Tencent Media Lab

Standard Activities on Learned Visual Data Compression

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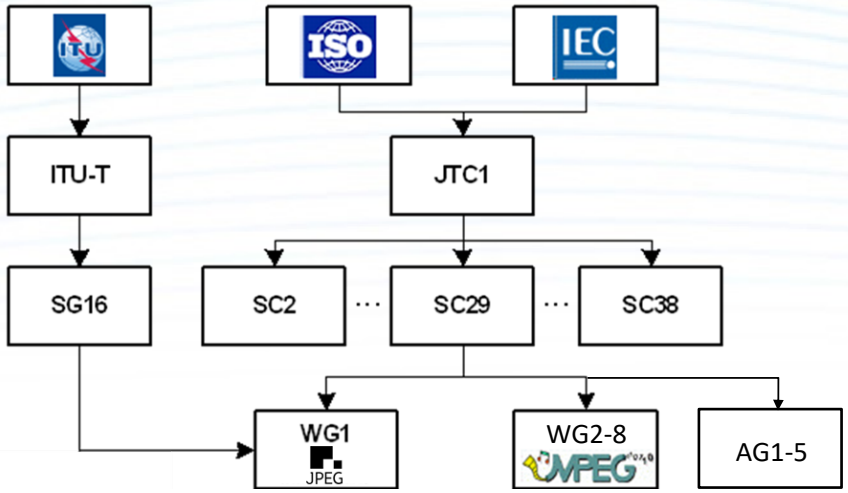
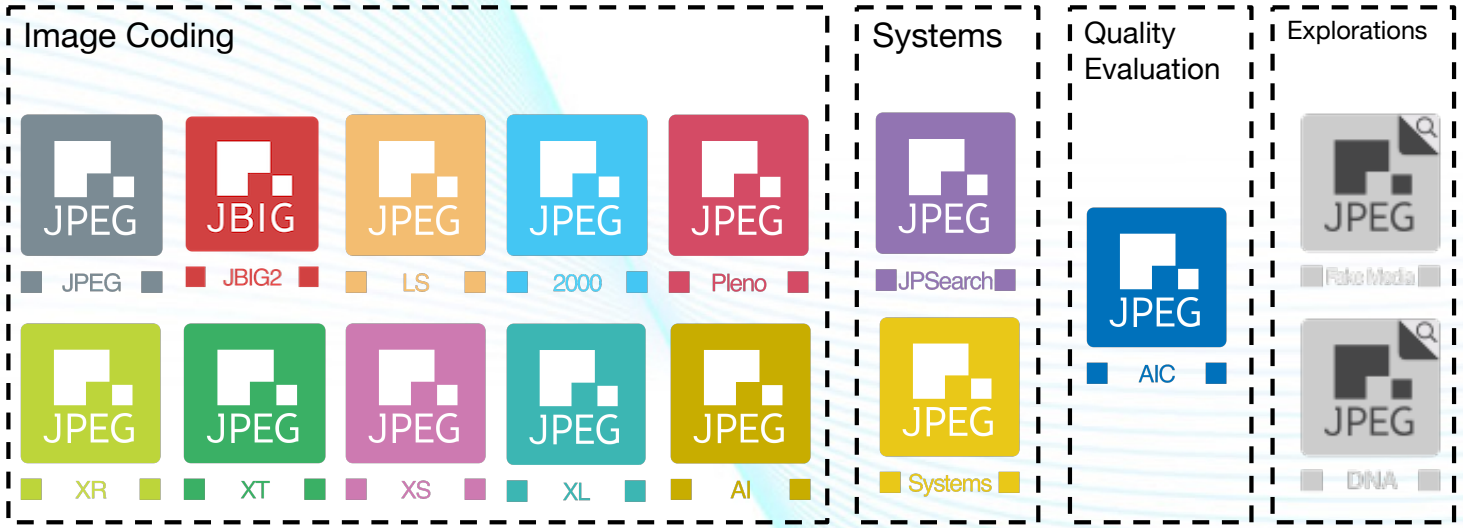
July 2021

Introduction to JPEG AI

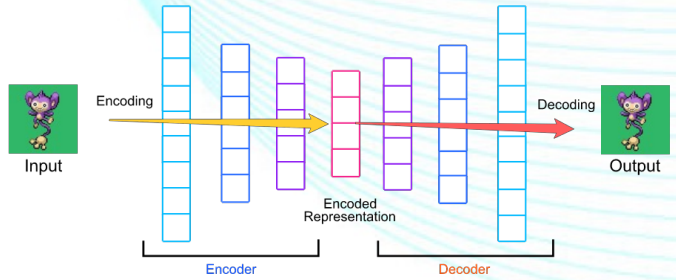
- What is JPEG?



JPEG family standards



- JPEG AI
  - Auto-encoder (as opposed to learning-based tools or components in conventional coding architecture)



JPEG AI History and Timeline

- **January 2019**: Establishment of an AHG on learning-based image coding as an Exploration activity
- **March 2019**: A first public report on state of the art in learning-based image coding
- **November 2019**: A first complete objective and subjective assessment of the state-of-the-art learning-based image coding
- **February 2020**: A Call for Evidence issued combined with the IEEE MMSP Workshop Grand Challenge
  - 6 codecs submitted (out of 8 registered)
- **October 2020**: Final report of the call for Evidence and decision to initiate JPEG AI as a New Work Item
- **January 2021**: A draft Call for Proposal.
- **April 2021**: Call for Proposal

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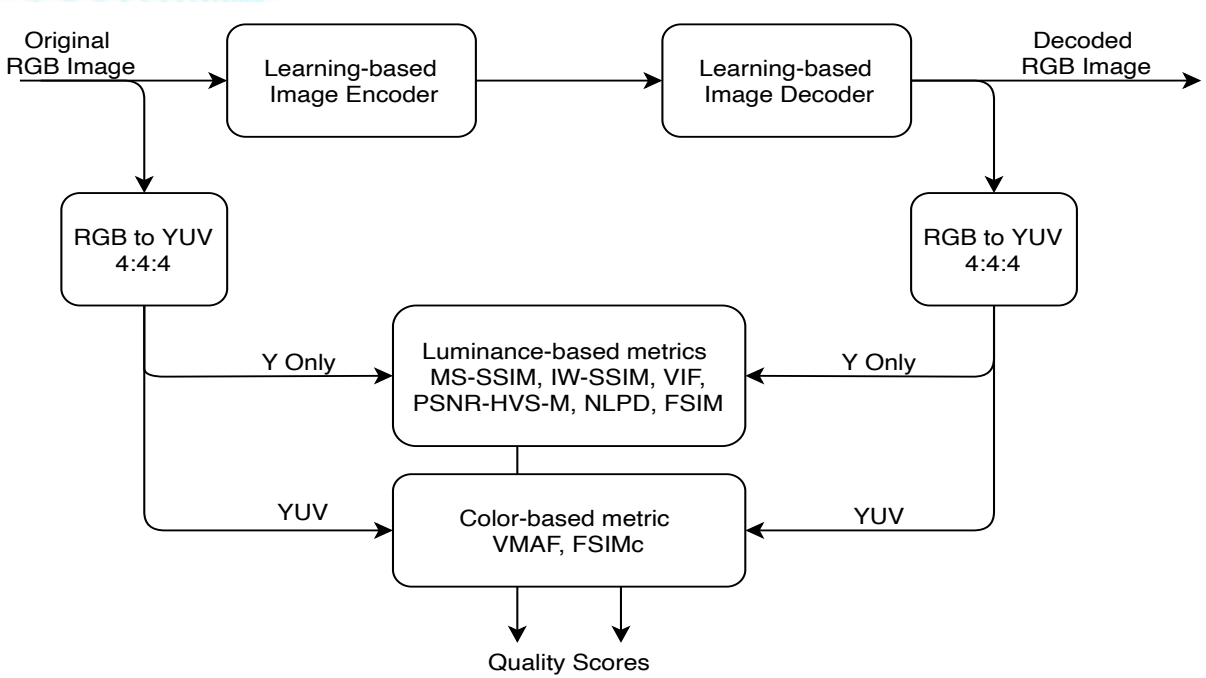
JPEG AI CfE Test Conditions

