PhD Defense

Data-Driven Visual Quality Estimation Using Machine Learning

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Introduction – General Scope

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- mobile phones, camera/screen technology, internet
- more content + consumption [45]
- higher resolutions (4K/8K screens, recordings)
- traditional 2D videos and images

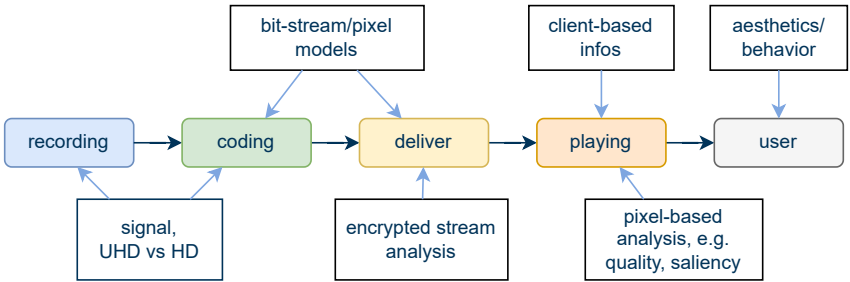
Introduction

- internet:
  - **higher demand for video streaming**, up to 80% video streaming [5]
  - **increase of uploaded images**, e.g., up to 95M per day for Instagram [1]
  - internet bandwidth not necessarily adapting to trends
- new image/video compression methods

image: `https://matrix.fandom.com/wiki/The_Architect`

Motivation

- 10 s UHD-1 raw video[1] $\approx$ 12 *GB* vs. Wikipedia-text-only-zip $\approx$ 14 *GB* [48]
- lossy image/video compression $\rightarrow$ quality evaluation required



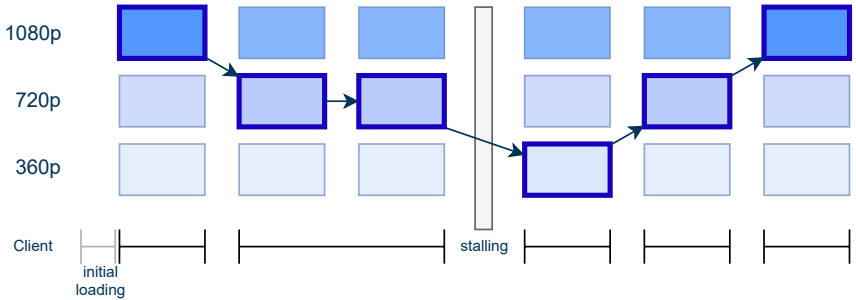
[1] (YUV, 4:2:2, 10bit, 60 fps)

Context – Quality of Experience

- system factors, context factors, human factors[2]
- quality perceived by users; overall media experience

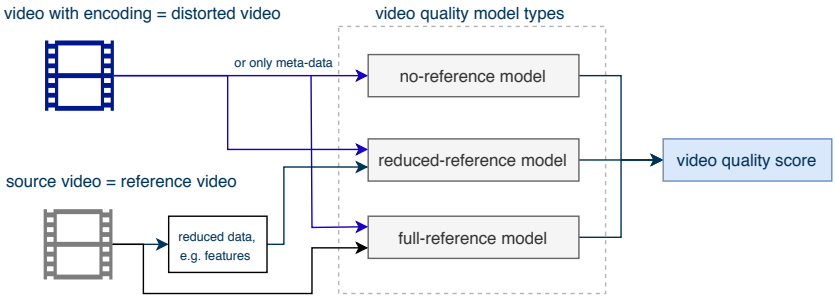
[2] *Le Callet et al.* 2012: "Qualinet white paper on definitions of quality of experience"

Context – HAS/DASH Streaming and Encoding



- long-term audio-visual quality, e.g, P.1203.3 [21]
- short-term "segment"-level visual quality

Context – Visual Quality Prediction Models



- parametric models: P.1203.1 P_v [21], P.1204.5 [23], ...
- machine learning/dnn models: P.1204.3 [22], VMAF [31], NIMA [44], ...
- common: overall mean opinion score VQ_{mos}, other: VQ_{class}, VQ_{prop}

