Data
Compression
Conference

An Adaptive Intra-Frame Quantization Parameter Derivation Model Jointing with Inter-frame Analysis

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Outline

Data Compression Conference

- Background
- Pilot Experiments
  - -- *Quantization parameter and compression performance*
- Intra-frame & Inter-frame Analysis
  - -- *Modeling on frame reconstruction relevance*
- Bitrate Allocation Optimization
  - -- *An adaptive quantization parameter derivation model*
- Experimental Performance
  - -- *Compression comparison and bitrate curve variance*
- Conclusion & Outlook

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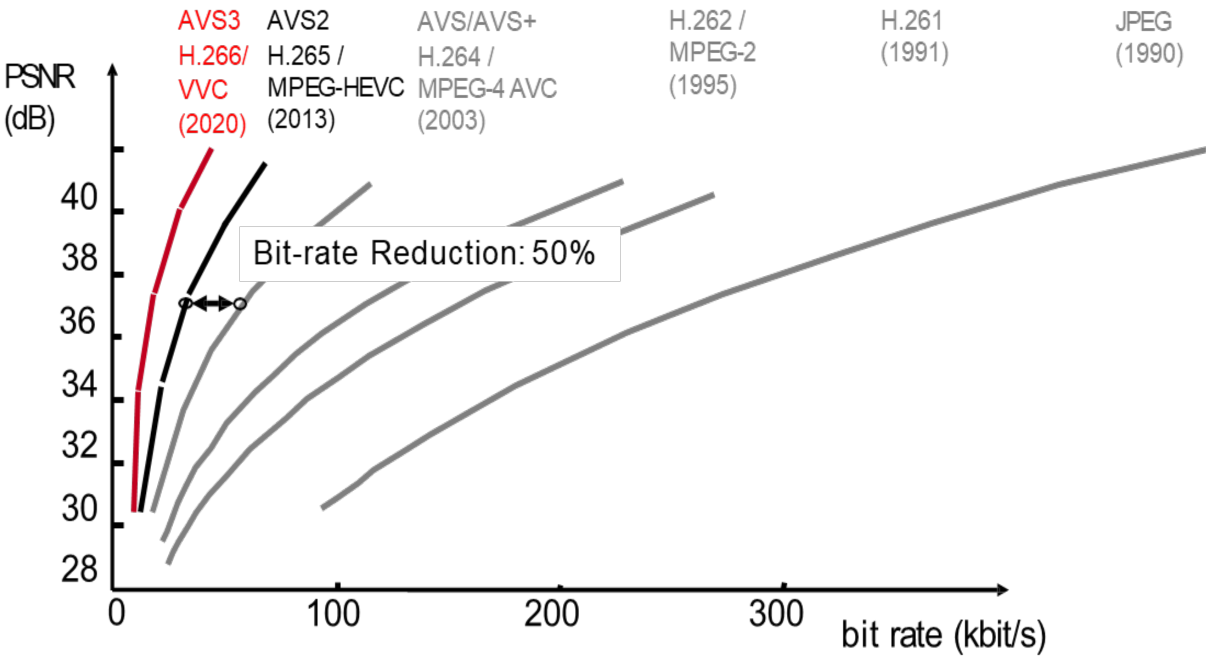
Background

- Demands drive technology evolution
  - Larger Resolution
  - Higher Dynamic Range
  - Denser Spatiotemporal Sampling Rate

Alliance for Open Media
An Alliance of Global Media Innovators
AVS
ISO JTC1 IEC
INFORMATION TECHNOLOGY STANDARDS
ITU International Telecommunication Union
AV1
AVS3
VVC