- Target rates (JPEG N90055)
  - bpp @ {0.06, 0.12, 0.25, 0.50, 0.75, 1.00, 1.50, and 2.00}
  - Max deviation <=15%
- Evaluation Procedure
  - Objective metric: MS-SSIM, VMAF, VIFP, NLPD, FSIM
  - Subjective evaluation:
    - Critical since the type of artifacts that learning-based image compression may be different from standard image codecs.
    - Double Stimulus Continuous Quality Scale with 5-point scale
    - Four bitrate points covering a wide range of qualities will be used



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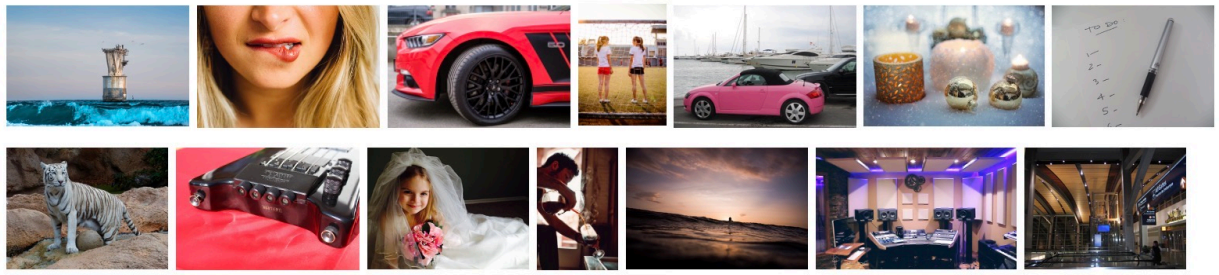
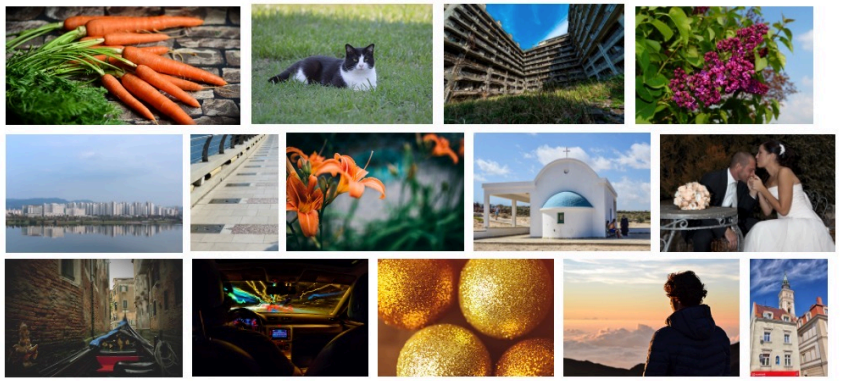
JPEG AI CfE Dataset

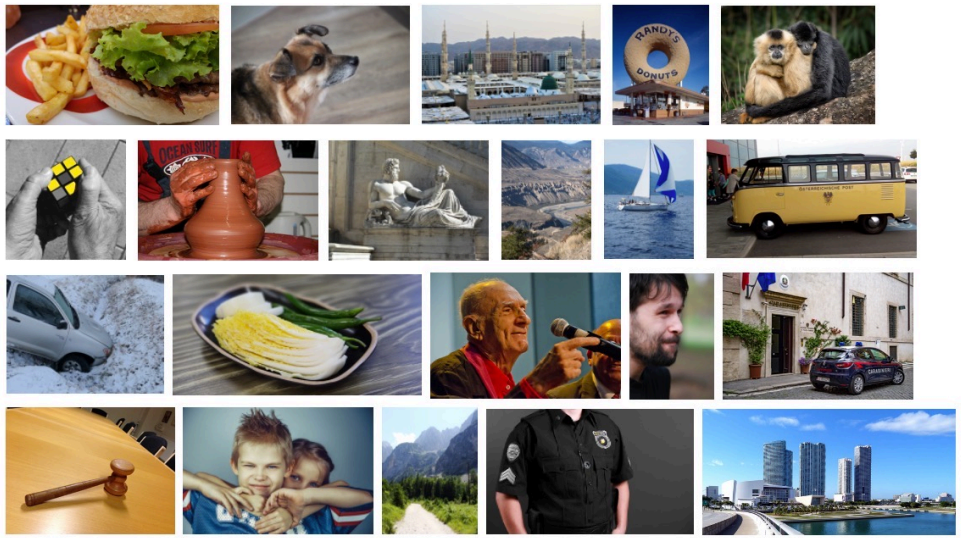
- Training/validation dataset (right)
  - PNG images (RGB)
  - 256×256 to 8K (8 bit) resolution
  - 5264/350 images (righ thand side)
- Test dataset (hidden during CfE)
  - PNG images (RGB)
  - 960x642 to 6016x4016 (8 bit) resolution
  - 40 images (below)