Research Questions

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- **RQ 1**: robust video quality models using machine learning
- **RQ 2**: speed up of state-of-the-art quality models
- **RQ 3**: perceivable difference for higher quality content
- **RQ 4**: predict more than mean opinion scores
- **RQ 5**: using video quality models/compression for images

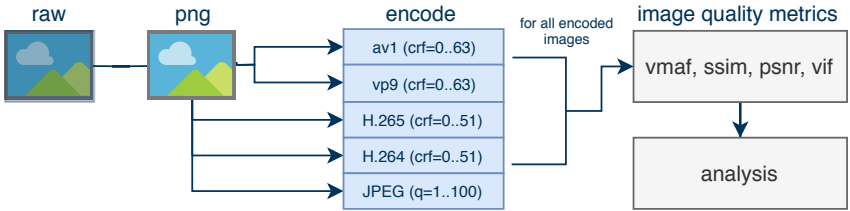
  $\rightarrow$ image quality, video quality, other applications

High Resolution Image Quality Evaluation

- image formats for web [6]: JPEG, PNG, GIF
- recent: AVIF [32], HEIF [26], VVC + DNN [28]: video based
- **open:** quality evaluation/models for
  - newer methods, higher resolutions,
  - large + diverse datasets, more than PSNR/SSIM

  $\rightarrow$ pre-analysis for video compression approaches

Objective Evaluation for Image Compression using Video Encoders

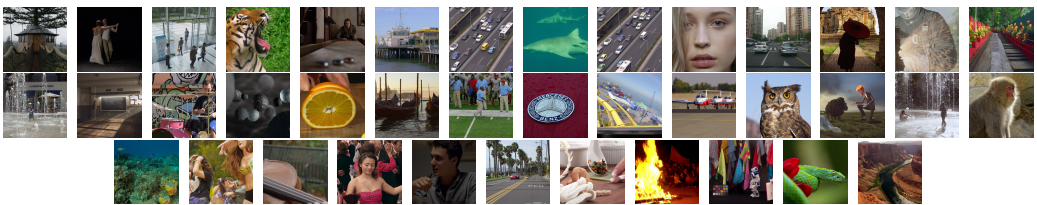


- AVT-Image-Database[3]: 1133 source images CC0 (wesaturate)[4]
- 380k encoded images + objective scores: AV1|VP9 > H.265 > JPEG

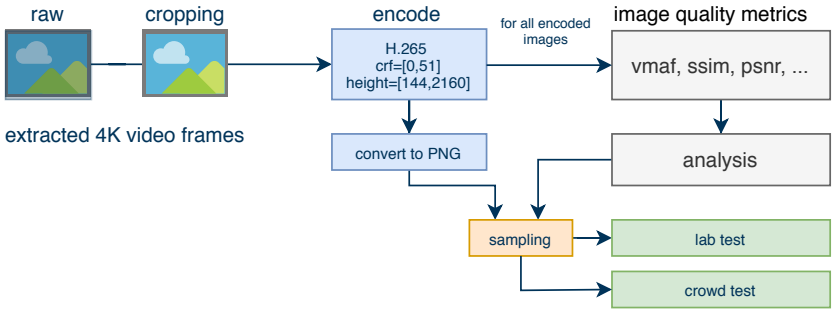
[3] *Göring et al.* 2019: "Evaluation of Intra-coding based image compression"
[4] code + data: `http://git.avt-imt.de/image_compression`

Quality Evaluation for HighRes Images

- VMAF suitable for image quality?→ lab or remote/crowd test required
- H.265 encoding, UHD-1/4K center cropped frames



Quality Evaluation for HighRes Images – Pipeline



- 39 source UHD-1/4K frames $\rightarrow$ 246k compressed images
- meta-data models: *IMG-h265-rf*, *IMG-h265-para*: VMAF predictions
- two rounds of sub-sampling $\rightarrow$ 371 stimuli