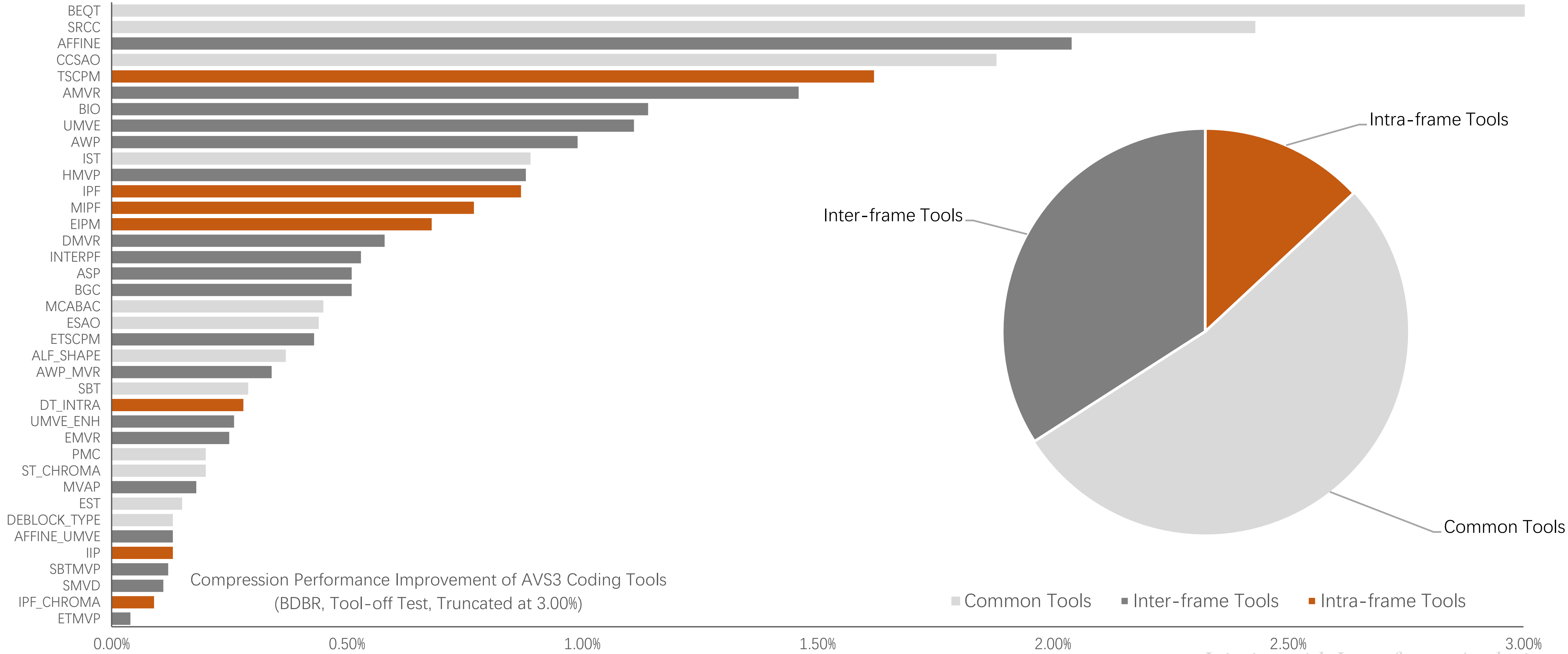
Background

- Demands drive technology evolution



Background

- Advanced technologies