Validation set



Training set



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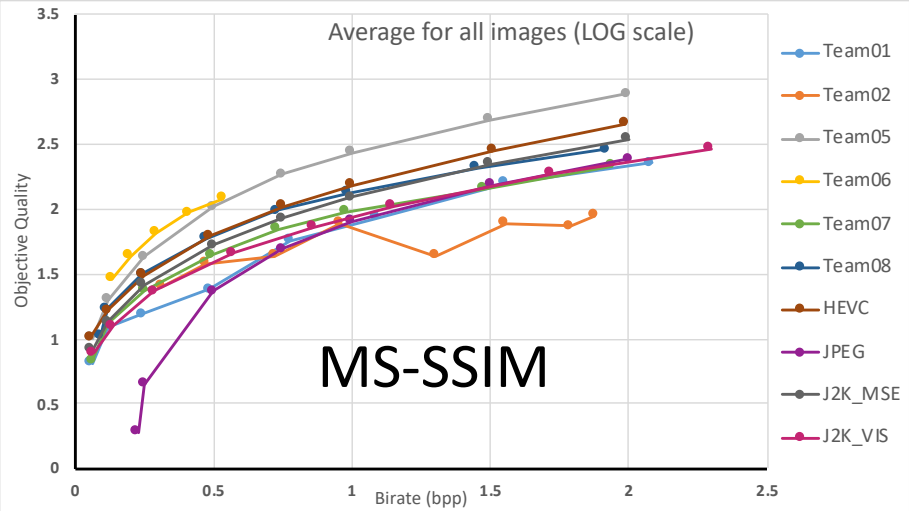
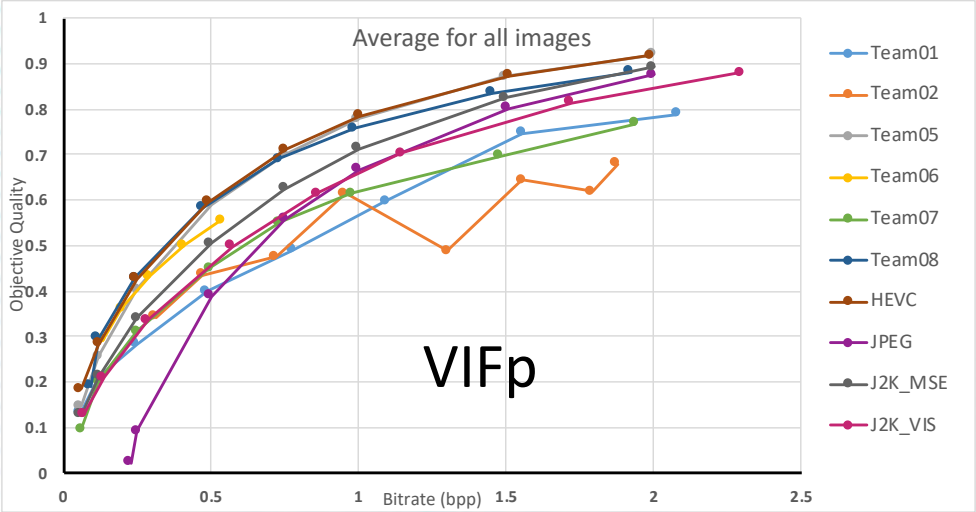
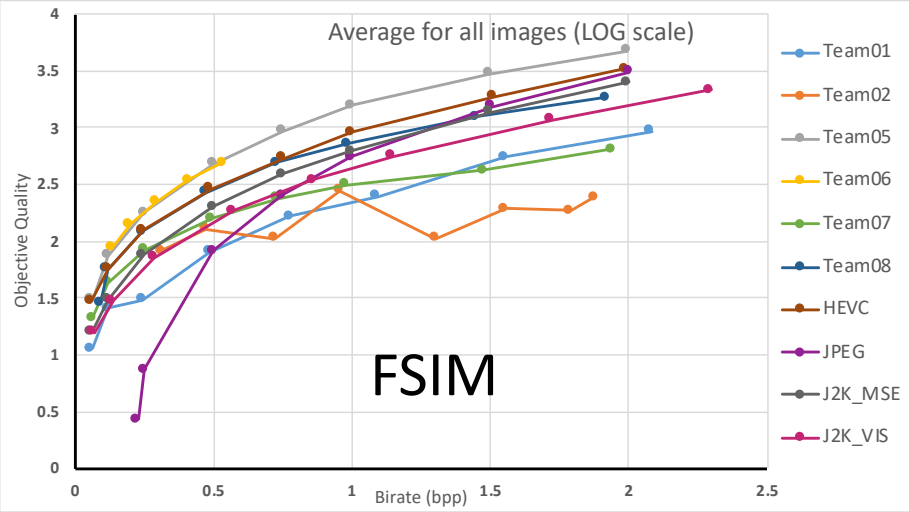
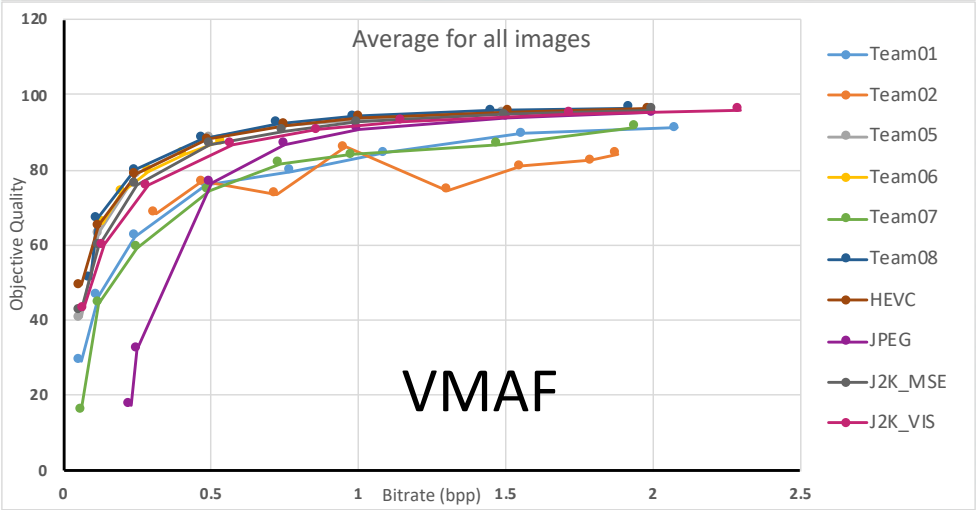
JPEG AI CfE Results (objective metrics)

