PER-TITLE ENCODING - 2019

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Agenda

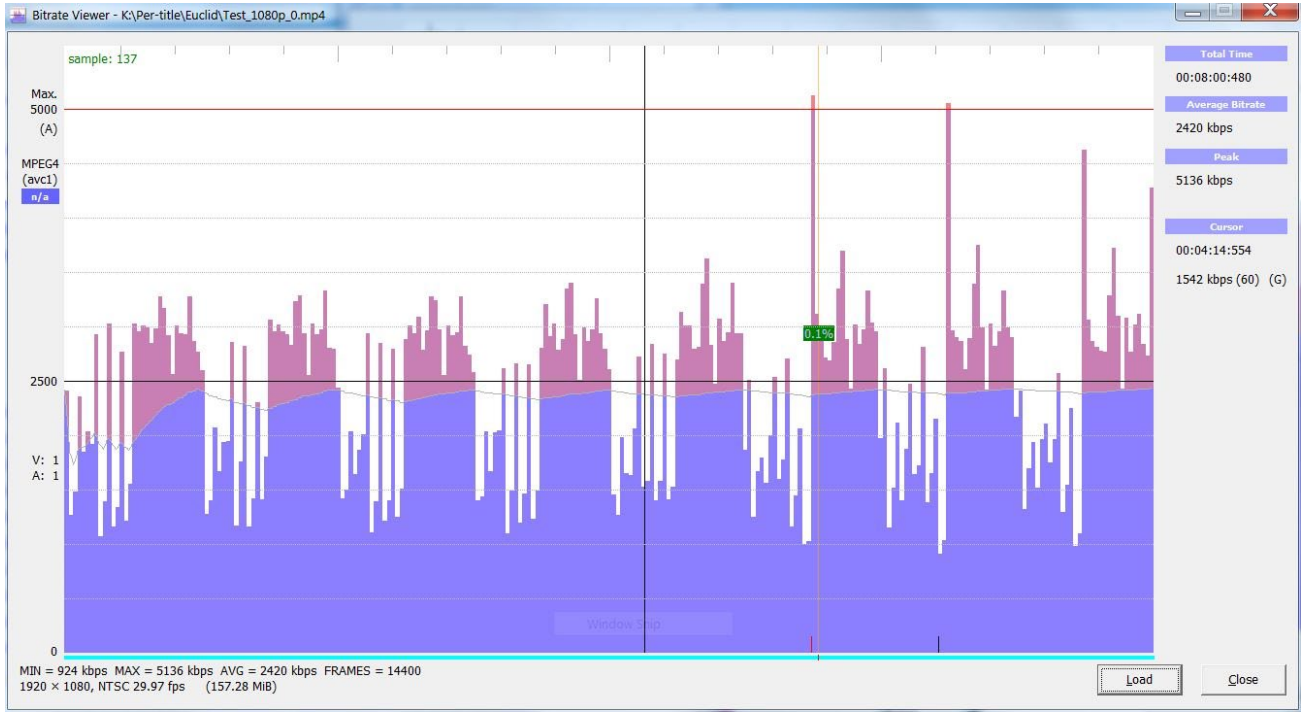
- What is per-title encoding
  - Why is it important
  - Universe of features
- Our contestants
- Our tests
- Our results

What is Per-Title Encoding

- Customizing encoding for each file
- Started as frame by frame optimization from companies like Beamr and Euclid IQ
- First implemented at scale by Netflix and YouTube
- First third party encoder implementation – Capella Systems Cambria Encoder
- Now almost all encoding vendors offer
- DIY - via capped CRF

Evolution of Per-Title/Optimization

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

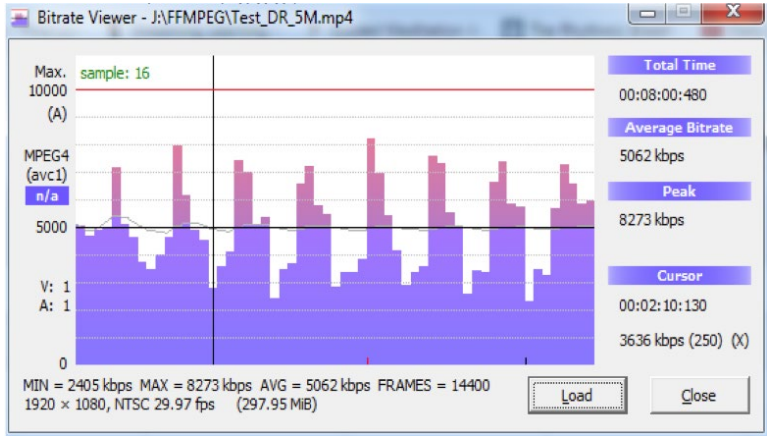


Video – 30 seconds talking head/
30 seconds ballet – repeat 8x

No bitrate control except cap

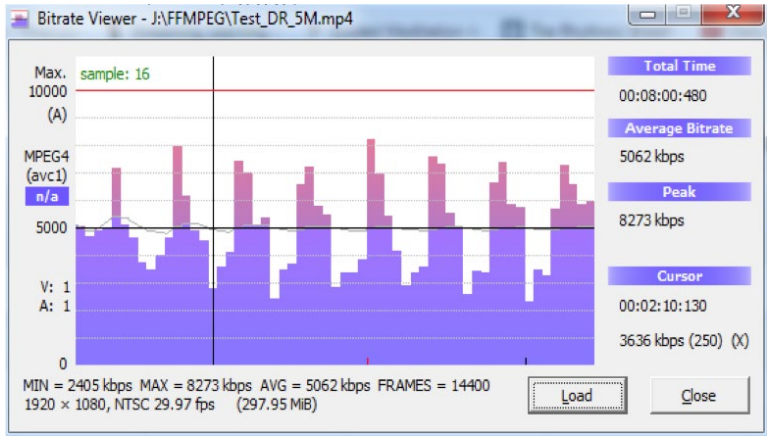
Evolution of Per-Title/Optimization

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



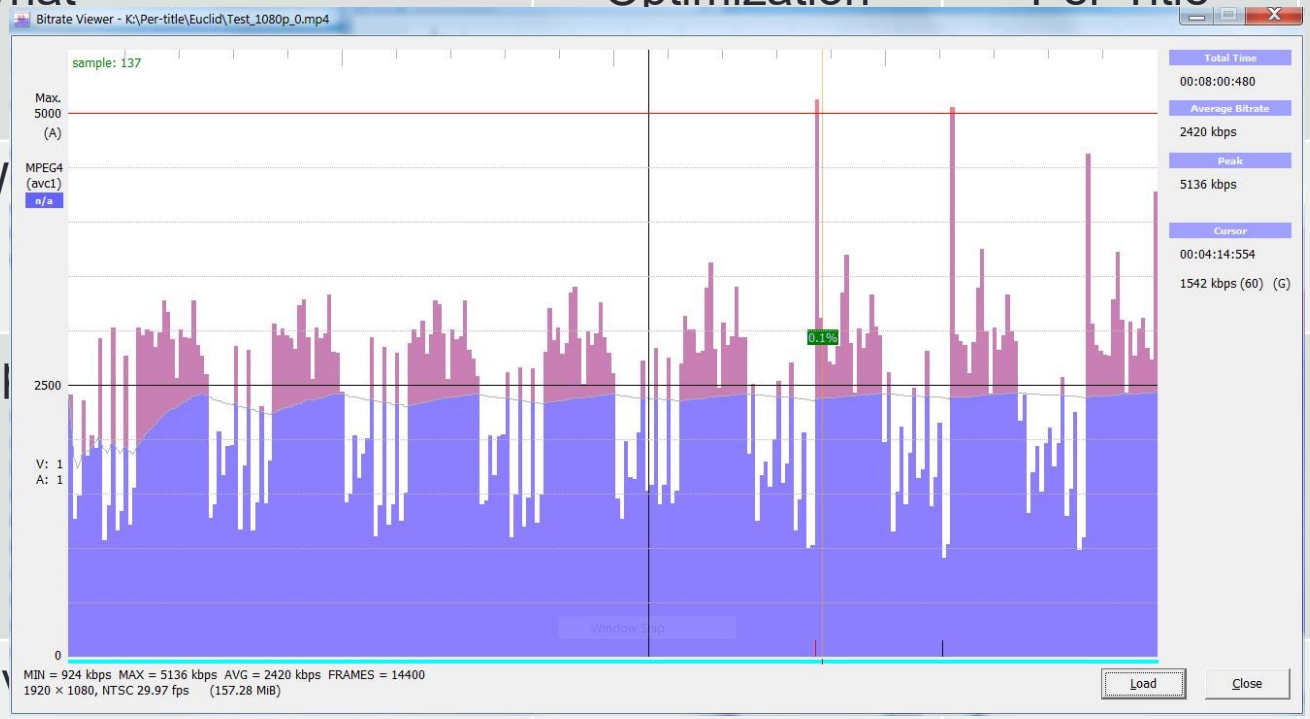
Evolution of Per-Title/Optimization

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



Evolution of Per-Title/Optimization

When	Prior to 2015	Late 2015	2016-2017	Late 2017
What	Optimization	Per-Title	Commercial Per-title	Segment-based encoding
W			Capella Systems, BC, others	Euclid, others
Op			Gauge video complexity/ encode traditionally	Gauge complexity for each segment; encode segment
Ov			CBR/VBR	Cap, but no CBR
Change GOP/Segment	No	No	No	No