enlarge coding variance



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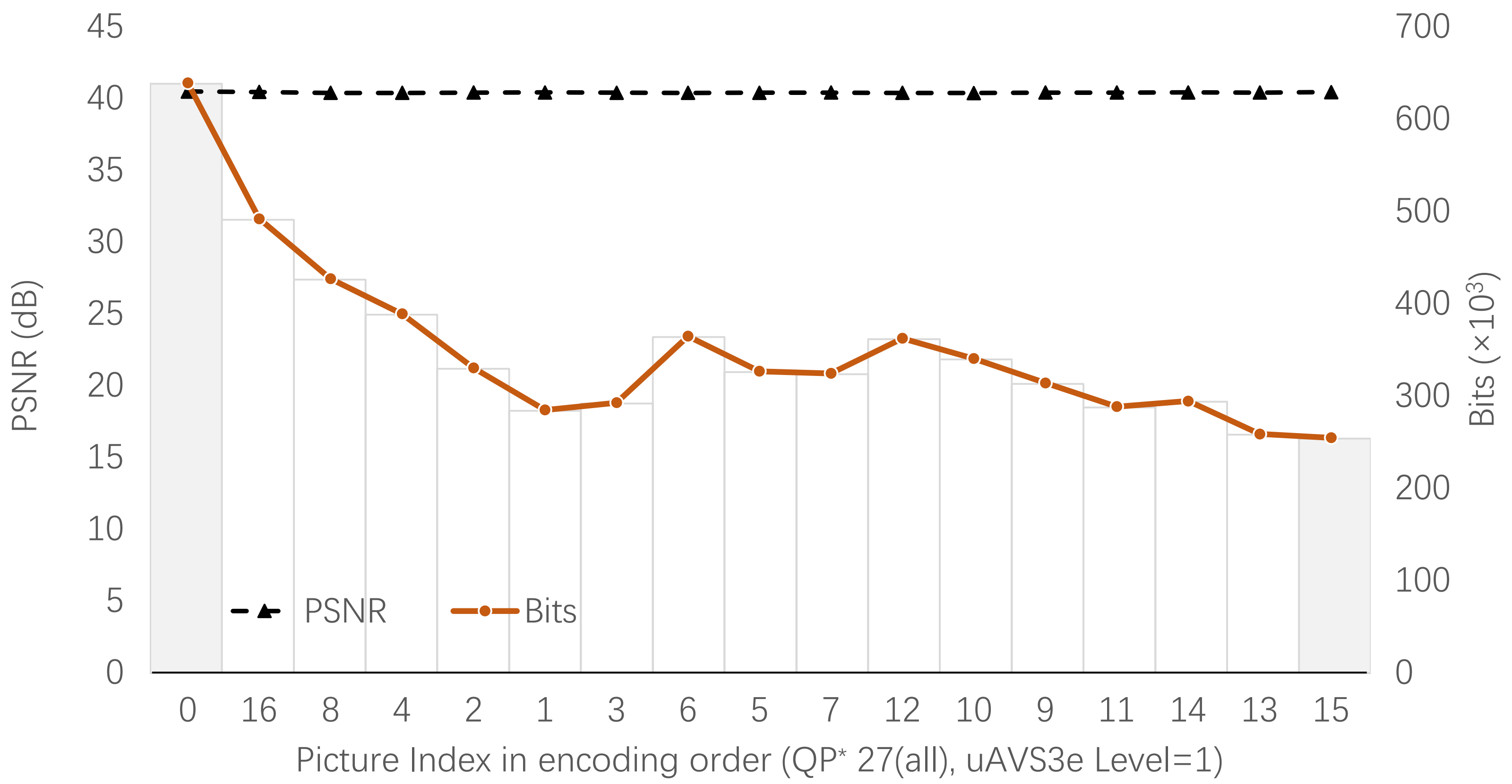

