Analyze Ba	ckground Task - EL_UL	
Storage	< 1		3148688	Media	Analyze Ba	ckground Task - EL_UI	TIMO_480p_C
			3148687	Media	Analyze Ba	ckground Task - el_ult	imo_720p_CVE
Q Media Analyzer	1		3148686	Media	Analyze Ba	ckground Task - EL_UL	TIMO_180p_C
	,		3148685	Media	Analyze Ba	ckground Task - el_ult	imo_272p_CVE
≓ Tasks	<		3148684	Media	Analyze Ba	ckground Task - EL_Ul	TIMO_272p_C
_			3148683	Media	Analyze Ba	ckground Task - el_ult	imo_1080p_CV
			3148682	Media	Analyze Ba	ckground Task - EL_Ul	
Create	1		3148681	Media	Analyze Ba	ckground Task - EL_Ul	TIMO_720p_C
			3148680	Media	Analyze Ba	ckground Task - el_ult	imo_180p_CVE

Ranking the Contestants

- Very early days of per-title
- Highly programmable tools/complex test cases
- Wanted to create some scoring mechanisms to measure the contendors

Ranking the Contestants

- Very early days of per-title
- Highly programmable tools/complex test cases
- Wanted to create some scoring mechanisms to measure the contenders



Grading - Absolute

idth	Height	Data Rate	Jump	PSNR	VMAF
0	1080	4,503	1.67	40.91	93.39
280	720	2,697	1.42	38.86	87.87
960	540	1,893	1.41	37.37	82.02
852	480	1,340	1.51	36.17	76.45
640	360	889	1.83	34.13	65.04
480	272	485	2.06	31.42	41.23
320	180	235		28.84	9.68
		12,041			

- Fifteen test clips (most completed 14)
- Encode standard ladder

- Encode per-title
 - Fewer rungs
 - Different resolutions data rates

Grading - Experiential

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Epiphan	Width	Height	Data Rate	Jump	PSNR	VMAF		Width	Height	Data Rate	PSNR	VMAF	File	Data Rate	VMAF
	1920	1080	3,194	1.64	44.74	93.19	4500	1920	1080	841	42.73	91.47	1080	-73.69%	-1.72
	1280	720	1,951	1.43	40.28	89.88	2700	1920	1080	841	42.73	91.47	720	-56.92%	1.60
	960	540	1,362	1.35	37.84	84.82	1900	1920	1080	841	42.73	91.47	540	-38.29%	6.65
	852	480	1,007	1.50	36.88	81.82	1350	1920	1080	841	42.73	91.47	480	-16.53%	9.66
	640	360	672	1.74	34.67	70.99	900	1920	1080	841	42.73	91.47	360	25.17%	20.49
	480	272	387	2.01	32.50	54.54	50 0	1280	720	443	38.95	85.62	272	14.47%	31.08
	320	180	192		29.85	23.57	250	852	480	229	35.76	75.48	180	19.21%	51.91
														-18.08%	17.09

- Which per-title clip would viewer watch at bandwidth target of original ladder
 - Highest quality per-title clip under the bandwidth of the original source

- How does the VMAF rating of per-title clip compare to original?
 - Here, higher by 17.09
 - This would be a significant benefit particularly for mobile
 - Most VMAF benefits in bottom two rungs
 - Significant for Euclid

Wins/Losses/Hits

Wins/Losses

• Win

- Experiential VMAF > -2.99
- With bandwidth reduction
- Loss
 - Experiential VMAF < 2.99 or lower
 - You didn't deploy per-title to make your videos look visibly worse

Hits

- **Home run** experiential VMAF positive
- Triple Win with 20%+ bitrate saving
- Double Win with 10-20% bitrate saving
- Single Win with less than 10% saving

Other Scores

Errors

- Didn't meet lowest data rate target
 - Cellular viewers get no stream

	Width	Height	Data Rate	PSNR	VMAF	
4500	1920	1080	4,477	41.05	86.27	
2700	1280	720	2,416	39.32	80.70	
1900	960	540	1,562	38.35	77.20	
1350	852	480	1,313	37.88	75.49	
900	640	360	852	36.40	68.58	
500	480	272	555	34.43	58.06	
250	320	180	300	31.82	34.67	

Other Scores

Errors

- Jump between streams greater than 2x or less than 1x
 - Could degrade operation of ABR mechanism
- Just because you're using per-title doesn't mean you don't need an orderly bitrate ladder

Width	Height	Data Rate	Jump	PSNR	VMAF
1920	1080	4,411	1.66	43.01	93.69
1280	720	2,656	1.42	41.54	88.84
960	540	1,867	1.42	40.26	84.75
852	480	1,318	1.50	39.69	82.36
640	360	882	1.84	38.27	74.54
480	272	480	2.06	36.26	57.78
320	180	233		33.36	24.04