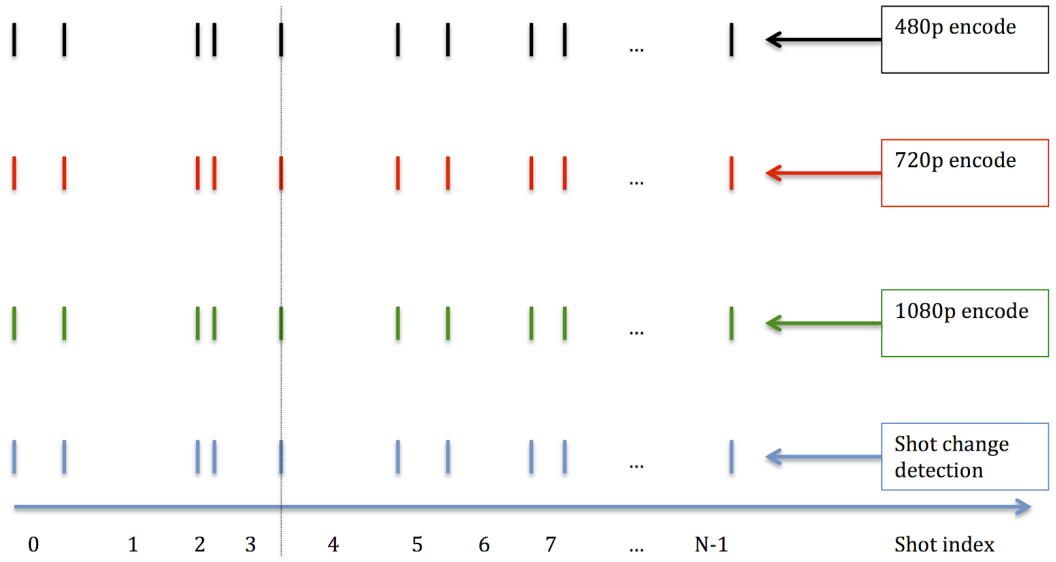


Evolution of Per-Title/Optimization

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

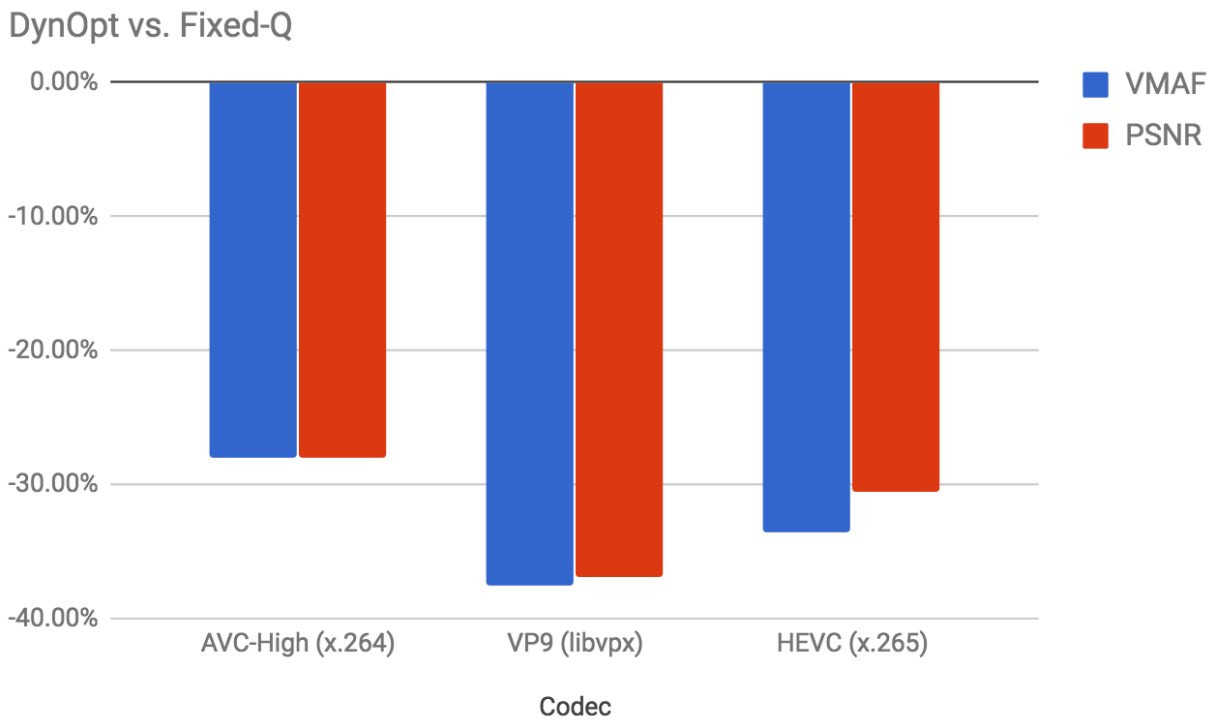
- Significant data rate reductions
  - 17% lower bitrate
  - 3.7 higher VMAF score

TITLE	Best fixed-QP 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

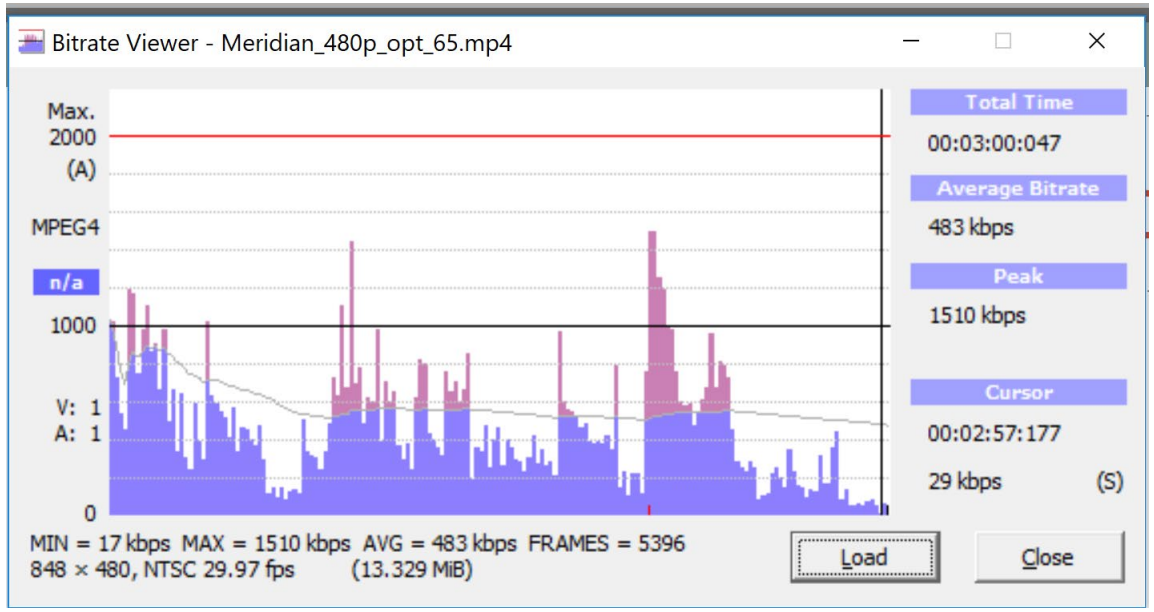
- Benefits are very significant
- Not codec-dependent