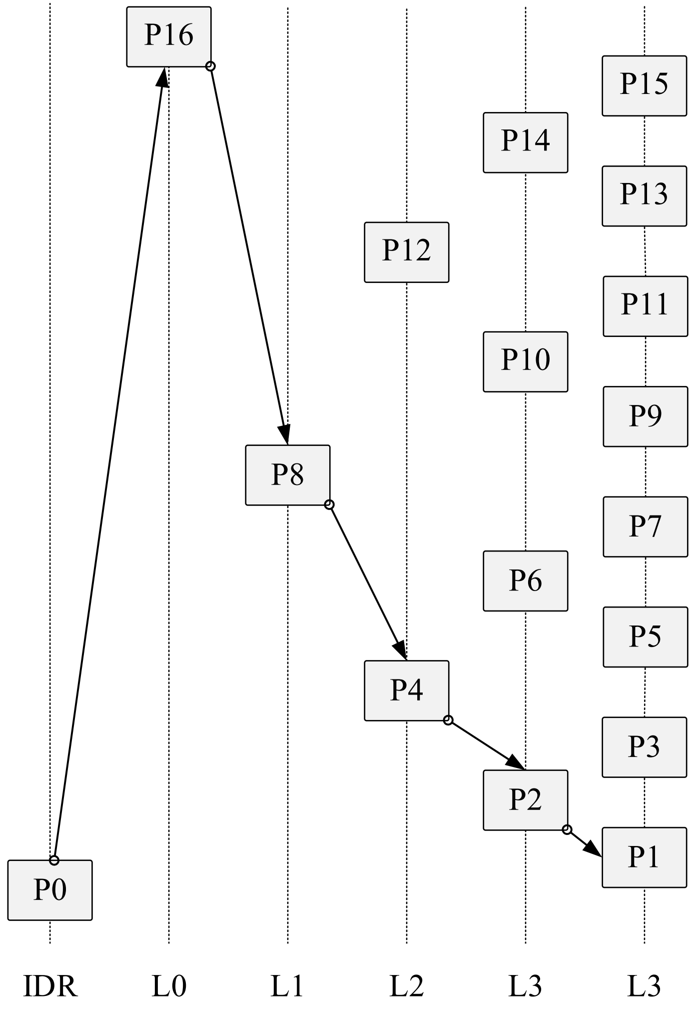

*QP: Quantization Parameter, refers to the step length in the uniform reconstruction quantization (URQ) model that has been widely used since H.264/AVC.

Background

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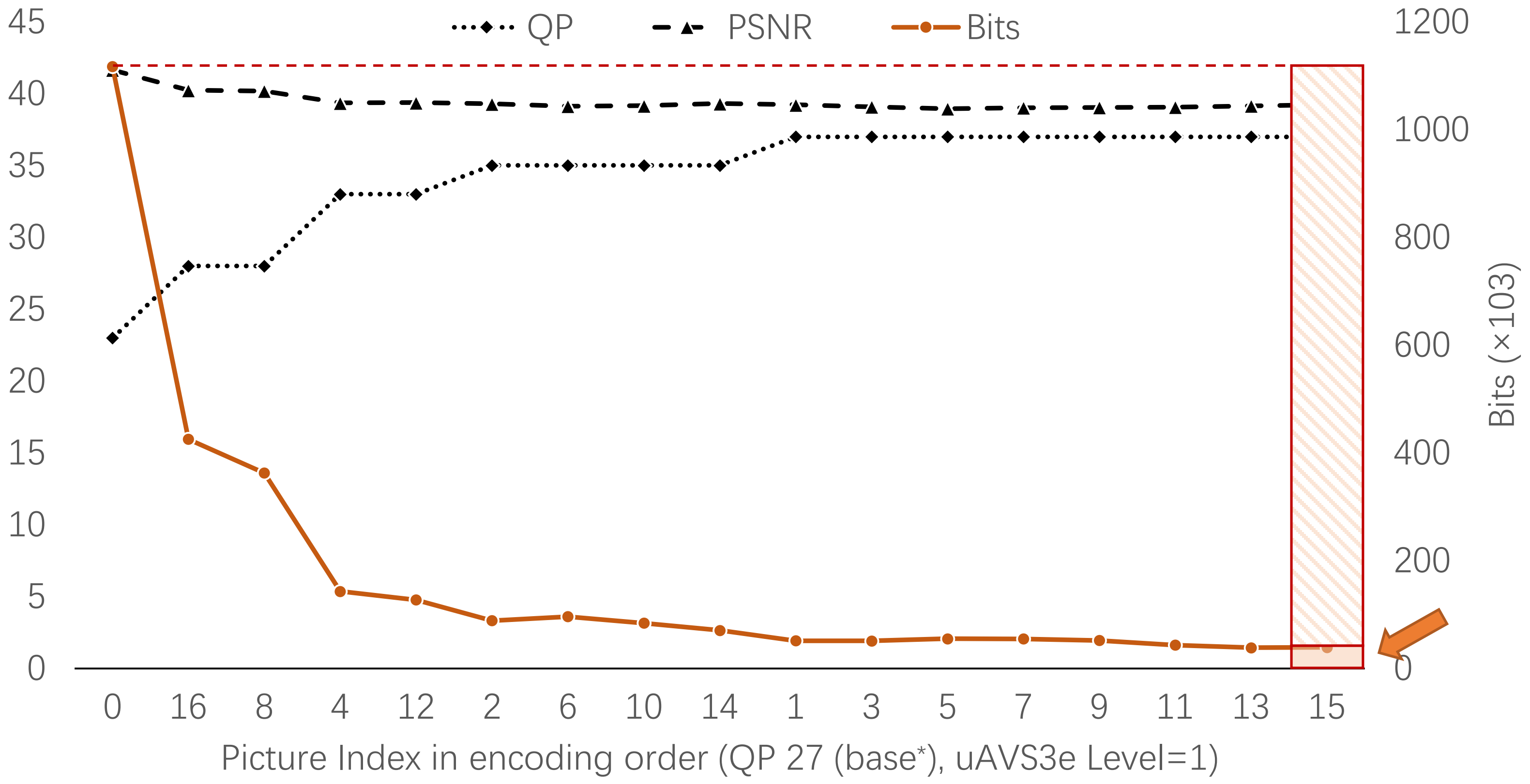