Save (encoding costs)

- Reduced the number of rungs in the ladder
 - One save for each eliminated rung
 - Without violating any other rule

• Eliminate encoding pass

			Data		DONE				Data		DONE	
Epiphan	Width	Height	Rate	Jump	PSNR	VMAF	Width	Height	Rate	Jump	PSNR	VMAF
	1920	1080	4,483	1.67	49.68	96.66	1920	1080	2,261	1.75	49.60	95.38
	1280	720	2,686	1.43	42.01	93.90	1280	720	1,289	1.75	41.43	92.54
	960	540	1,884	1.41	39.10	<mark>89.50</mark>	1024	<mark>576</mark>	736	1.78	38.84	88.63
	852	480	1,332	1.51	37.92	86.72	768	432	413	1.78	36.40	80.99
	640	360	883	1.84	35.20	76.48	576	324	232		33.97	68.18
	480	272	480	2.05	32.73	60.39						
	320	180	235		30.09	29.89						

Model-Related Caveats

- Doesn't effectively deal with increases to data rate for hard to encode clips
 - Each is a win / single
 - Will evolve this over time
- Real goal not to pick a winner or loser, but to identify features and operating characteristics to consider and evaluate

Our Participants

- Capped CRF
- Capella Systems Source Adaptive Bitrate Ladder
- Brightcove Context Aware Encoding
- Euclid IQ Rithm

Capped CRF

- Encoding mode available in x264, x265, VP8/9
- Encodes to a specific quality level, not a data rate
- Can "cap" to meet data rate targets
- Procedure
 - Choose quality level (CRF 23)
 - Choose maximum bitrate
- One pass encode, so saves time

Feature	Capped CRF
Туре	Optimization
Core schema	CRF encode
Adjust data rate	Yes
Change number of files in ladder	No
Adjust resolution	No
Customizability	CRF/max rate
Bitrate control (CBR/VBR)	No
Post-encode quality check	No

ffmpeg -i input -crf 23 -maxrate 6750k -bufsize 4500k output

High Level View

Width	Height	Data Rate	Jump	PSNR	SSIM	VMAF
1920	1080	1,009	1.97	48.06	1.00	96.74
1280	720	512	1.48	32.85	0.99	89. <mark>6</mark> 3
960	540	347	1.18	29.89	0.98	83.57
852	480	294	1.51	28.67	0.97	80.41
640	360	195	1.49	26.36	0.95	67.77
480	272	130	1.80	24.18	0.92	45.86
320	180	72		21.19	0.85	5.30

- Inability to reduce the number of rungs produces ladders like this
- Don't need three rungs below 300 kbps

No Data Rate Control Under the Cap



- One concern with capped CRF is potential impact on QoE
 - Big data rate swings in test file reduced QoE substantially (see article at http://bit.ly/BRC_QOE)
 - Counterpoint: used by JWPlayer, presumably with good results

Capped CRF Box Score

- All wins, no losses
- Three errors where 720p > 1080p jump exceeded 200%
 - May strand viewers at 720p rung
 - Try lower quality CRF 24/25 for top rung?
- Data rate 1080p file most expensive, highest quality
 - Down 13% lowest
 - Minimal impact on VMAF

	Capped CRF
Wins	14
Losses	0
Storage saved	42,259
Streaming saved	23,818
Net impact on VMAF	66.21
Saves	98
Singles	4
Doubles	2
Triples	0
Home runs	8
Errors	3
Experiental PSNR	1.54
Experiental SSIM	0.00856
Data rate 1080p	-13.216%
VMAF 1080p	-0.14

Capella Systems – Source Adaptive Bitrate Ladder

- Feature of Cambria FTC encoder
- Technical description
 - Use CRF encode to measure complexity of encoded footage
 - Adjust encoding ladder up or down based up results
 - If 7000 or higher, adjust data rate upwards by 1.5
 - If lower than 2000, adjust downwards by 50%
- Implemented as a JSON script
 - Pretty simple to make simple adjustments (no real programming required)

Function to get Multiplier value sub getMultiplierValue
{
my \$complexityValue = \$_[0];
if (\$complexityValue <= 0) { return 1.0; }
<pre>if (\$complexityValue >= 7000) { return 1.5; }</pre>
<pre>if (\$complexityValue >= 5000) { return 1.25; }</pre>
if (\$complexityValue >= 4000) { return 1.0; }
<pre>if (\$complexityValue >= 3500) { return 0.9; }</pre>
<pre>if (\$complexityValue >= 3000) { return 0.8; }</pre>
<pre>if (\$complexityValue >= 2500) { return 0.7; }</pre>
<pre>if (\$complexityValue >= 2000) { return 0.6; }</pre>
return 0.5;
}