Quality Evaluation for HighRes Images – Tests

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test	tool	environment	#images	to-be-rated	#participants
lab-test	AVRateNG [2]	standardized; 4K screen	full; 371	all	21
online-test	AvrateVoyager-Dev [17]	wide range	1080p-patches; 1488	150 random	238

- lab-test: no outliers $\rightarrow$ VMAF best
- online-test: mostly: $720p$-$900p$ screens; pre-study, follow up [37]
- both: quality distribution + SOS-analysis [20] similar results

Quality Evaluation for HighRes Images – Results

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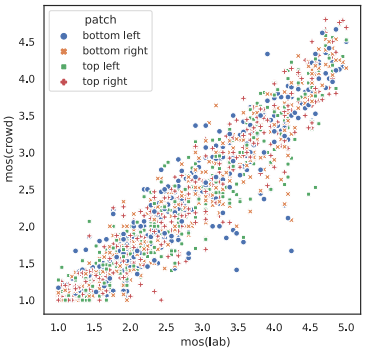
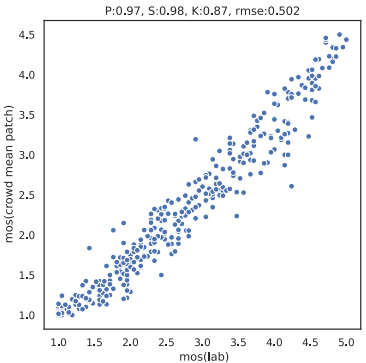
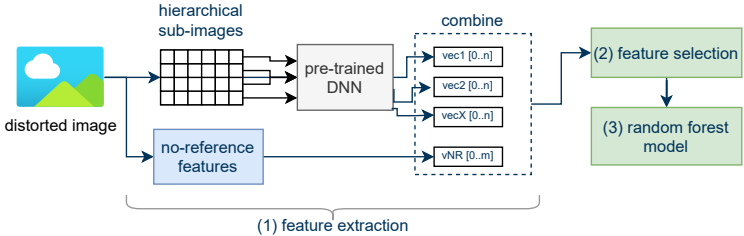
- lab vs. online test: per patch, mean patch
- individual patches: high correlation to lab test





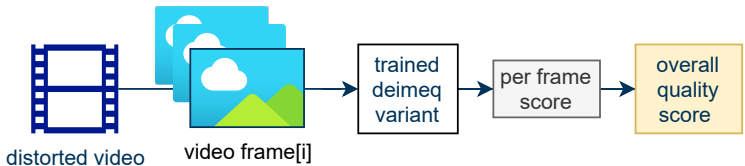
Pixel-based Image Quality Prediction – deimeq



- *deimeq*[5]: DNN-based image quality (mid-high resolution) model
  - feature extractor + RF model, hierarchical sub-images
  - cross dataset evaluation (TID 2013 [34], Live 2 [43])
  - similar to NIMA [44]

[5] *Göring et al.* 2018: "deimeq – A DNN Based Hybrid No-reference Image Quality Model"

Pixel-based Image Quality Prediction – deviq



- *deviq*[6]: extension of *deimeq* to UHD-1/4K video quality prediction
- **limits:** processing time; trained on VMAF per frame; motion aspects

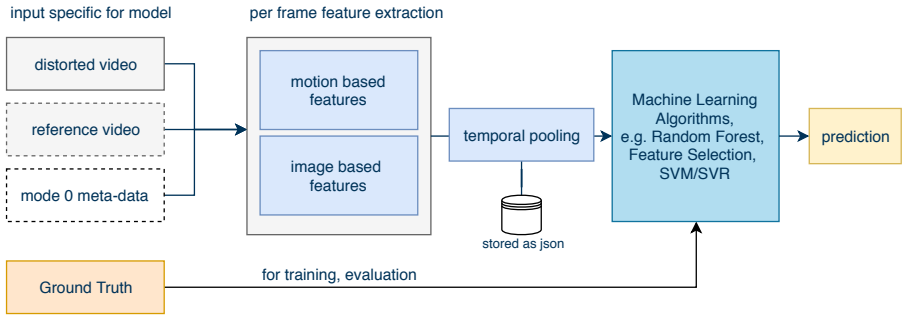
[6] *Göring et al.* 2018: "DeViQ – A deep no reference video quality model"