BasketballDrive 1920x1080

Frame	QP
0	23
8,16	27
4,12	33
6,10,14	35
otherwise	37

*Refers to the QP used to specify the basis for generating frame-QPs via certain offset strategy that generally recommended by its compression platform.

Pilot Experiments

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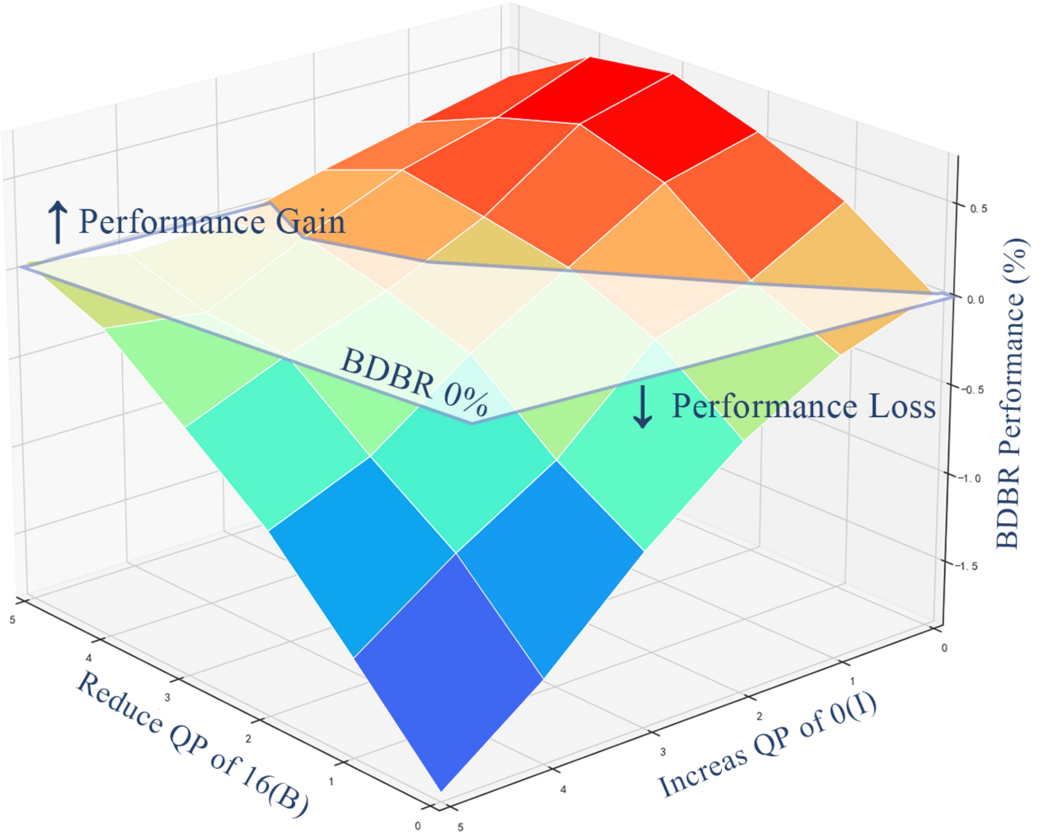
- A simple experiment of QP tuning
  - Using BDBR* as the performance metric. Redistribute bitrate on *RitualDance*.
  - Increase the QP of 0(I), i.e. reduce the encoding quality of key-frames.
  - Decrease the QP of 16(B), i.e. improve the bit allocation of top-layer B frames



Key-frames deserve high bitrates ?