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



Evolution of Per-Title/Optimization

When	Prior to 2015	Late 2015	2016-2017	Late 2017	2018	2018-2019
What	Optimization	Per-Title Encoding	Commercial Per-title	Segment-based encoding	Shot-based encoding	Context-aware encoding
Who	Beamr/Euclid / Capped CRF	Netflix	Capella Systems, BC, others	Euclid, others	Netflix	Brightcove, Epic Labs, Mux
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	Incorporate bandwidth and device data into encoding ladder
Overall bitrate control	No	Yes	CBR/VBR	Cap, but no CBR	Probably cap only	Can
Change GOP/Segment	No	No	No	No	Yes	Can

How it Works

Usage Pattern

Device type	Usage [%]	Average bandw
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**

TABLE 2: USAGE AND AVERAGE BANDWIDTH STATISTICS FO

Mostly mobile with low bandwidth

Device type	Usage [%]	Average bandwidt
PC	63.49	14.720
Mobile	6.186	10.609
Tablet	9.165	12.055
TV	21.15	24.986
All devices	100	16.393

TABLE 3: USAGE AND AVERAGE BANDWIDTH STATISTICS FOR OPE

Mostly PC/TV at high bitrates

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

TABLE 4: USAGE AND AVERAGE BANDWIDTH STATISTICS FOR OPERATOR 3.

All TV at very high bandwidth

Encoding Ladder

Concentrate on lower rungs

Re	Profile	Resolution	Framerate	Bitrate	SSIM
1	seline	320x180	30	125	0.93369
2	Baseli	480x270	30	223.08	0.93793
3	Main	640x360	30	398.11	0.94636
4	Main	960x540	30	774.78	0.94953
5	Main	1280x720	30	1549.5	0.95637
6	High	1600x900	30	2765.3	0.96105
7	High	1920x1080	30	4935.1	0.96576
Storage				10771	

TABLE 9: CAE-GENERATED ENCODING LADDER FOR OPERATOR 1.

Higher in the middle

Rendition	Profile	Resolution	Framerate	Bitrate	SSIM
1	Baseline	320x180	30	125	0.93338
2	Baseline	480x270	30	239.71	0.94122
3	Main	640x360	30	469.54	0.95202
4	Main	1024x576	30	939.08	0.95221
5	Main	1280x720	30	1568.8	0.95658
6	High	1600x900	30	2765.3	0.96105
7	High	1920x1080	30	4935.1	0.96576
Storage				11026	

TABLE 10: CAE-GENERATED ENCODING LADDER FOR OPERATOR 2.

Higher end, fewer lower rungs

Rendition	Profile	Resolution	Framerate	Bitrate	SSIM
1	Baseline	320x180	30	125	0.93447
2	Baseline	512x288	30	307.42	0.94855
3	Main	960x540	30	803.59	0.95050
4	Main	1280x720	30	1727.8	0.95864
5	High	1920x1080	30	5050.7	0.96599
Storage				8014.6	

TABLE 11: CAE-GENERATED ENCODING LADDER FOR OPERATOR 3.

bit.ly/bc_contextaware

Features of Per-Title Techniques

Feature	Netflix	YouTube
Type	Iterative encodes	Gauge complexity and encode
Core schema	Shot-based	Neural Network
Passes	Hundreds	2
Factor in QoE stats	No	No
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)	Yes	Presume yes
Post-encode quality check	Essential to Schema	Presume yes

- Universe of features

Why the Number of Rungs is So Important

Adjusts # of rungs – fewer for simple file

	Width	Height	Data Rate		PSRN	SSIM	VMAF
Tutorial_PT_1080p_840825.mp4	1920	1080	859.9	2.07	49.25	0.996	96.99
Tutorial_PT_1080p_449219.mp4	1920	1080	415.7	1.94	45.09	0.995	95.94
Tutorial_PT_900p_240000.mp4	1600	900	214.8		35.05	0.988	90.22
			1,490		**43.13**	**0.993**	**94.39**

	Width	Height	Bitrate	PSNR	SSIM	VMAF
tutorial_1080p_CVBR.mp4	1920	1080	4,475	55.32	0.998	97.51
tutorial_720p_CVBR.mp4	1280	720	2,687	33	0.989	90.48
tutorial_540p_CVBR.mp4	960	540	1,885	29.99	0.979	84.82
tutorial_480p_CVBR.mp4	854	480	1,342	28.76	0.972	81.70
tutorial_360p_CVBR.mp4	640	360	891	26.42	0.951	69.63
tutorial_270p_CVBR.mp4	480	270	484	24.16	0.918	46.28
tutorial_180p_CVBR.mp4	320	180	237	21.21	0.849	6.05
			12,002	**31.27**	**0.951**	**68.07**

Doesn't - Create 5 rungs you'll never use (potentially dysfunctional ladder)

	Width	Height	Data Rate		VMAF
Tutorial_1080p	1920	1080	375	1.93	95.68
Tutorial_720p_	1280	720	194	1.65	88.33
Tutorial_540p_	960	540	118	1.20	81.15
Tutorial_480p_	854	480	99	1.57	77.75
Tutorial_360p_	640	360	63	1.51	64.43
Tutorial_270p_	480	270	42	1.90	41.38
Tutorial_180p_	320	180	22		4.24
			912		**64.71**

Why Adjusting Resolution is So Important

Deploy higher rez files (with higher VMAF) scores lower in ladder

	Width	Height	Bitrate	PSNR	SSIM	VMAF
TOS_1080p_CVBR.mp4	1920	1080	4,519	41.8	0.964	95.92
TOS_720p_CVBR.mp4	1280	720	2,714	39.31	0.954	92.54
TOS_540p_CVBR.mp4	960	540	1,917	37.64	0.943	88.35
TOS_480p_CVBR.mp4	854	480	1,363	36.56	0.932	83.43
TOS_360p_CVBR.mp4	640	360	911	34.71	0.910	73.34
TOS_270p_CVBR.mp4	480	270	504	32.5	0.878	55.62
TOS_180p_CVBR.mp4	320	180	248	29.76	0.831	26.98
			12,176	**36.04**	**0.916**	**73.74**

	Width	Height	Data Rate		PSRN	SSIM	VMAF
TOS_PT_1080p_4041073.mp4	1920	1080	3966	1.60	41.62	0.964	95.76
TOS_PT_1080p_2579196.mp4	1920	1080	2476	1.56	39.88	0.954	91.82
TOS_PT_900p_1646160.mp4	1600	900	1586	1.90	38.11	0.941	87.10
TOS_PT_576p_866400.mp4	1024	576	836	1.91	35.86	0.921	78.31
TOS_PT_360p_456000.mp4	640	360	436.6	2.00	33.32	0.888	61.58
TOS_PT_288p_240000.mp4	512	288	218.6		31.15	0.852	42.76
			9,519		**36.66**	**0.920**	**76.22**

Stuck at same resolutions

	Width	Height	Data Rate		PSRN	SSIM	VMAF
TOS_1080p_YT.mp4	1920	1080	4,403	1.84	40.93	0.959	93.49
TOS_720p_YT.mp4	1280	720	2,391	1.79	38.2	0.944	87.29
TOS_480p_YT.mp4	854	480	1,338	2.15	34.23	0.896	64.44
TOS_360p_YT.mp4	640	360	623	1.88	32.79	.879	55.56
TOS_240p_YT.mp4	426	240	331			0.828	27.84
					35.20	**0.901**	**65.72**

More pronounced gaps in quality

Features of Per-Title Techniques

Feature	Netflix	YouTube
Type	Iterative encodes	Gauge complexity and encode
Core schema	Shot-based	Neural Network
Passes	Hundreds	2
Factor in QoE stats	No	No
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)	Yes	Presume yes
Post-encode quality check	Essential to Schema	Presume yes