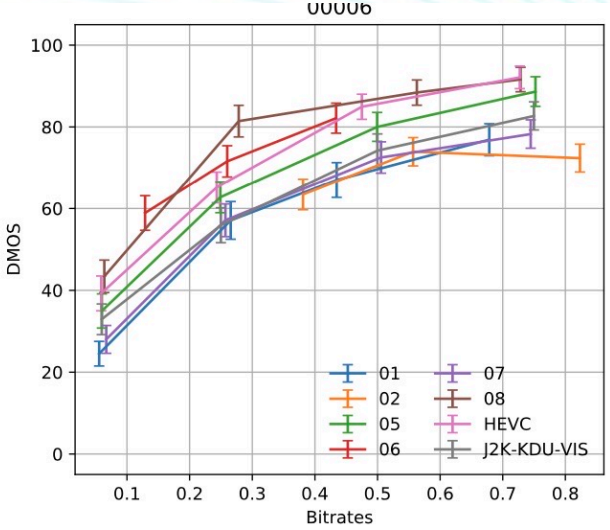


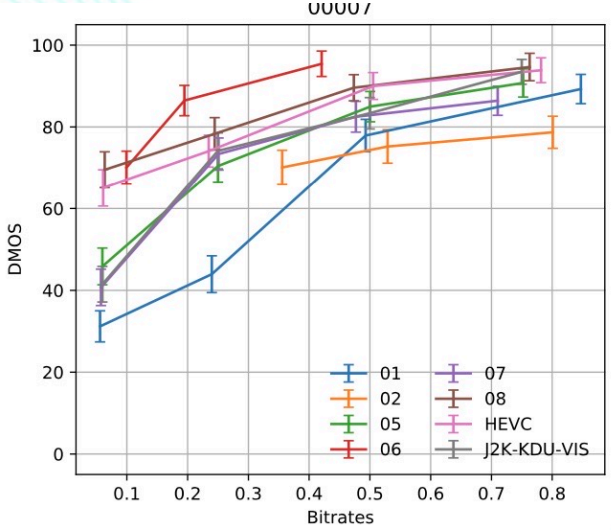


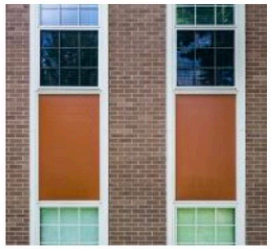


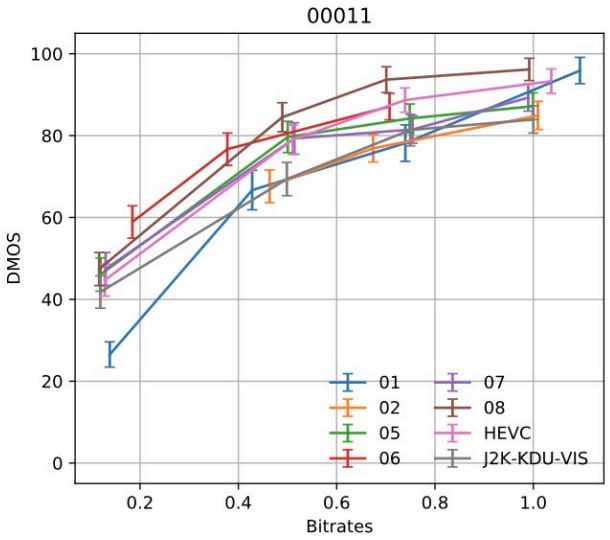


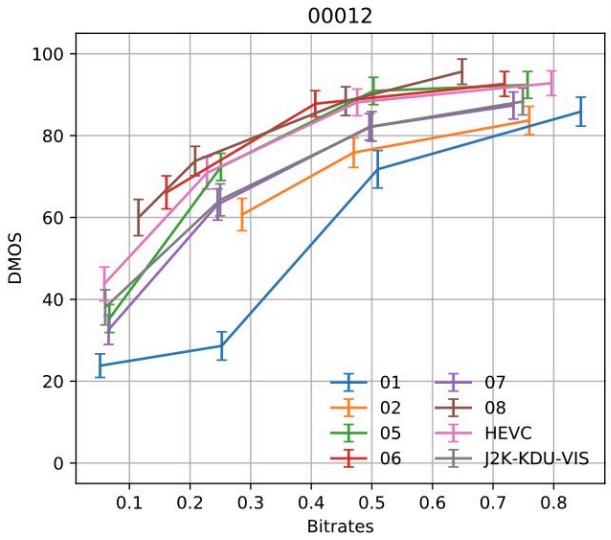
JPEG AI CfE Results (subjective metrics)