Capella Systems – Source Adaptive Bitrate Ladder

Schema

- Gauge complexity; encode traditionally (CBR or VBR)
- Can control
 - CRF level for quality assessment
 - Duration of assessment period (hardest to encode segment)
- Can adjust
 - Data rate
 - Resolution
 - Number of files

Feature	Capped CRF	Capella Systems
Туре	Optimization	Per-Title
Core schema	CRF encode	CRF encode
Adjust data rate	Yes	Yes
Change number of files in ladder	No	Yes
Adjust resolution	No	Yes
Customizability	CRF/max rate	Some
Bitrate control (CBR/VBR)	No	Yes
Post-encode quality check	No	No

Cambria Adjustments

Width	Height	Data Rate	Jump	PSNR	SSIM	VMAF		Width	Height	Data Rate	Jump	PSNR	SSIM	VMAF
1920	1080	4,264	1.65	38.49	0.99	96.50	4500	1920	1080	887	1.70	36.91	0.98	93.66
1280	720	2,592	1.39	27.47	0.94 🔇	83.50	2700	1600	<mark>90</mark> 0	523	1.47	29.14	0.94	84.67
960	540	1,863	1.42	26.11	0.90	73.24	1900	1200	674	355	1.43	26.88	0.91	76.76
852	480	1,312	1.54	25.58	0.89	70.38	1350	1064	600	248		26.19	0.89	71.03
640	360	853	1.73	24.66	0.85	60.47	900							
480	272	493	2.04	23.82	0.81	44.89	500							
320	180	242		22.71	0.75	15.87	250							

- Reductions in ladder are "saves"
- Increasing resolution improves quality

Box Score

Cambria is CRF with

- Better bitrate control (CBR or VBR)
- More control over CRF computation
- Better control over adjustment to bitrate ladder
- Very simple, mechanical system that works very well
 - Capped CRF better in some instances because no bitrate control

	Capped CRF	Capella Systems
Wins	14	14
Losses	0	0
Storage saved	42,259	39,717
Streaming saved	23,818	34,959
Net impact on VMAF	66.21	63.52
Saves	98	25
Singles	4	5
Doubles	2	2
Triples	0	2
Home runs	8	5
Errors	3	0
Experiental PSNR	1.54	0.88
Experiental SSIM	0.00856	0.00848
Data rate 1080p	-13.216%	-27.442%
VMAF 1080p	-0.14	-0.89

Brightcove Context Aware Encoding



- Feature of Brightcove OVP and encoding service
- Free with OVP; pricing not set for service

- Black Box, considers
- 1. Properties of the content
- 2. Distribution of user devices (connected TVs, PCs, smartphones, tablets, etc.)
- 3. Properties of user devices and networks
- 4. Constraints specific to video codecs, profiles, etc.

Highly Customizable (JSON)

- Can choose
 - Min/max renditions
 - Min/max resolution
 - Max frame rate
 - Key frame rate
 - Min/max bitrate
 - Max first rendition bitrate
 - Min/max ssim (as quality check)
 - Select baseline config

- Plus all normal configuration options
 - Resolution
 - Aspect ratio
 - Frame rate
 - Codec/profile/level
 - Reference frames
 - Bframes

Implemented via JSON

{

"input": "http://s3.amazonaws.com/pertitle/Zoo_1080p.mp4", "notifications": ["jozer@mindspring.com"], "generate_dynamic_profile": true, "dynamic_profile_options":

{

"speed": 2, "min_renditions": 1, "max renditions": 8, "max resolution": {"width": 1920,"height":1080}, "min resolution": {"width": 320, "height": 180}, "max first rendition bitrate": 250, "max bitrate": 4500, "bitrate_cap_to_bitrate_ratio": 2.0, "bitrate_cap_offset": 0, "buffer_size_to_bitrate_ratio": 1.0, "buffer_size_offset": 0, "max frame rate": 30, "keyframe rate": 0.5, "max granularity": 100, "quality rate tune": -10, "fast_profile_generation": false, "select_baseline_profile_configuration": false,

"video_configurations": [

},

{"width": 320, "height": 180, "video codec profile": "high"}, {"width": 384, "height": 216, "video codec profile": "high"}, {"width": 416, "height": 234, "video_codec_profile": "high"}, {"width": 480, "height": 270, "video codec profile": "high"}, {"width": 512, "height": 288, "video codec profile": "high"}, {"width": 576, "height": 324, "video_codec_profile": "high"}, {"width": 640, "height": 360, "video_codec_profile": "high"}, {"width": 768, "height": 432, "video_codec_profile": "high"}, {"width": 800, "height": 450, "video_codec_profile": "high"}, {"width": 960, "height": 540, "video_codec_profile": "high"}, {"width": 1024, "height": 576, "video_codec_profile": "high"}, {"width": 1152, "height": 648, "video_codec_profile": "high"}, {"width": 1280, "height": 720, "video_codec_profile": "high"}, {"width": 1440, "height": 810, "video_codec_profile": "high"}, {"width": 1536, "height": 864, "video_codec_profile": "high"}, {"width": 1600, "height": 900, "video_codec_profile": "high"}, {"width": 1920, "height":1080, "video_codec_profile": "high"}