Why Customizability so Important

	Width	Height	Data Rate	PSNR	SSIM	VMAF
basketball_1080p_CVBR.mp4	1920	1080	4,563	41.74	0.968	98.72
basketball_720p_CVBR.mp4	1280	720	2,730	39.47	0.952	95.53
basketball_540p_CVBR.mp4	960	540	1,919	38.32	0.938	91.27
basketball_480p_CVBR.mp4	854	480	1,358	36.89	0.924	83.53
basketball_360p_CVBR.mp4	640	360	903	35.36	0.906	72.47
basketball_270p_CVBR.mp4	480	270	496	33.08	0.875	54.20
basketball_180p_CVBR.mp4	320	180	242	30.37	0.831	30.58
			12,212	**36.46**	**0.913**	**75.19**
			12,212	**36.46**	**0.913**	**75.19**

4500	basketball_1080p_CRF_2xbuff.mp4	1920	1080	7,447
2700	basketball_720p_CRF.mp4	1280	720	3,959
1900	basketball_540p_CRF.mp4	960	540	2,606
1350	basketball_480p_CRF.mp4	854	480	2,173
900	basketball_360p_CRF.mp4	640	360	1,424
500	basketball_270p_CRF.mp4	480	270	902
250	basketball_180p_CRF.mp4	320	180	476
				18,988
				18,988

Low rung is 250 kbps

Capped CRF – data rate goes up with complexity, lose lowest rung

Our Contestants

- Capped CRF
  - Used by some OVPs (JW Player); available using FFmpeg and multiple encoders
- YouTube
  - Not a commercial service; in for comparison purposes
- Bitmovin
  - Our winner
  - Three others will rename nameless
    - Two - some scores from Hybrik are anomalous – want to verify with another VMAF tool before scoring
    - Third - results just bad – poor schema (bit rates just too low). Small company, don't want to identify
    - Will use for illustrative purposes
  - Will reissue results with names once files are verified (give me 4 weeks)

How I Tested

Title	Genre
https://s3.amazonaws.com/pertitle/Basketball_1080p.mp4	Basketball
https://s3.amazonaws.com/pertitle/El_Ultimo_1080p.mp4	Simple animated movie
https://s3.amazonaws.com/pertitle/Elektra_1080p.mp4	Movie
https://s3.amazonaws.com/pertitle/Epiphan_1080p.mp4	Screencam and video
https://s3.amazonaws.com/pertitle/Football_1080p.mp4	Harmonic football clip
https://s3.amazonaws.com/pertitle/Freedom_1080p.mp4	Music video
https://s3.amazonaws.com/pertitle/Haunted_1080p.mp4	Movie like video
https://s3.amazonaws.com/pertitle/Hockey_1080p.mp4	Animated movie
https://s3.amazonaws.com/pertitle/India_1080p.mp4	Videos from India
https://s3.amazonaws.com/pertitle/Meridian_1080p.mp4	Meridian
https://s3.amazonaws.com/pertitle/New_1080p.mp4	Test clip
https://s3.amazonaws.com/pertitle/Screencam_1080p.mp4	Screencam only
https://s3.amazonaws.com/pertitle/Sintel_1080p.mp4	Animated movie
https://s3.amazonaws.com/pertitle/Skateboard_1080p.mp4	Skateboard
https://s3.amazonaws.com/pertitle/Soccer_1080p.mp4	Soccer match
https://s3.amazonaws.com/pertitle/Sponge_Bob_1080p.mp4	Animated movie
https://s3.amazonaws.com/pertitle/TOS_1080p.mp4	Movie with computer generated content
https://s3.amazonaws.com/pertitle/TalkingHead_1080p.mp4	Simple talking head
https://s3.amazonaws.com/pertitle/Test_1080p.mp4	Mixed talking head and ballet
https://s3.amazonaws.com/pertitle/Tutorial_1080p.mp4	Mixed PowerPoint and video
https://s3.amazonaws.com/pertitle/Zoo_1080p.mp4	Movie footage

About 50 minutes of video in total

Animation
El_Ultimo
Sintel
Sponge Bob
Average
Movie-ish
Elektra
Freedom
Haunted
India
Meridian
Tears of Steel
Zoolander
Average
Synthetic
Screencam
Tutorial
Average
Other Business
Epiphan
New
Talking head
Test
Average
Sports
Basketball
Football
Hockey
Skateboard
Soccer
Average

How I Tested

Width	Height	Profile	Preset	GOP	Data Rate	Max Rate	VBV Buffer	FPS	Audio
1920	1080	High	Medium	2 seconds	4500	9000	9000	Native	None
1280	720				2700	5400	5400		
960	540				1900	3800	3800		
854	480				1350	2700	2700		
640	360				900	1800	1800		
480	270				500	1000	1000		
320	180				250	500	500		

- This encoding ladder as baseline (with FFmpeg)

- Per-title
  - 2 second GOP, 2 second VBV
  - High profile
  - 150% upwards
  - Unlimited downwards

Scoring

	1080p VMAF Std Deviation	Storage Saved	Streaming Bitrate Saved	PSNR	SSIM	VMAF	Rungs Saved	Errors	Good Decisions	Bad Decisions	Wins	Home Run	Losses	Draws
YouTube	2.251	-104,099	-857	0.26	-0.0040	-1.89	42	17	11	10	3	2	13	3
Capped CRF	1.485	-17,002	-64	0.33	0.0001	0.19	0	10	14	7	5	2	5	9
Unsub 1	1.887	-33,179	-266	0.27	-0.0008	-0.54	0	9	10	11	2	3	12	4
Unsub 2	2.446	-71,785	-741	0.29	-0.0023	-0.77	0	0	11	8	2	4	10	5
Bitmovin	1.448	-69,767	-557	0.86	0.0016	0.94	26	0	16	5	4	6	0	11
Unsub 3	3.091	-142,299	-1,846	-0.33	-0.0053	-2.28	0	11	4	17	4	0	17	0

- Green is best, brown is worst

Scoring

	1080p VMAF Std Deviation	Storage Saved	Streaming Bitrate Saved	PSNR	SSIM	VMAF	Rungs Saved	Errors	Good Decisions	Bad Decisions	Wins	Home Run	Losses	Draws
YouTube	2.251	-104,099	-857	0.26	-0.0040	-1.89	42	17	11	10	3	2	13	3
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Unsub 1	1.887	-33,179	-266	0.27	-0.0008	-0.54	0	9	10	11	2	3	12	4
Unsub 2	2.446	-71,785	-741	0.29	-0.0023	-0.77	0	0	11	8	2	4	10	5
Bitmovin	1.448	-69,767	-557	0.86	0.0016	0.94	26	0	16	5	4	6	0	11
Unsub 3	3.091	-142,299	-1,846	-0.33	-0.0053	-2.28	0	11	4	17	4	0	17	0

- 1080p VMAF standard deviation
  - Measures accuracy of quality metric used by per-title technique relating to VMAF
  - Lower numbers are better

Scoring

	1080p VMAF Std Deviation	Storage Saved	Streaming Bitrate Saved	PSNR	SSIM	VMAF	Rungs Saved	Errors	Good Decisions	Bad Decisions	Wins	Home Run	Losses	Draws
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Unsub 1	1.887	-33,179	-266	0.27	-0.0008	-0.54	0	9	10	11	2	3	12	4
Unsub 2	2.446	-71,785	-741	0.29	-0.0023	-0.77	0	0	11	8	2	4	10	5
Bitmovin	1.448	-69,767	-557	0.86	0.0016	0.94	26	0	16	5	4	6	0	11
Unsub 3	3.091	-142,299	-1,846	-0.33	-0.0053	-2.28	0	11	4	17	4	0	17	0

- Storage bandwidth saved over test videos (~50 minutes)

Scoring

	1080p VMAF Std Deviation	Storage Saved	Streaming Bitrate Saved	PSNR	SSIM	VMAF	Rungs Saved	Errors	Good Decisions	Bad Decisions	Wins	Home Run	Losses	Draws
YouTube	2.251	-104,099	-857	0.26	-0.0040	-1.89	42	17	11	10	3	2	13	3
Capped CRF	1.485	-17,002	-64	0.33	0.0001	0.19	0	10	14	7	5	2	5	9
Unsub 1	1.887	-33,179	-266	0.27	-0.0008	-0.54	0	9	10	11	2	3	12	4
Unsub 2	2.446	-71,785	-741	0.29	-0.0023	-0.77	0	0	11	8	2	4	10	5
Bitmovin	1.448	-69,767	-557	0.86	0.0016	0.94	26	0	16	5	4	6	0	11
Unsub 3	3.091	-142,299	-1,846	-0.33	-0.0053	-2.28	0	11	4	17	4	0	17	0