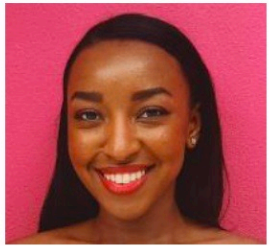




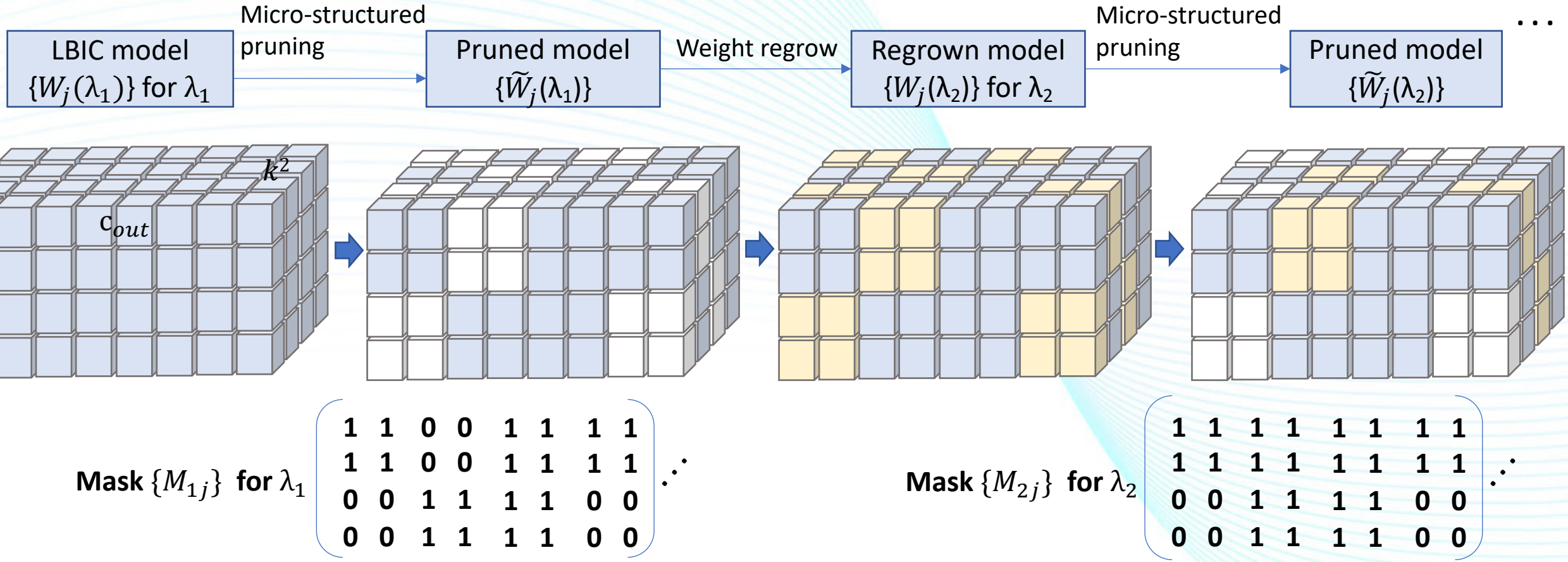








Variable Bit-rate Coding

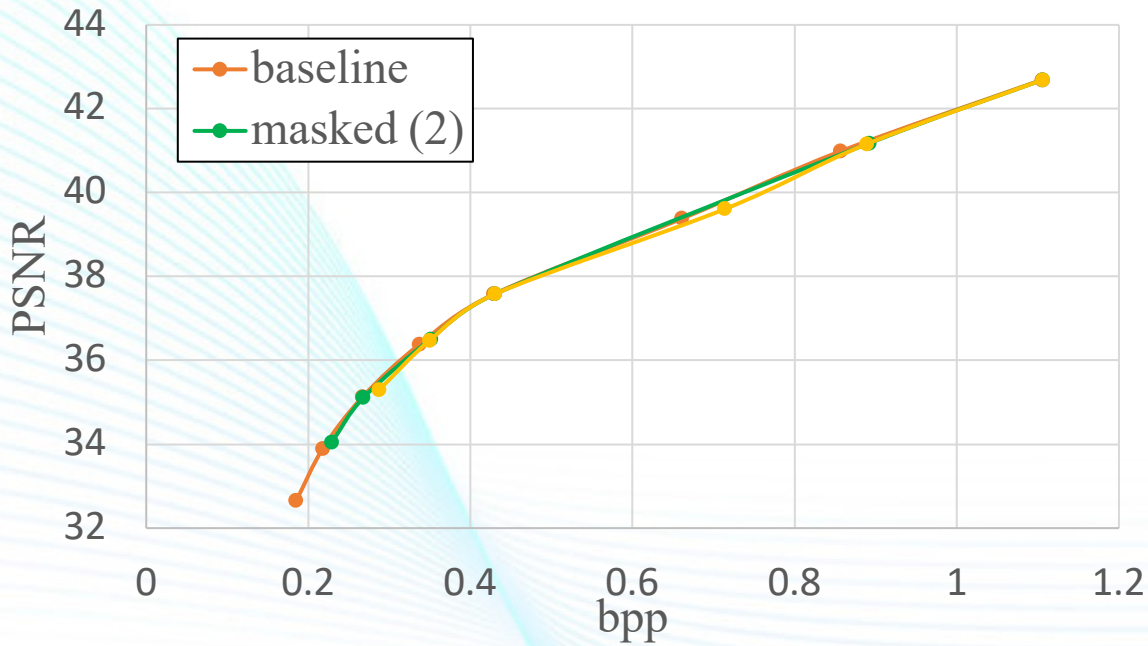


W. Jiang, et al. "Multi-Rate Learning-Based Image Coding with Micro-Structured Masks", ISO|IEC MPEG wg1, m89074, Oct. 2020.
W. Jiang, et al. "PnG: Micro-structured Prune-and-Grow Networks for Flexible Image Restoration", NTIRE 2021.

Results

2-task (bitrate) model
3-task (bitrate) model

Less than 1% performance drop
About 50% model reduction



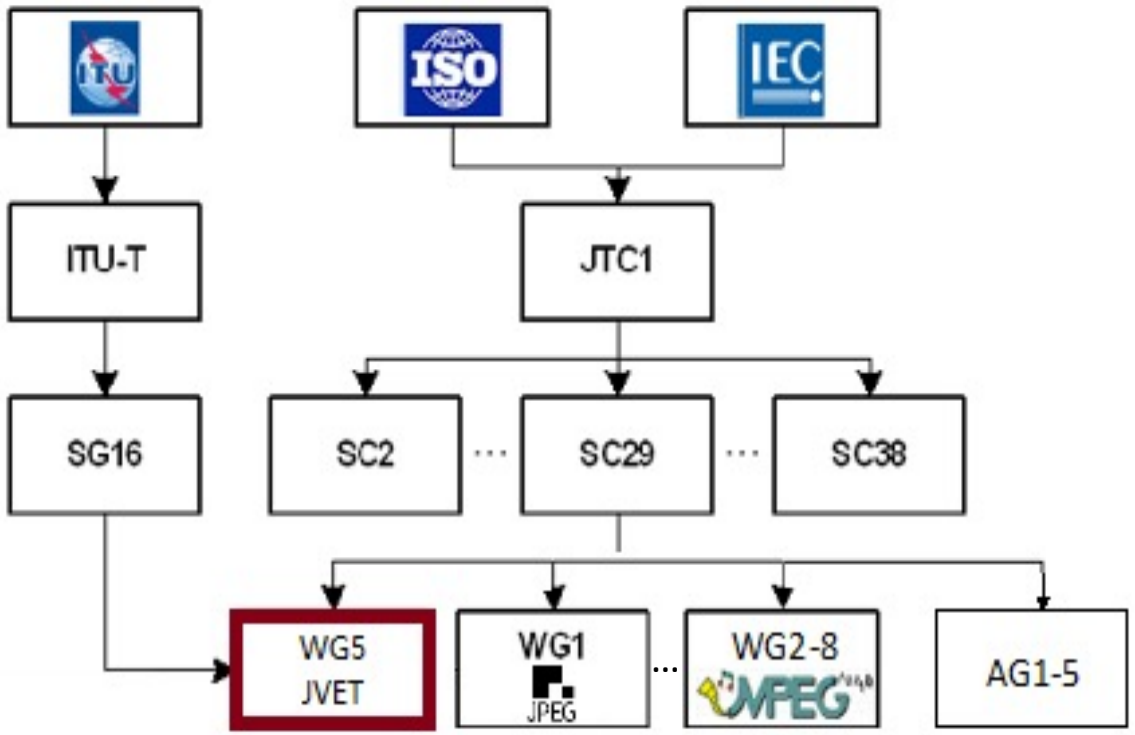
Statistics of model parameters

	# shared			# independent			# used		
λ	Baseline	masked (2)	masked (3)	baseline	masked (2)	masked (3)	baseline	masked (2)	masked (3)
0.18	0	10076160	10076160	11,816,323	1740163	1740163	11,816,323	11190151	1190151
0.0932	0	10076160	10076160	11,816,323	1740163	1740163	11,816,323	11,816,323	11644500
0.0483	0	10076160	10076160	11,816,323	1740163	1740163	11,816,323	--	11,816,323
0.025	0	4317184	4317184	5,075,843	758659	758659	5,075,843	4803991	4803991
0.013	0	4317184	4317184	5,075,843	758659	758659	5,075,843	5,075,843	504892
0.0067	0	4317184	4317184	5,075,843	758659	758659	5,075,843	4807175	5,075,843
0.0035	0	4317184	4317184	5,075,843	758659	758659	5,075,843	5,075,843	--
0.0018	0	4317184	4317184	5,075,843	758659	758659	5,075,843	--	--

W. Jiang, et al. “Multi-Rate Learning-Based Image Coding with Micro-Structured Masks”, ISO|IEC MPEG WG1, m89074, Oct. 2020.