Brightcove Taxonomy

Feature	Capped CRF	Capella Systems	Brightcove
Туре	Optimization	Per-Title	Per-TItle
Core schema	CRF encode	CRF encode	Probe encodes
Adjust data rate	Yes	Yes	Yes
Change number of files in ladder	No	Yes	Yes
Adjust resolution	No	Yes	Yes
Customizability	CRF/max rate	Some	Extensive
Bitrate control (CBR/VBR)	No	Yes	Yes
Post-encode quality check	No	No	Yes - SSIM

Box Score

Highly functional

- Change numbers of files
- Change resolution
- Post-encode quality check

	Capped CRF	Capella Systems	Brightcove
Wins	14	14	14
Losses	0	0	0
Storage saved	42,259	39,717	48,824
Streaming saved	23,818	34,959	31,195
Net impact on VMAF	66.21	63.52	64.12
Saves	98	25	25
Singles	4	5	1
Doubles	2	2	4
Triples	0	2	0
Home runs	8	5	9
Errors	3	0	0
Experiental PSNR	1.54	0.88	1.38
Experiental SSIM	0.00856	0.00848	0.00645
Data rate 1080p	-13.216%	-27.442%	-23.842%
VMAF 1080p	-0.14	-0.89	-0.79

EuclidIQ Rithm - Preview

- Rithm automatically senses how "difficult" each video is to encode
- Combines two patented AI technologies:
 - Signal-Adaptive Bit Rate Estimation (SABRE)
 - Perceptual Quality Optimization (PQO).

- SABRE dynamically sets the bitrate for each segment to achieve the desired mean opinion score (MOS), or quality level, in that segment.
- PQO dynamically sets the bitrate for each frame, assigning more bits to the most perceptually important areas of a frame.

Taxonomy

Feature	Capped CRF	Capella Systems	Brightcove	Euclid
Туре	Optimization	Per-Title	Per-TItle	Per-Segment
Core schema	CRF encode	CRF encode	Probe encodes	AI
Adjust data rate	Yes	Yes	Yes	Yes
Change number of files in ladder	No	Yes	Yes	No
Adjust resolution	No	Yes	Yes	No
Customizability	CRF/max rate	Some	Extensive	Minimal
Bitrate control (CBR/VBR)	No	Yes	Yes	Сар
Post-encode quality check	No	No	Yes - SSIM	No

- Set MOS target
- Create encoding ladder
- Set cap

 As tested – couldn't encode bottom two layers

Euclid Scorecard (five rungs only)

- Issue with one file
- Highest 1080p savings (with largest drop in VMAF)
- Net VMAF impact excellent given that most savings are on lower rungs
- Overall, very promising

	Capped CRF	Capella Systems	Brightcove	Euclid - top Five Rungs
Wins	14	14	14	13
Losses	0	0	0	1
Storage saved	42,259	39,717	48,824	37,182
Streaming saved	23,818	34,959	31,195	27,950
Net impact on VMAF	66.21	<mark>63.52</mark>	64.12	46.34
Saves	98	25	25	NA
Singles	4	5	1	3
Doubles	2	2	4	1
Triples	0	2	0	3
Home runs	8	5	9	6
Errors	3	0	0	0
Experiental PSNR	1.54	0.88	1.38	1.50
Experiental SSIM	0.00856	0.00848	0.00645	0.0031
Data rate 1080p	-13.216%	-27.442%	-23.842%	-27.740%
VMAF 1080p	-0.14	-0.89	-0.79	-1.03

Final

	Capped CRF	Capella Systems	Brightcove	Euclid - top Five Rungs	
Wins	14	14	14	13	
Losses	0	0	0	1	
Storage saved	42,259	39,717	48,824	37,182	
Streaming saved	23,818	34,959	31,195	27,950	
Net impact on VMAF	66.21	63.52	64.12	46.34	
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When Considering Per-Title Technologies

- What kind (optimization, per-title, per-scene, per-shot)
- Can you apply traditional data rate controls (VBR/CBR)?
- Does it reduce the number of rungs?
- Can it adjust ladder resolutions?
- How does it impact encoding cost?
- Can you specify lowest bitrate file?
- Can it *increase* the number of rungs
- For testing:
 - Collect relevant set of files
 - Compare against capped CRF