- Streaming bandwidth saved over test videos (~50 minutes)

Scoring

	1080p VMAF Std Deviation	Storage Saved	Streaming Bitrate Saved	PSNR	SSIM	VMAF	Rungs Saved	Errors	Good Decisions	Bad Decisions	Wins	Home Run	Losses	Draws
YouTube	2.251	-104,099	-857	0.26	-0.0040	-1.89	42	17	11	10	3	2	13	3
Capped CRF	1.485	-17,002	-64	0.33	0.0001	0.19	0	10	14	7	5	2	5	9
Unsub 1	1.887	-33,179	-266	0.27	-0.0008	-0.54	0	9	10	11	2	3	12	4
Unsub 2	2.446	-71,785	-741	0.29	-0.0023	-0.77	0	0	11	8	2	4	10	5
Bitmovin	1.448	-69,767	-557	0.86	0.0016	0.94	26	0	16	5	4	6	0	11
Unsub 3	3.091	-142,299	-1,846	-0.33	-0.0053	-2.28	0	11	4	17	4	0	17	0

- Overall impact on QoE as measured by PSNR, SSIM, and VMAF
  - Higher scores are better with all three metrics

Scoring

	1080p VMAF Std Deviation	Storage Saved	Streaming Bitrate Saved	PSNR	SSIM	VMAF	Rungs Saved	Errors	Good Decisions	Bad Decisions	Wins	Home Run	Losses	Draws
YouTube	2.251	-104,099	-857	0.26	-0.0040	-1.89	42	17	11	10	3	2	13	3
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Unsub 1	1.887	-33,179	-266	0.27	-0.0008	-0.54	0	9	10	11	2	3	12	4
Unsub 2	2.446	-71,785	-741	0.29	-0.0023	-0.77	0	0	11	8	2	4	10	5
Bitmovin	1.448	-69,767	-557	0.86	0.0016	0.94	26	0	16	5	4	6	0	11
Unsub 3	3.091	-142,299	-1,846	-0.33	-0.0053	-2.28	0	11	4	17	4	0	17	0

- Rungs eliminated
  - Started with 7 for each video
  - Can save encoding and storage costs

Scoring

	1080p VMAF Std Deviation	Storage Saved	Streaming Bitrate Saved	PSNR	SSIM	VMAF	Rungs Saved	Errors	Good Decisions	Bad Decisions	Wins	Home Run	Losses	Draws
YouTube	2.251	-104,099	-857	0.26	-0.0040	-1.89	42	17	11	10	3	2	13	3
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Unsub 1	1.887	-33,179	-266	0.27	-0.0008	-0.54	0	9	10	11	2	3	12	4
Unsub 2	2.446	-71,785	-741	0.29	-0.0023	-0.77	0	0	11	8	2	4	10	5
Bitmovin	1.448	-69,767	-557	0.86	0.0016	0.94	26	0	16	5	4	6	0	11
Unsub 3	3.091	-142,299	-1,846	-0.33	-0.0053	-2.28	0	11	4	17	4	0	17	0

- Errors – ladder integrity issues
  - Rungs should be between 1.5 – 2x apart to ensure proper operation
  - Anytime encoder exceeded this in any direction by 10% it was an error
  - This from YouTube

	Width	Height	Data Rate		PSRN	SSIM	VMAF
Haunted_1080p_YT.mp4	1920	1080	4,365	2.18	41.22	0.968	89.31
Haunted_720p_YT.mp4	1280	720	2,006	1.64	39.25	0.963	83.70
Haunted_480p_YT.mp4	854	480	1,225	2.67	36.16	0.949	66.93
Haunted_360p_YT.mp4	640	360	460	1.38	34.63	0.941	59.76
Haunted_240p_YT.mp4	426	240	332		31.65	0.924	37.24
			8,387		**36.58**	**0.949**	**67.39**

Scoring

	1080p VMAF Std Deviation	Storage Saved	Streaming Bitrate Saved	PSNR	SSIM	VMAF	Rungs Saved	Errors	Good Decisions	Bad Decisions	Wins	Home Run	Losses	Draws
YouTube	2.251	-104,099	-857	0.26	-0.0040	-1.89	42	17	11	10	3	2	13	3
Capped CRF	1.485	-17,002	-64	0.33	0.0001	0.19	0	10	14	7	5	2	5	9
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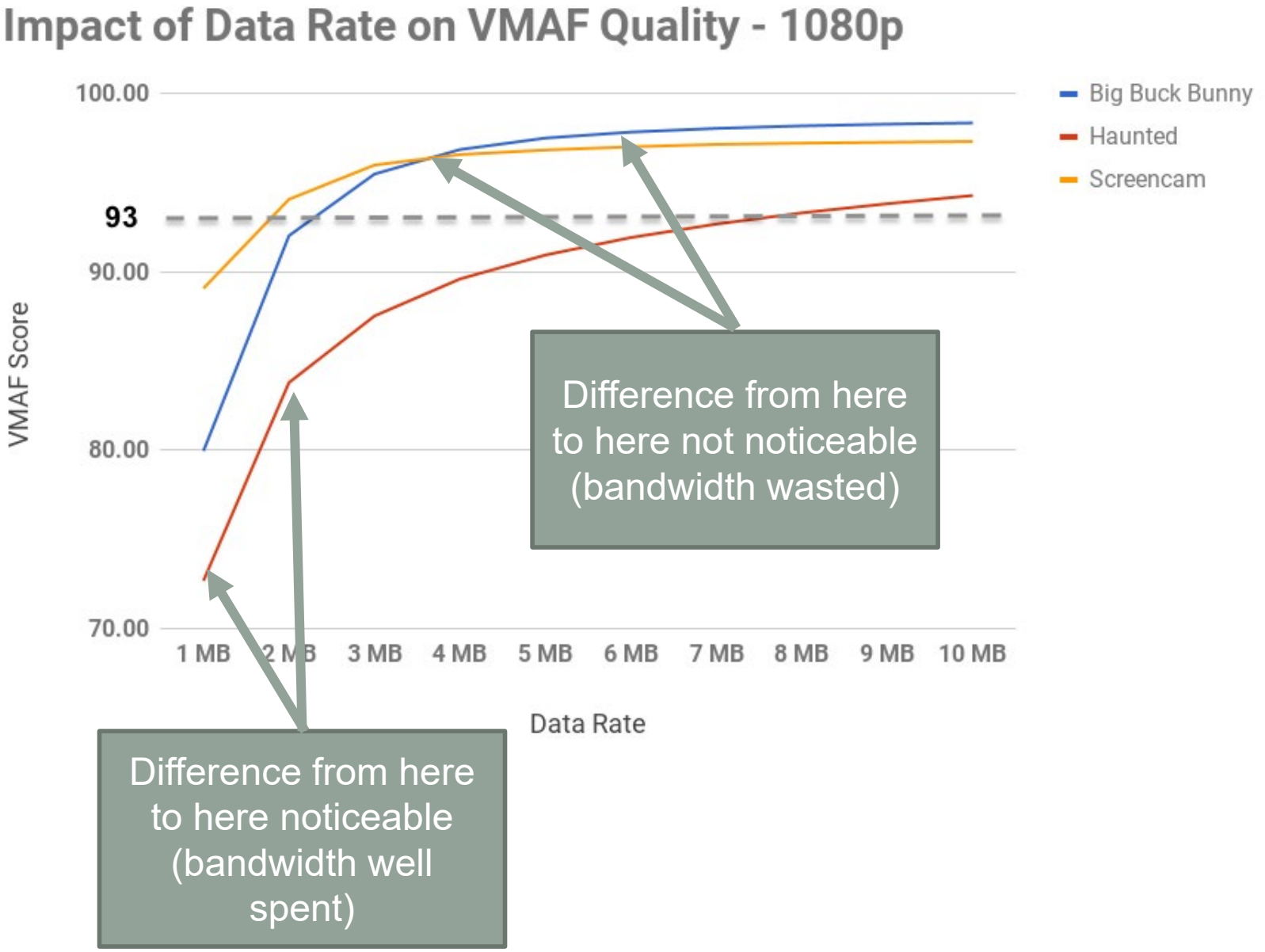
Unsub 2	2.446	-71,785	-741	0.29	-0.0023	-0.77	0	0	11	8	2	4	10	5
Bitmovin	1.448	-69,767	-557	0.86	0.0016	0.94	26	0	16	5	4	6	0	11
Unsub 3	3.091	-142,299	-1,846	-0.33	-0.0053	-2.28	0	11	4	17	4	0	17	0

- Good and bad decisions
  - Theory: if you were encoding manually, would you increase or decrease the 1080p bitrate?
    - If over 95 VMAF you would decrease data rate
    - If under 93 you would increase data rate

- Good and bad decisions
  - Theory: if you were encoding manually, would you increase or decrease the 1080p bitrate?