*BDBR metric: Comparison of the bitrate required for encoding at the same objective reconstruction quality. A positive value means more bits are needed for the same peak signal-to-noise ratio (PSNR).

Pilot Experiments

- Appropriate bit allocation is essential for both rate control schemes and broadcast applications.

- In this paper:

  -- *The dependency enhancement that key-frames provide to subsequent B- frames will be discussed.*

  -- *An adaptive intra-frame QP derivation model is proposed jointing with Intra-frame & Inter-frame Analysis.*

  -- *A significant reduction in bit rate fluctuation is achieved with about a neutral overall impact on PSNR-based coding efficiency.*

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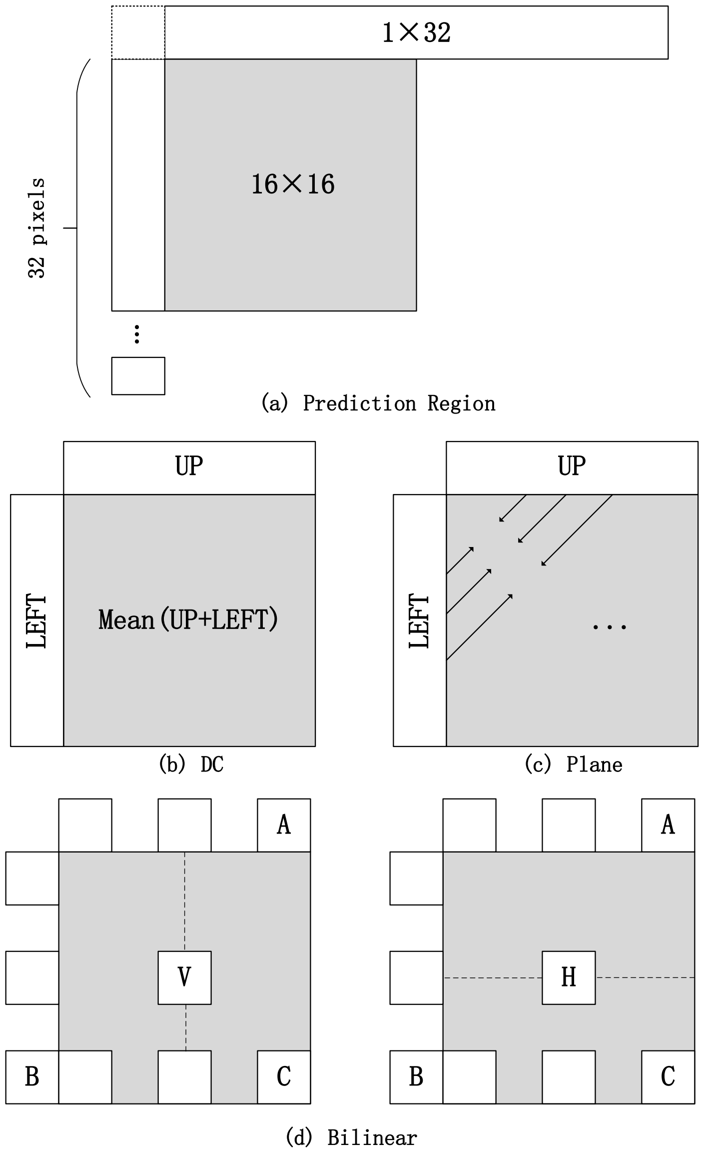
Intra-frame & Inter-frame Analysis

- Residual Simulation
  - Prediction → Residual → Energy (SAD)
  - Prediction Region:
    - 16×16 pixels as the basic prediction unit (PU)
    - 1×32 (top) and 32×1 (left) pixels as reference sources
  - Intra-frame Prediction Simulation :
    - Angular: 30°, 45°, 60°, 90°, 120°, 135°, 150°, 180°
    - DC, Plane, Bilinear
  - Inter-frame Motion Estimation Search:
    - Precision: 1×, 2×, 4×
    - Range: 8×8×PU diamond-shape