Introduction to JVET NNVC

- What is JVET?
  - Joint Video Expert Team by ITU-T SG16 VQEG and ISO/IEC JTC 1/SG 29 MPEG WG5
  - Standard committee that has been responsible for H.266/VVC standardization
- ITU-T/SG 16 and ISO IEC JTC 1/SG 29 joint family standards, all based on conventional hybrid coding framework
  - H.262/MPEG-2 (1995)
  - H.264/MPEG-4 AVC (2003)
  - H.265/MPEG-H HEVC (2013)
  - H.266/MPEG-I VVC (2020)
- JVET NNVC (Neural-Network based Video Coding)
  - VVC is finalized in July 2020
  - NNVC to study and develop coding technologies beyond VVC's capacity using NN based coding tools



JVET NNVC History and Timeline

- **January 2018**: JVET established AHG9 to study NN based video coding tools.
  - More than 100 experts participated the AHG activities and proposed 40 contributions through the study.
  - NN based coding tools in a broad range of technology options were proposed, and coding performance improvement was demonstrated during the two-year study.
- **October 2018**: JVET established evaluation methodology for NNVC (JVET-L1006, JVET-M1006)
- **January 2019**: JVET established Core Experiment on NN based video coding (JVET-M1033, JVET-N1030)
- **June 2020**: JVET re-established AHG11 to study NN based video coding with the goal of developing a potential VVC extension supporting learning-based video coding tools.
- **October 2020**:
  - JVET established a common test condition (CTC) for NNVC (JVET-T2006, JVET-U2016).
  - JVET established Exploration Experiments on NN based video coding (JVET-T2023, JVET-U2023).

JVET NNVC Test Conditions

- Test sequences and conditions (JVET-U2016)
  - Class A~F for VVC development mandatory; class H (HDR) optional
  - VTM-11.0 as anchor
  - All Intra (AI), Random Access (RA) and Low Delay B (LDB) tested
  - CTC for VVC development
  - Config. 1 (hybrid structure): QP@{22, 27, 32, 37, 42}
  - Config. 2 (E2E structure): Each rate points to be within ±10% of the rates of the anchor QP @ {27, 32, 37, 42 }.

Class	Sequence name	Frame count	Frame rate	Bit depth	Intra	Random access	Low-delay
A1	Tango2	294*	60	10	M	M	O*
A1	FoodMarket4	300*	60	10	M	M	O*
A1	Campfire	300*	30	10	M	M	O*
A2	CatRobot	300*	60	10	M	M	O*
A2	DaylightRoad2	300*	60	10	M	M	O*
A2	ParkRunning3	300*	50	10	M	M	O
B	MarketPlace	600	60	10	M	M	M
B	RitualDance	600	60	10	M	M	M
B	Cactus	500	50	8	M	M	M
B	BasketballDrive	500	50	8	M	M	M
B	BQTerrace	600	60	8	M	M	M
C	RaceHorses	300	30	8	M	M	M
C	BQMall	600	60	8	M	M	M
C	PartyScene	500	50	8	M	M	M
C	BasketballDrill	500	50	8	M	M	M
D	RaceHorses	300	30	8	M	M	M
D	BQSquare	600	60	8	M	M	M
D	BlowingBubbles	500	50	8	M	M	M
D	BasketballPass	500	50	8	M	M	M
E	FourPeople	600	60	8	M	-	M
E	Johnny	600	60	8	M	-	M
E	KristenAndSara	600	60	8	M	-	M
F	ArenaOfValor	600	60	8	M	M	M
F	BasketballDrillText	500	50	8	M	M	M
F	SlideEditing	300	30	8	M	M	M
F	SlideShow	500	20	8	M	M	M
H2	DayStreet2	300	60	10	O	O	-
H2	FlyingBirds3	300	60	10	O	O	-
H2	PeopleInShoppingCenter2	300	60	10	O	O	-
H2	SunsetBeach3	300	60	10	O	O	-

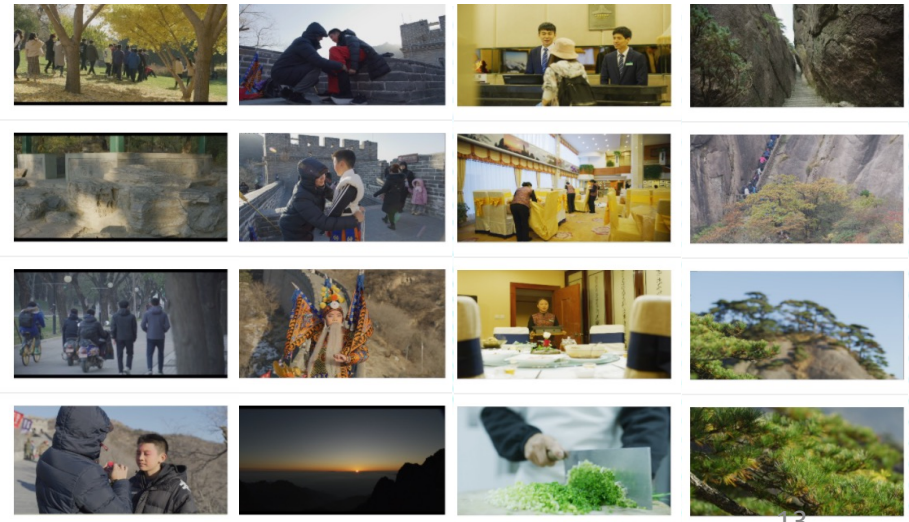
M: Mandatory; O: Optional

S. Liu, A. Segall, E. Alshina, R. Liao, "JVET common test conditions and evaluation procedures for neural network-based video coding technology", JVET-U2016, Jan. 2021.

JVET NNVC Dataset

- Training dataset
  - Candidate videos during VVC development
    - Various resolutions and durations
  - DIV2K (used in CVPR challenge)
    - 1000 images in 2K resolution, RGB format
  - BVI-DVC from University of Bristol
    - 200 different sequences.
    - Four resolutions of each content up to 4K; 65 frames each.
  - Tencent Video Dataset (TVD)
    - 86 different sequences; in 3840x2160 resolution; 65 frames each.
    - X. Xu, et al. “A video dataset for training in neural network based video coding”, JVET-U0116, Jan. 2021.
- Training conditions
  - A proposal may elect to use only a subset of the defined sequences if desired.
  - A proposal may also elect to sub-divide the set of defined sequences into different sub-sets.
  - The use of any additional sequences should be described in the contribution

Thumbnails of BVI-DVC videos



Thumbnails of TVD videos

JVET NNVC Complexity Evaluation

- Complexity Measurement
  - Platform information
  - Training information
  - Inference information
  - Encoder/Decoder runtime (CPU, GPU, combined)