Working With VMAF

- Range – 0 – 100
- Top rung target – typically 93 – 95
  - Higher is a waste because difference not noticeable
- Scores map to subjective
  - 0-20 bad - 20 – 40 poor
  - 40 – 60 fair - 60 – 80 good
  - 80 – 100 excellent
- 6 VMAF points = Just noticeable difference



Good and Bad Decisions

Was 98.72

	ata	VMAF	
basketball_1080p_CVBR.mp4	4,563	98.72	4500
basketball_720p_CVBR.mp4	2,730	95.53	2700
basketball_540p_CVBR.mp4	1,919	91.27	1900
basketball_480p_CVBR.mp4	1,358	83.53	1350
basketball_360p_CVBR.mp4	903	72.47	900
basketball_270p_CVBR.mp4	496	54.20	500
basketball_180p_CVBR.mp4	242	30.58	250
	,212	**75.19**	

Cut data rate

VMAF down, but still above 93

Good decision

	Data Rate		VMAF	Rungs	Errors	Good	Bad
	4059	1.96	96.17			1	
	2069	1.72	87.02				
	1203	1.20	74.57				
	1002						
	656						
	410						
	226						
	,625						

Was 95.21

	Bit te	VMAF	
Skateboard_1080p_CVBR.mp4	4,437	95.21	4500
Skateboard_720p_CVBR.mp4	2,671	91.57	2700
Skateboard_540p_CVBR.mp4	1,882	87.39	1900
Skateboard_480p_CVBR.mp4	1,333	83.18	1350
Skateboard_360p_CVBR.mp4	886	74.32	900
Skateboard_270p_CVBR.mp4	485	59.51	500
Skateboard_180p_CVBR.mp4	234	34.60	250
	11,928	**75.11**	

Slashed data rate

VMAF down to 86.20; noticeably poorer quality

Bad decision

	Data Rate		VMAF	Rungs	Errors	Good	Bad
	1927	2.10	86.20		1		1
	919	1.82	77.01				
	504	1.20	65.71				
	418	1.57	61.68				
	266	1.70	50.47				
	157	1.93	37.91				
	81		19.50				
	4,272		**56.93**				

Scoring

	1080p VMAF Std Deviation	Storage Saved	Streaming Bitrate Saved	PSNR	SSIM	VMAF	Rungs Saved	Errors	Good Decisions	Bad Decisions	Wins	Home Run	Losses	Draws
YouTube	2.251	-104,099	-857	0.26	-0.0040	-1.89	42	32	11	10	3	2	13	3
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Unsub 2	2.446	-71,785	-741	0.29	-0.0023	-0.77	0	0	11	8	2	4	10	5
Bitmovin	1.448	-69,767	-557	0.86	0.0016	0.94	26	0	16	5	4	6	0	11
Unsub 3	3.091	-142,299	-1,846	-0.33	-0.0053	-2.28	0	11	4	17	4	0	17	0

- Good decision
  - VMAF above 95, drop data rate but stay over 93
  - VMAF under 93, increase data rate
- Bad decision
  - Increase data rate when VMAF above 94
  - Didn’t drop when above 95
  - Reduce VMAF to below 93
  - Decrease data rate when VMAF below 93

Scoring

	1080p VMAF Std Deviation	Storage Saved	Streaming Bitrate Saved	PSNR	SSIM	VMAF	Rungs Saved	Errors	Good Decisions	Bad Decisions	Wins	Home Run	Losses	Draws
YouTube	2.251	-104,099	-857	0.26	-0.0040	-1.89	42	32	11	10	3	2	13	3
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- Wins, Home Runs, Losses and Draws

Wins, Home Runs, Losses, and Draws

- Gets painful, but here's the scoring system

Data Rate	Overall VMAF	Result
	Down > 1	Loss
Down > 1 Mbps	Between -1 – 0	Draw
	Up	Win
	Down > 1	Loss
- 1 mbps - +1 Mbps	Between -1 - +1	Draw
	Up > 1	Win
	Down >	Loss
Up > 1 Mbps	Between 0 - +1	Draw
	Up > 1	Win
	Over 1.5	Home Run

Scoring

- Starting point is constrained VBR ladder

	Width	Height	Bitrate	PSNR	SSIM	VMAF
Meridian_1080p_CVBR.mp	1920	1080	4,560	43.95	0.964	95.92
Meridian_720p_CVBR.mp4	1280	720	2,734	40.02	0.957	90.53
Meridian_540p_CVBR.mp4	960	540	1,921	37.99	0.949	85.14
Meridian_480p_CVBR.mp4	854	480	1,364	37.07	0.943	81.90
Meridian_360p_CVBR.mp4	640	360	905	35.35	0.930	72.73
Meridian_270p_CVBR.mp4	480	270	496	33.88	0.913	58.30
Meridian_180p_CVBR.mp4	320	180	239	31.36	0.883	24.86
			12,218	**37.09**	**0.934**	**72.77**

- Get the per-title encode

	Width	Height	Data Rate		PSRN	SSIM	VMAF
Meridian_PT_1080p_2839158.mp4	1920	1080	2830	1.95	43.33	0.960	95.17
Meridian_PT_1080p_1545226.mp4	1920	1080	1451	1.87	41.74	0.950	92.09
Meridian_PT_900p_840998.mp4	1600	900	776.8	1.89	39.21	0.939	86.10
Meridian_PT_576p_442631.mp4	1024	576	410.7	1.95	36.75	0.928	77.63
Meridian_PT_432p_240000.mp4	768	432	210.8		34.74	0.910	65.35
			5,679		**39.15**	**0.937**	**83.27**

Scoring

	Width	Height	Data Rate		PSRN	SSIM	VMAF
Meridian_PT_1080p_2839	1920	1080	2830	1.95	43.33	0.960	95.17
Meridian_PT_1080p_1545	1920	1080	1451	1.87	41.74	0.950	92.09
Meridian_PT_900p_840998	1600	900	776.8	1.89	39.21	0.939	86.10
Meridian_PT_576p_44263	1024	576	410.7	1.95	36.75	0.928	77.63
Meridian_PT_432p_240000	768	432	210.8		34.74	0.910	65.35
			5,679		**39.15**	**0.937**	**83.27**

	Width	Height	Data Rate	PSRN	SSIM	VMAF
Meridian_PT_	1920	1080	2,830	43.33	0.960	95.17
Meridian_PT_	1920	1080	2,830	43.33	0.960	95.17
Meridian_PT_	1920	1080	1,451	41.74	0.950	92.09
Meridian_PT_	1920	1080	1,451	41.74	0.950	92.09
Meridian_PT_	1600	900	777	39.21	0.939	86.10
Meridian_PT_	1024	576	411	36.75	0.928	77.63
Meridian_PT_	768	432	211	34.74	0.910	65.35
			9,960	**40.12**	**0.942**	**86.23**

- Slot the files into the new ladder based upon the rung the viewer would see at each bandwidth @ 110%

Compare Per-Title Ladder to

- On a rung by rung basi
  difference in bitrate and
- Allocate change based
  viewing percentage of each rung

Device type	Usage [%]	Average bandwidth [Mbps]
PC	63.49	14.720
Mobile	6.186	10.609
Tablet	9.165	12.055
TV	21.15	24.986
All devices	100	16.393