Models for Video Quality Prediction

- limits of VMAF: framerate: test #4 AVT-VQDB-UHD-1[7]
- feature-based models + machine learning
  - pixel-based features (no bitstream models)
  - context of P.NATS Phase 2
  - TUIL+DT pixel candidate models
  - framework[8], extensible, reproducible, open-source[9]
  - extensions to other applications

[7] *Rao et al.* 2019: "AVT-VQDB-UHD-1: A Large Scale Video Quality Database for UHD-1"
[8] *Göring et al.* 2021: "Modular Framework and Instances of Pixel-based VideoQM for UHD-1/4K"
[9] library: `http://git.avt-imt.de/quat` | models: `http://git.avt-imt.de/pixelmodels`

Models for Video Quality Prediction – Architecture



Models for Video Quality Prediction – Features

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Feature	Feature Type	Source	#Values
contrast, blur	img	own [15]	1/F
fft	img	[25]*	1/F
colorfulness	img	[19]*	1/F
tone, saturation	img	[3]*	1/F
scene_cuts	mov	own	1/F
movement, temporal	mov	own [15]	1/F
si, ti	img, mov	[24]	1/F
blockmotion	mov	own [12, 15]	3 /F
cub{row,col}.{0,0.3, 0.5, 0.6,1.0}	mov	own [12]	1/F
staticness	mov	own [12, 15]	1/F
uhdhdsim	img	own [15]	1/F
blockiness	img	own [12]	1/F
noise	img	[7]	1/F
PSNR, SSIM, VIF	img-fr	[47, 46, 42]	1/F
fps_est	mov-fr	own	1/F
framerate , bitrate, codec, resolution, bpp	bs		1/S
log(framerate, bitrate, resolution), norm(framerate, resolution)	bs		1/S
brisque	img-nofu	[30]	36/F

Models for Video Quality Prediction – Instances

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- instances:
  - **nofu**: no-reference: img + mov + img-nofu features
  - **hyfu**: hybrid no-reference (mode 0): img + mov + bs features
  - **fume**: full-reference: img/mov(dis, ref), img-fr, mov-fr
  - **hyfr**: hybrid-full-reference: fume + bs features
- all 360p center crop, temporal pooling, RF-based with feature selection
- trained+validated for VQ_{mos} , VQ_{class}, VQ_{prob}

Models for Video Quality Prediction – Datasets

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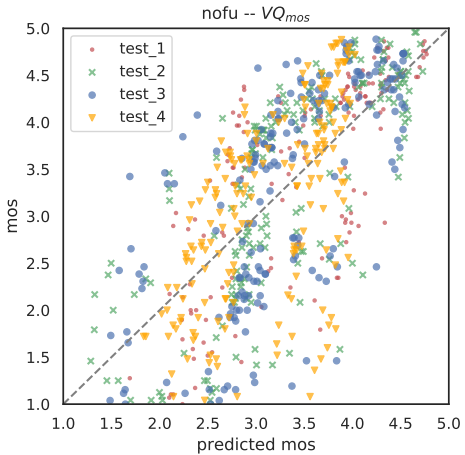
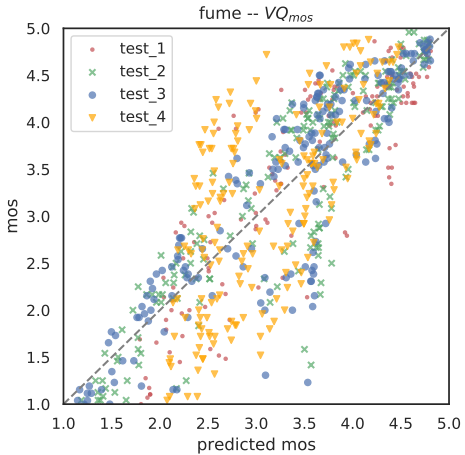
dataset	# tests	# srcs	fps	bitrates	codecs	resolutions
AVT-PNATS-UHD-1	4	>50	15 - 60	100 kbps to 50 mbps	VP9, H.264, H.265	360p - 2160p
AVT-VQDB-UHD-1	4	17	15 - 60 (test #4)	200 kbps to 50 mbps	VP9, H.264, H.265	360p - 2160p