Network Information in Inference Stage		
Mandatory	HW environment:	
	GPU Type	CPU only
	Framework:	Pytorch 1.2.0
	Number of GPUs per Task	0
	Total Parameter Number	22371
	Parameter Precision (Bits) in Float	32
	Memory Parameter (MB)	0.085338593
	MAC (Giga) per 3840x2160 pixels	186.64
Optional	Total Conv. Layers	13
	Total FC Layers	0
	Total Memory (MB)	
	Batch size:	1
	Patch size	
	Changes to network configuration or weights required to generate rate points	(e.g.)
	Peak Memory Usage	
	Other information:	

Network Information in Training Stage		
Mandatory	GPU Type	Intel Core i7-8700 3.20 GHz (6 cores), 32GB RAM and one 11 GB Nvidia GTX 1080Ti
	Framework:	PyTorch v1.4.0
	Number of GPUs per Task	1 Nvidia GTX 1080Ti was used for training
	Epoch:	300
	Batch size:	16
	Training time:	48h
	Training data information:	DIV2K still images
	Training configurations for generating compressed training data (if different to VTM CTC):	QP = 22, 27, 32, 37
Optional	Number of iterations	
	Patch size	64x64
	Learning rate:	1.00E-03
	Optimizer:	ADAM
	Loss function:	L1
	Preprocessing:	randomly cropped and rotated
	Other information:	

Y. Li, S. Liu, K. Kawamura, “Methodology and reporting template for neural network coding tool testing”, JVET-M1006, Jan. 2019.

S. Liu, A. Segall, E. Alshina, R. Liao, “JVET common test conditions and evaluation procedures for neural network-based video coding technology”, JVET-U2016, Jan. 2021.

JVET NNVC Tools and Experiments

- In JVET NNVC, the latest progress include both hybrid learning based coding tools, and end-to-end coding tools.
  - In-loop filter
  - Intra prediction
  - Inter-prediction
  - Super resolution
  - End-to-end coding
- Based on input contributions, JVET NNVC established the Exploration Experiments (EE) on NN-based video coding, to investigate commonly interested topics (JVET-T2023, JVET-U2023)

IEEE DCSC FVC

- The Future Video Coding Study Group (FVC-SG) under IEEE Data Compression Standard Committee (DCSC) started investigating deep learning-based image and video compression in 2019.
- **April 2020**: A Call for Evidence (CfE) has been issued. Seven teams registered and submitted results.
- **June 2020**: CfE results have been collected and evaluated.
- **November 2020**: FVC has released the reference software NIC-0.1 as an open-source package (GitHub: https://github.com/fvc-sg/NIC)
- **March 2021**: FVC has released the reference software NIC-0.2 with some updated features.

IEEE DCSC FVC Test Conditions

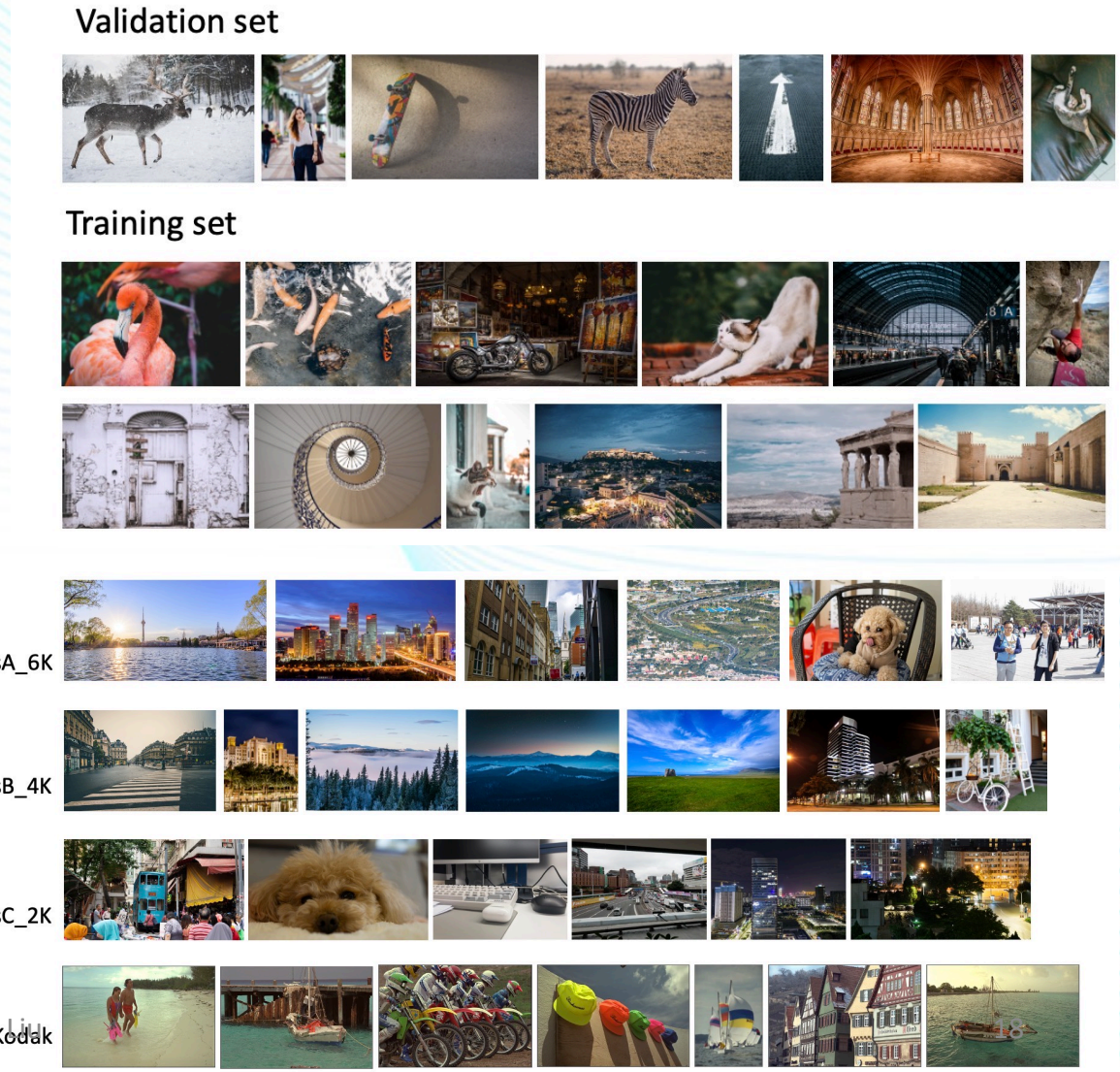
- Anchors
  - BPG (0.9.8), VVC (VTM-8.0 AI config.)
- Target bitrates
  - bpp @{0.06, 0.12, 0.25, 0.5, 1.0, 1.5}
  - Fix-rate model: use λ values in the loss function to train different models for MSE and MS-SSIM criteria
  - Variable-rate model: compress image to meet the 6 target bpp rates with max deviation <=5%
- Evaluation procedure
  - Objective assessment
    - For metrics: YUV 4:2:0 VMAF, RGB PSNR, RGB MS-SSIM (dB), YUV 4:4:4 PSNR, Y MS-SSIM (dB)
  - Subjective assessment
    - MOS from double stimulus protocol
  - Encoder/Decoder runtime
    - processor platforms should be specified

$$L = \lambda * D + R_{main} + R_{hyper}$$

Loss Criteria	λ value			
MSE	0.04	0.08	0.16	0.32
	0.64	1.28	3.20	6.40
MS-SSIM	2	4	8	16
	32	64	128	256