TABLE 3: USAGE AND AVERAGE BANDWIDTH STATISTICS FOR O

Bitrate	VMAF	Allocation	Data Rate	PSNR	SSIM	VMAF
-37.4%		71.30%	-1,239	-0.444	-0.003	0.541
	4.64	13.48%	13	0.446	0.000	0.625
-24.47%	6.94	9.44%	-44	0.354	0.000	0.655
6.38%	10.19	3.26%	3	0.152	0.000	0.332
-14.14%	13.37	1.21%	-2	0.047	0.000	0.162
-17.11%	19.32	0.58%	0	0.017	0.000	0.113
-11.69%	40.49	0.19%	0	0.007	0.000	0.078
				0.578	**-0.002**	**1.424**
5 top			**-1,269**	**1.022**	**0.**	**1.966**

4.64 point VMAF bump here

File played 13.48% of the time

Overall effect is much larger

40 point VMAF bump here

File only played .19% of the time

Benefit must be weighted

One Last Thing

	Width	Height	Bitrate	PSNR	SSIM	VMAF	
Epiphan_1080p_CVBR.mp4	1920	1080	4,493	51.05	0.989	96.63	**4500**
Epiphan_720p_CVBR.mp4	1280	720	2,671	41.8	0.984	92.81	**2700**
Epiphan_540p_CVBR.mp4	960	540	1,872	38.97	0.974	87.61	**1900**
Epiphan_480p_CVBR.mp4	854	480	1,329	37.8	0.968	84.55	**1350**
Epiphan_360p_CVBR.mp4	640	360	892	35.26	0.952	73.59	**900**
Epiphan_270p_CVBR.mp4	480	270	496	32.79	0.931	56.26	**500**
Epiphan_180p_CVBR.mp4	320	180	245	30	0.904	25.32	**250**
			11,998	**38.24**	**0.957**	**73.83**	

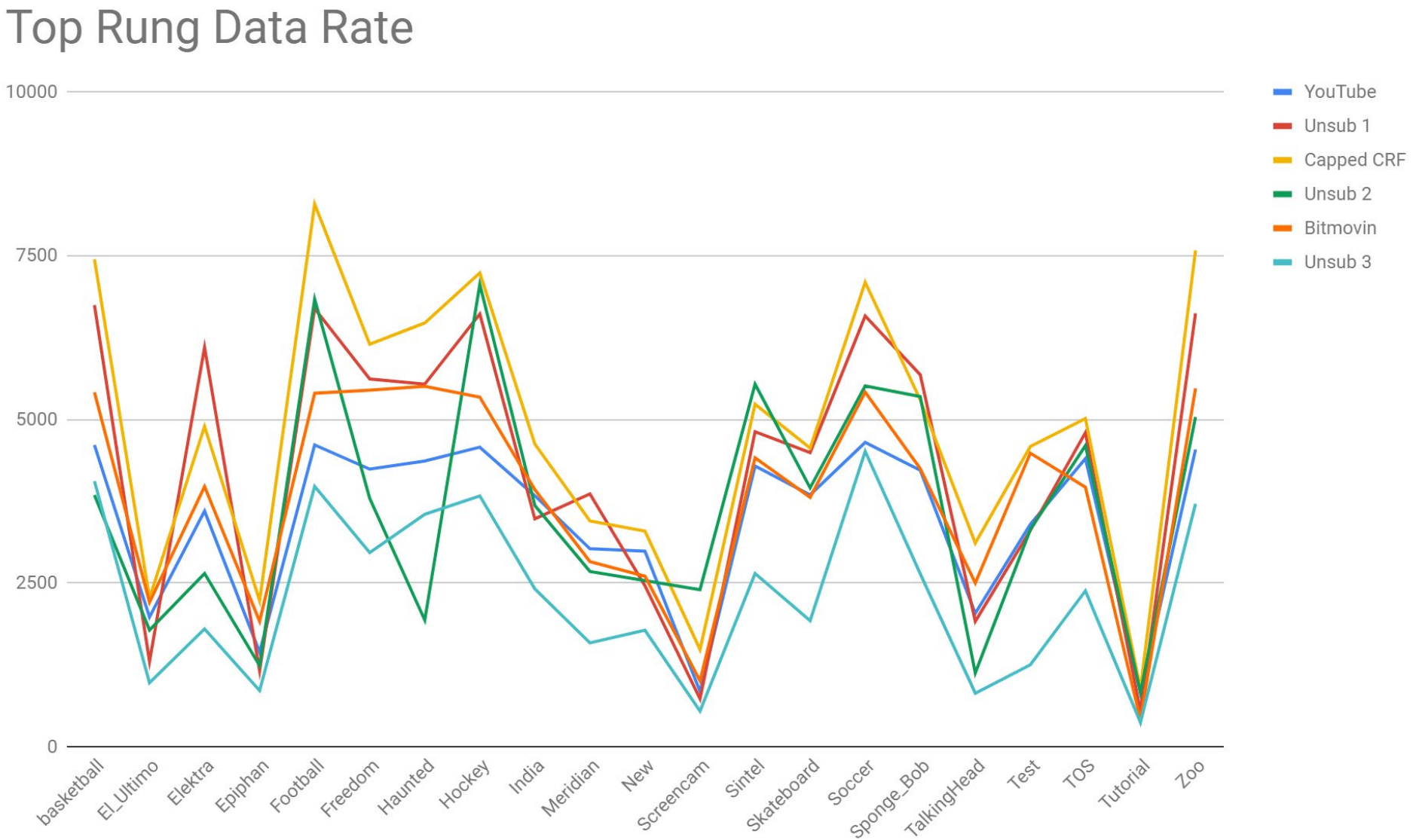
	Width	Height	Data Rate		PSRN	SSIM	VMAF
Epiphan_1080p_YT.mp4	1920	1080	1,449	1.69	47.68	0.984	94.65
Epiphan_720p_YT.mp4	1280	720	856	2.04	40.61	0.979	90.41
Epiphan_480p_YT.mp4	854	480	419	1.83	35.26	0.956	73.30
Epiphan_360p_YT.mp4	640	360	229	1.84	33.82	0.943	65.30
Epiphan_240p_YT.mp4	426	240	125		30.51	0.912	35.59
			3,077		**37.58**	**0.955**	**71.85**

- Constrained VBR 1080p VMAF is 96.63; YouTube drops to 94.65, a drop of 2
- 1080p file played 71% of the time, so this could have a huge impact on overall score
- Should we include or exclude this from overall calculation?

- I excluded: Since both scores above 94, drop in quality would not be visible
  - Included only when per-title technology dropped score from above 94 to below 93
- Also excluded increases in quality when score already above 93

High Level Point

- Highest quality files from all services
- Significant consistency in quality assessment
- A few outliers



Our Participants

- YouTube
- Capped CRF
- Bitmovin
- Unsub 3 (unsub 1-2 had anomalous results)

YouTube

- Schema
  - One file in five rungs out – all same resolution

Feature	YouTube
Type	Gauge complexity and encode
Core schema	Neural Network
Passes	2
Factor in QoE stats	No
Adjust data rate	Yes
Change number of files in ladder	Yes
Adjust resolution	No
Customizability	Presume yes
Bitrate control (CBR/VBR)	Presume yes
Post-encode quality check	Don't know

YouTube

Surprising lack of consistency from Neural network

Improved overall PSNR, decreased SSIM and VMAF (by a lot)

Lack of file between 480p and 720p lead to lots of losses

	10 VMAF Deviation	Storage Saved	Streaming Bitrate Saved	PSNR	SSIM	VMAF	Rungs Saved	Errors	Good Decisions	Bad Decisions	Wins	Home Run	Losses	Draws
YouTube	2.251	-104,099	-857	0.26	-0.0040	-1.89	42	17	11	10	3	2	13	3
Capped CRF	1.485	-7,002	-64	0.33	0.0001	0.19	0	10	14	7	5	2	5	9
Unsub 1	1.887	3,179	-266	0.27	-0.0008	-0.54	0	9	10	11	2	3	12	4
Unsub 2	2.446	71,785	-741	0.29	-0.0023	-0.77	0	0	11	8	2	4	10	5
Bitmovin	1.448	69,767	-557	0.86	0.0016	0.94	2	0	16		4	6	0	11
Unsub 3	3.09	142,299	-1,846	-0.33	-0.0053	-2.28		11	4		4	0	17	0