- training: AVT-PNATS-UHD-1: subset of P.NATS Ph2 data [36]
- validation: AVT-VQDB-UHD-1[10]: publicly available
- no common sequences in train/validation

[10] *Rao et al.* 2019: "AVT-VQDB-UHD-1: A Large Scale Video Quality Database for UHD-1"

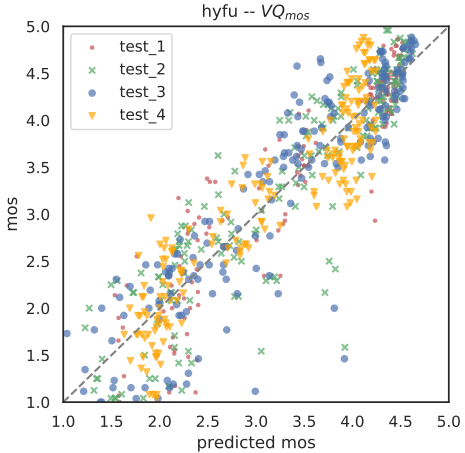
Models for Video Quality Prediction– Evaluation (1)

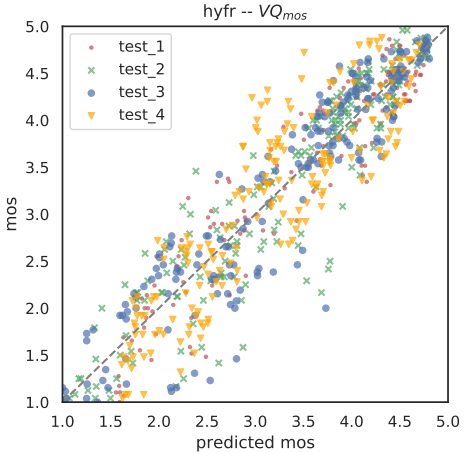




- **nofu** (P=0.701) < VMAF (P=0.816) < **fume** (P=0.835)

Models for Video Quality Prediction– Evaluation (2)





- **fume** (P=0.835) < **hyfu** (P=0.910) < **hyfr** (P=0.922)

Models for Video Quality Prediction– Evaluation (3)

- VQ_{class}, VQ_{prob}; other performance metrics; ML-algos: similar results
- **fume**: problems with test #4 (training: lesser low fps cond.)
- **nofu**: similar to PSNR/SSIM
  - better for specialized use-cases
  - larger center crop: small improvement
  - pure no-reference models: still challenging
- switching train/validation: better results; no reproducibility of predictions

Other Applications of the Model Pipeline

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- proposed architecture (features, pooling, ml-aglos) usable for:
  - source video classification for UHD-1/4K [15]
  - gaming video quality [12] and genre prediction [16]
  - encoding parameter estimation [13]
  - speed up approaches [8]

Gaming Video Quality Prediction

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- specialized **nofu** model= **nofu-gaming**[11]
  - features: *fft*, *ti*, *si*, *block{iness, motion}*, *staticness*, *cub{col,row}-{0,1.0}*
  - pooling: mean value, std, first value, $n = 3$ temporal groups: mean + std
- dataset: GamingVideoSET [4]
- 10-fold cross-validation: P=0.91 > re-trained brisque+niqe > vmaf
- src-video fold: nofu-gaming > brisque+niqe

[11] *Göring et al.* 2019: "nofu - A Lightweight No-Reference Pixel Based VideoQM for Gaming Content"