IEEE DCSC FVC Dataset

- NIC_Dataset is an open dataset
  - https://www.bitahub.com/dataset
- Training set
  - 607,714 256x256 patches, cropped from 1,600 original images and the 2x and 4x down-sampled versions
- Validation set
  - 169,798 256x256 patches, cropped from 293 original images and the 2x and 4x down-sampled versions
- Test set
  - 96 images with 4 different resolutions (ClassA_6K, ClassB_4K, ClassC_2K, ClassD_Kodak)



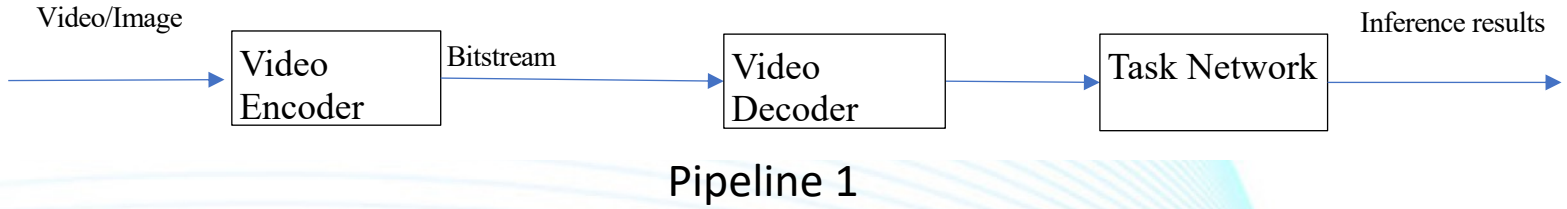
Discussion

- Complexity issue
  - Decoder runtime typically 30x~400x (with CPU) when compared to conventional solutions (JVET-U0023)
  - Lack of cost-efficient hardware support
- Model limitation
  - Network processing (such as Hyper prior) performs multiple down-sampling to extract features, which impose limitation on feasible block sizes
- Traditional coding method also shows promising results
  - 11% improvement over VVC can be achieved via conventional methods, with ~4x decoder runtime (JVET-U0100)

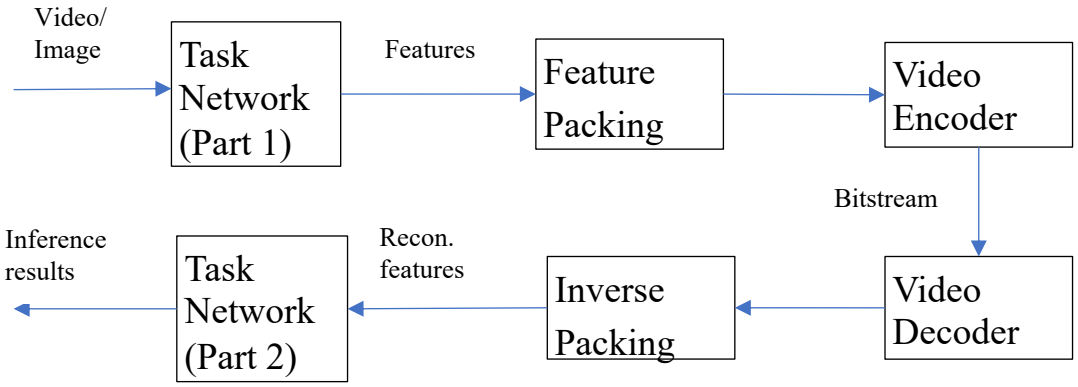
Related Work (1) Video Coding for Machines

- Due to emerging 5G and IoT technologies, an increased portion of video traffic will be consumed by machines leading to a variety of machine vision tasks such as
  - Object detection/segmentation/tracking, action recognition, etc.
- Machine vision differs from human vision in multiple aspects
  - Such as sensitivity, purpose, and evaluation metric
- Video coding for machines becomes an interesting and challenging problem
  - Traditional video codec may not compress video for machine vision efficiently
- MPEG has created an Ad-Hoc group called “VCM” in July 2019
  - To study use cases, requirements and standardization of VCM technologies
  - Call for Evidence has issued in January 2021

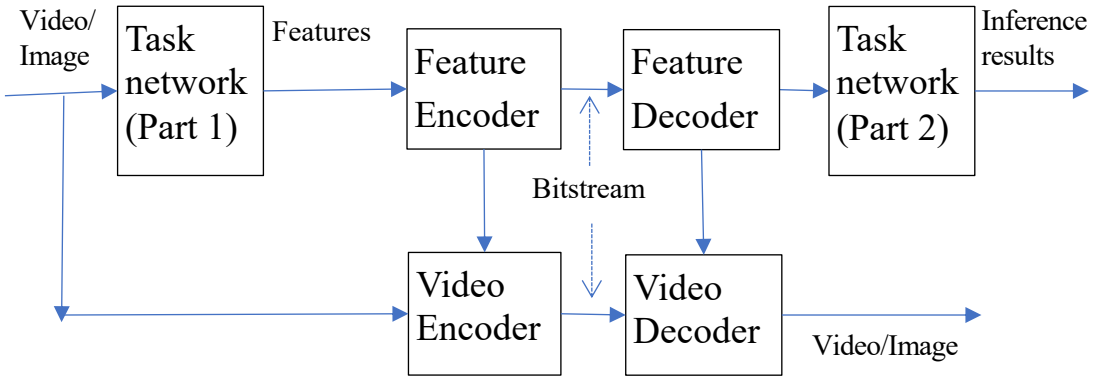
MPEG VCM Processing Pipelines



Pipeline 1



Pipeline 2



Pipeline 3

M. Rafie, Y. Zhang, S. Liu, “Evaluation Framework for Video Coding for Machines”, ISO/IEC JTC 1/SC 29/WG2 output document, N00041, January 2021, Online.

Related Work (2) Neural Network Compression

- MPEG has issued a CfP for Neural network compression in MPEG 125 meeting in January 2019.
  - To reduce model size, and enable model running on low power edge devices
  - The first part of the standardization has been completed (now in DIS).
- MPEG NNR
  - Combined structure pruning and unstructured sparsity
  - Micro-structured sparsity
  - Micro-structured unification
  - Low rank decomposition
  - Local scaling adaption
  - Uniform quantization
  - Dependent quantization
  - Entropy coding