Cut two rungs from each ladder – significant storage savings

Errors could interrupt ABR operation

Decent but not great decision making

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
Type	Frame by frame optimization
Core schema	CRF encode
Passes	1
Factor in QoE stats	No
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
```

Capped CRF

No rungs eliminated – poor savings

Great here.

But several losses

	1080p VMAF Std Deviation	Sto… Sav…	Streaming Bitrate Saved	PSNR	SSIM	VMAF	Ru… Sav…	Errors	Good Decisions	Bad Decisions	Wins	Home Run	…sses	Draws
YouTube	2.251	-104,0…	-857	0.26	-0.0040	-1.89	42	17	11	10	3	2	13	3
Capped CRF	1.485	-17,002	-64	0.33	0.0001	0.19	0	10	14	7	5	2	5	9
Unsub 1	1.887	-33,179	…66	0.27	-0.…008	-0.54	0	9	10	11	2	3	12	4
Unsub 2	2.446	-71,785	…41	0.29	-0.…023	-0.77	0	0	11	8	…	4	10	5
Bitmovin	1.448	-69,767	…57	0.86	…016	0.94	26	0	16	5	…	6	0	11
Unsub 3	3.091	-142,299	…46	-0.33	…053	-2.28	0	11	4	17	…4	0	17	0

Modest savings here

And here

Most wins and 2 home runs – boost in QoE

Bitmovin

- Two operating modes
  - Upload file – they do the rest (what we used)
  - Upload file, set lots of limits
- Bitmovin assesses complexity and creates unique ladder

Feature	Bitmovin
Type	Per-Title
Core schema	Complexity assessment
Passes	3?
Factor in QoE stats	No
Adjust data rate	Yes
Change number of files in ladder	Yes
Adjust resolution	Yes
Customizability	Yes, not used
Bitrate control (CBR/VBR)	No
Post-encode quality check	No

Bitmovin

Most consistent quality assessor

Best quality improvements

Best decision making

	1(VM Dev	Storage Saved	Streaming Bitrate Saved	PSNR	SSIM	IAF	Rungs Saved	Errors	Goo Decisio	Bad Decisions	Wins	Home Run	Losses	Draws
YouTube	2	-104,099	-857	0.26	-0.0040	1.89	42	17	11	10	3	2	13	3
Capped CRF	1 6	-17,002	-64	0.33	0.0001	0.19	0	10	14	7	5	2	5	9
Unsub 1	1 87	-33,179	-266	0.27	-0.0008	-0.54	0	9	10	11	2	3	12	4
Unsub 2	2 446	-71,785	-741	0.29	-0.0023	-0.77	0	0	11	8	2	4	10	5
Bitmovin	1.448	-69,767	-557	0.86	0.0016	0.94	26	0	16	5	4	6	0	11
Unsub 3	3.091	-142	-1,846	-0.33	-0.0053	-2.28	0	11	4	17	4	0	17	0

Decent storage/bitrate savings

Excellent ladder integrity

Most total wins/home runs and no losses

The One Caveat on Bitmovin

- Won based upon this ladder distribution
  - Pretty reasonable
- Results would likely be different for different distribution pattern

Device type	Usage [%]	Average bandwidth [Mbps]
PC	63.49	14.720
Mobile	6.186	10.609
Tablet	9.165	12.055
TV	21.15	24.986
All devices	100	16.393

TABLE 3: USAGE AND AVERAGE BANDWIDTH STATISTICS FOR OPERATOR 2.

Unsub 3

- Upload file, get back 7 rungs
- Dramatic drops in data rate

Feature	Unsub 3
Type	Per-TItle
Core schema	Assess complexity, bomb data rate
Passes	2
Factor in QoE stats	No
Adjust data rate	Yes
Change number of files in ladder	No
Adjust resolution	No
Customizability	No
Bitrate control (CBR/VBR)	Yes
Post-encode quality check	No

Sample Result

Huge drops in data rate and all metrics

	Width	Height	Bitrate	PSNR	SSIM	VMAF			Width	Height	Data Rate	PSRN	SSIM	VMAF
Skateboard_1080	1920	1080	4,437	42.41	0.952	95.21	**4950**	Skateboard_	1920	1080	1,927	40.03	0.938	86.20
Skateboard_720p	1280	720	2,671	40.36	0.946	91.57	**2970**	Skateboard_	1280	720	919	37.92	0.924	77.01
Skateboard_540p	960	540	1,882	38.98	0.939	87.39	**2090**	Skateboard_	960	540	504	36.26	0.911	65.71
Skateboard_480p	854	480	1,333	38.16	0.932	83.18	**1485**	Skateboard_	854	480	418	35.73	0.906	61.68
Skateboard_360p	640	360	886	36.62	0.920	74.32	**990**	Skateboard_	640	360	266	34.36	0.895	50.47
Skateboard_270p	480	270	485	34.62	0.903	59.51	**550**	Skateboard_	480	270	157	32.86	0.883	37.91
Skateboard_180p	320	180	234	32.33	0.882	34.60	**275**	Skateboard_	320	180	81	30.97	0.868	19.50
			11,928	**37.64**	**0.925**	**75.11**					**4,272**	**35.45**	**0.903**	**56.93**

Bitrate	Rez	VMAF	Allocation	Data Rate	PSNR	SSIM	VMAF
-56.57%	0	-9.01	71.60%	-1,797	-1.704	-0.011	-6.454
-65.59%	0	-14.56	13.48%	-236	-0.329	-0.003	-1.962
-73.23%	0	-21.67	9.44%	-130	-0.257	-0.003	-2.046
-68.61%	0	-21.50	3.26%	-30	-0.079	-0.001	-0.700
-69.98%	0	-23.84	1.21%	-8	-0.027	0.000	-0.289
-67.71%	0	-21.60	0.58%	-2	-0.010	0.000	-0.126
-65.28%	0	-15.10	0.19%	0	-0.003	0.000	-0.029
					-2.409	**-0.017**	**-11.606**
No top				**-2,203**	**-2.409**	**-0.017**	**-11.606**

Loss was VMAF less than -1; here it's -11.6

Unsub 3

Most savings

	1080p VMAF Std Deviation	S Sa	Streaming Bitrate Saved	PSNR	SSIM	VMAF	Rungs Saved	Errors	Good Decisions	Bad Decisions	Wins	Home Run	Losses	Draws
YouTube	2.251	-104,	-857	0.26	-0.0040	-1.89	42	17	11	10	3	2	13	3
Capped CRF	1.485	-17,00	-64	0.33	0.0001	0.19	0	10	14	7	5	2	5	9
Unsub 1	1.887	-33,179	-266	0.27	-0.0008	-0.54	0	9	10	11	2	3	12	4
Unsub 2	2.446	-71,785	-741	0.29	-0.0023	-0.77	0	0	11	8	2	4	10	5
Bitmovin	1.448	-69,767	-557	0.86	0.0016	0.94	26	0	16	5	4	6	0	11
Unsub 3	3.091	-142,299	-1,846	-0.33	-0.0053	-2.28	0	11	4	17	4	0	17	0

Worst consistency

Worst QoE hit

By far the most losses

Unsub 3

- Upload file, get back 7 rungs
- Dramatic drops in data rate
- Included as cautionary tale
  - All that glitters is not gold
  - Huge data rate reductions ***always*** accompanied by lower quality

Feature	**Unsub 3**
Type	Per-TItle
Core schema	Assess complexity, bomb data rate
Passes	2
Factor in QoE stats	No
Adjust data rate	Yes
Change number of files in ladder	No
Adjust resolution	No
Customizability	No
Bitrate control (CBR/VBR)	Yes
Post-encode quality check	No

When Considering Per-Title Technologies

- Ask/Determine
  - What kind (optimization, per-title, per-scene, per-shot?)
  - Can it incorporate real world and device playback data?
    - Where can it get that data?
  - Can you apply traditional data rate controls (VBR/CBR)?
  - Does it reduce the number of rungs?
  - Can it adjust rung resolutions?
  - How does it impact encoding cost?
  - Can you specify lowest bitrate file and the maximum bitrate?
  - For testing:
    - Collect relevant set of files
    - Compare against capped CRF