Speed-up Approaches

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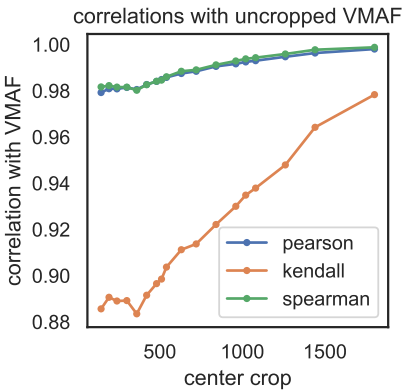
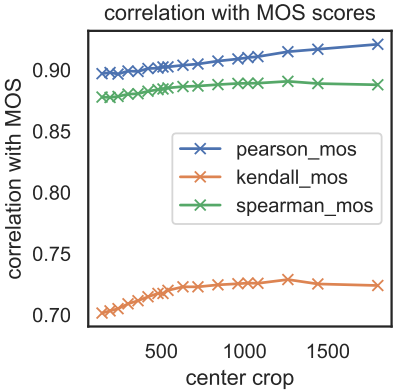
- **cencro**[12]: reduce processing time of SoA FR-models; per frame reduction
- center crop $144p$ to $1800p$: $360p$ (45 min to 3 min)





[12] *Göring et al.* 2019: "cencro – Speedup of Video Quality Calculation using Center Cropping"

Contributions to SoA

- publications
  - pixel-based image/video quality models, features, or analysis [18, 12, 15]
  - P.1203 [21, 40], P.1204 [39, 36], or bitstream-related [11, 35, 41], ...
- open source software for video quality
  - AVrateNG [2], AVrateVoyager [37, 17]
  - P.1203 open source implementation [40], ITU-P.1204.3 reference software [39]
  - cencro [8], quat + pixelmodels [18],
  - AVT-VQDB-UHD-1 [38], ...
- presented work= summary of 5 years

Conclusion

- high resolution image quality + compression:
  - using video codecs > JPEG
  - lab and crowd/remote/online tests for image quality
  - image quality prediction models
- video quality models for UHD-1/4K
  - general architecture, various model instances
  - other applications of the provided architecture

Future Work

- integration of video quality models in long-term quality prediction
- evaluation of new distortions: bending, compression artifacts (DNNs)
- UHD-2/8K, HDR, HFR, UGC, 360°, Point Clouds, light field
- end-to-end chain: encrypted streams; cameras; liking
- immersive media technology: room lighting, haptic feedback ...

Thank you for your attention

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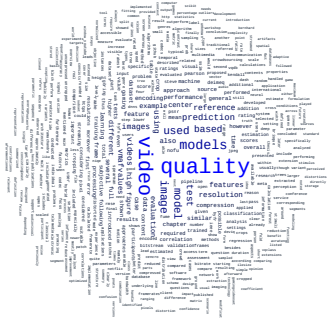

..... are there any questions?

Thanks to all ..

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colleagues, collaborators, friends, family, . . .

Alexander Raake Peter List Robert Steger Christiane Wisser Saman Zadtootaghaj Matthias Döring Nabajeet Barman Dominik Keller Konstantin Brand Silvio Borer Detlef Beyer Simon Broom Martin Meyer Jochen Seitz Lukas Treybig Ashutosh Singla Lea Skorin-Kapov Simon Wedel Thomas Wöhner Patrick Vogel Erik Hofman Marie-Neige Garcia Werner Robitza Janto Skowronek Frank Hofmeyer Monique Rodegast Bernhard Feiten Ulf Wüstenhagen Julian Zebelein Claudia Stirnat Alexander Dethof Rakesh Rao Ramachandra Rao Madlen Langbein Thaden Cohrs Gunnar Heikkilä Andrea Reis Patrick Le Callet Stephan Fremerey Bernd Hildenbrandt André Siegel Jörgen Gustafsson Juan Jose Villamar Villarreal Kazuhisa Yamagishi Tim Gubner Nicolas Pachatz Torsten Demmler Petra Göring David Lindero Annika Neidhardt Christopher Krämmer Shahid Satti Susann Kohout Stephan Werner Eckhardt Schön . . .

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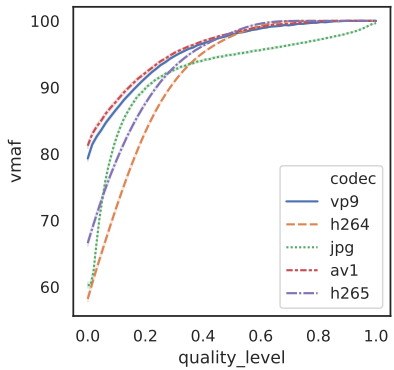
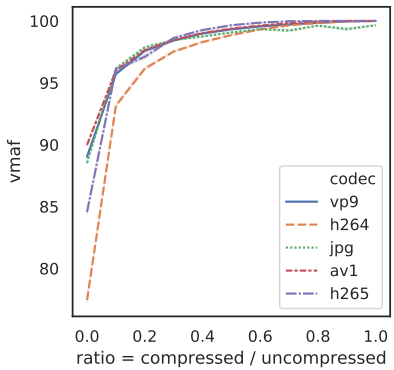
Image Compression using Video Encoders – Results





- quality-level= unified "setting" for compression
- similar results for other metrics: SSIM, PSNR, VIF
- higher quality range: video methods better (AV1|VP9; H.265)

Quality Evaluation for HighRes Images– Results Lab vs. obj. metrics

- lab test vs. objective quality metrics

metric	pearson	kendall	spearman
vmaf	0.919	0.757	0.925
adm2	0.868	0.722	0.901
vif scale2	0.861	0.740	0.911
vif scale3	0.852	0.786	0.941
vif scale1	0.846	0.674	0.859
ms ssim	0.701	0.658	0.851
psnr	0.698	0.524	0.719
ssim	0.658	0.802	0.948
vif scale0	0.619	0.472	0.643

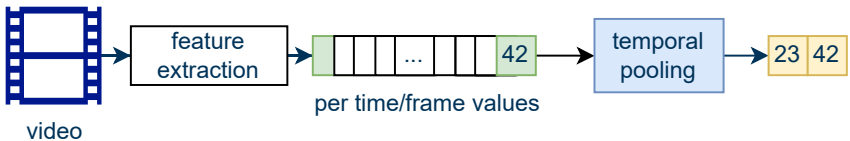
Models for Video Quality Prediction– Features – Examples (1)

- staticness: mean frame on all currently played frames + SI measure
- noise: wavelet-based estimator for noise [7] (skimage)
- scene_cuts: 0,1: resized $360p$ view + threshold-based detection, similar to [33, 49] (skvideo)
- cube{col,row}: similar to [29]: a sliding window=60 frames as cuboid, slicing planes + SI measure

Models for Video Quality Prediction– Features – Examples (2)

- movement: foreground-background % of moving foreground (open-cv)
- blockmotion: SE3SS algo, 10% of height as blocksize (may be suboptiomal, speed tradeoff), counting block movement directions
- temporal: $RMSE(f_i, f_{i+1})$, for RGB
- blockiness: "guessing" blocksize, canny edge detector, mean on blocklines horizontal, vertical, weighted
- uhdhdsim: PSNR to rescaled versions (Full-HD – 4K)

Models for Video Quality Prediction– Pooling



- most of the features produce per-frame scores
- time-independent features for ml-model required: temporal pooling
- for a given feature value vector $f \rightarrow$ total 25 statistical values:
  - mean value, std, skewness, kurtosis, IQR, quantiles, last + first value
  - split into $n = 3$ temporal groups: for each group: mean + std

Models for Video Quality Prediction– Speed-up

- full-frame calculation of all features: time consuming
- (A) reduction of frames: breaks movement features
- (B) reduction per frame: focus on 360p center cropped view of videos
  - drastic time reduction, nearly negligible error
  - wider range of features compensate for 360p view

Models for Video Quality Prediction– Evaluation - cc

- 32 runs each 10-fold-cross validation