Intra-frame & Inter-frame Analysis

- Relevance Modeling
  - Residual Energy

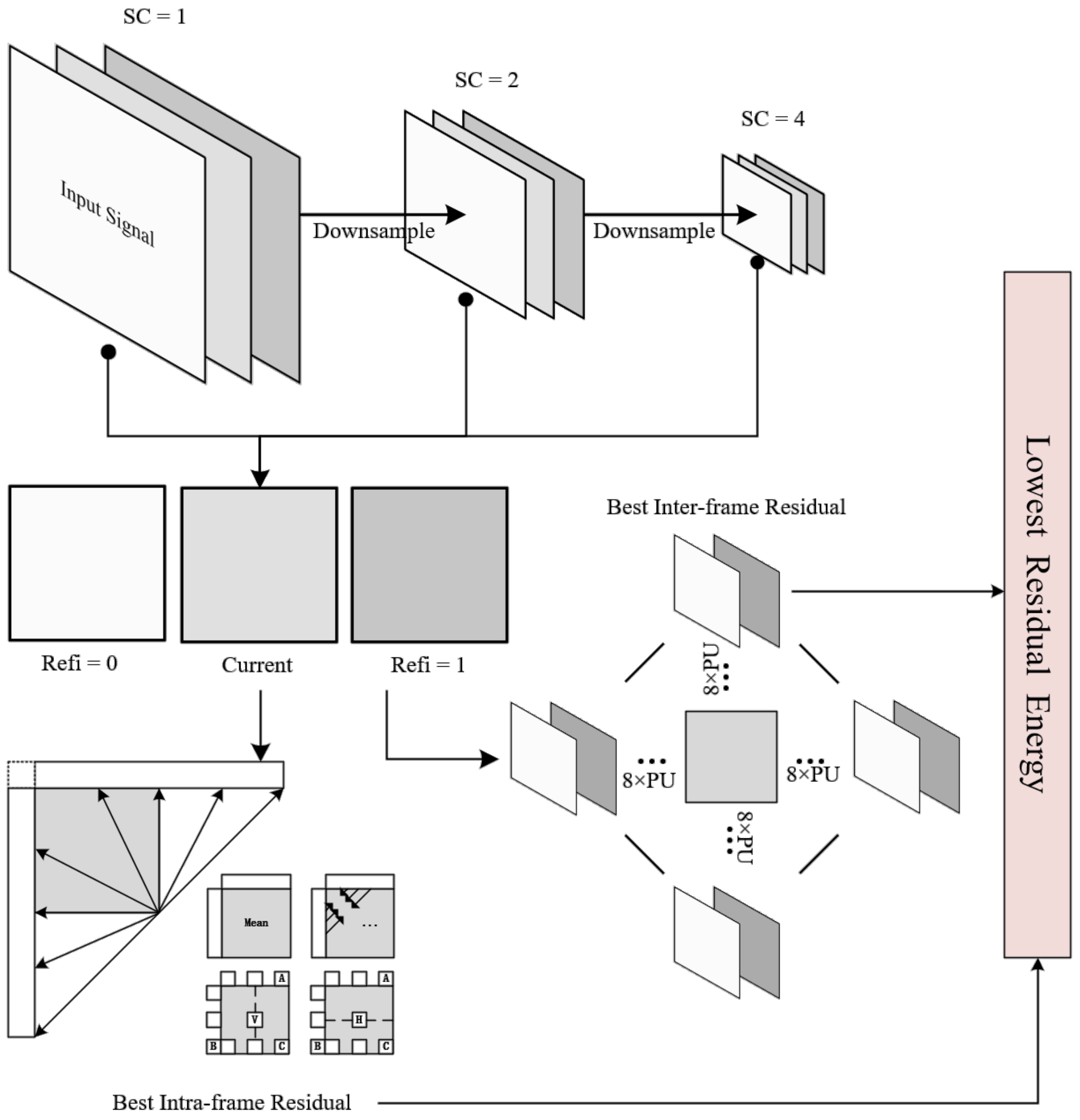
$$D(\theta) = \sum_{i=0}^{15}\sum_{j=0}^{15}|\hat{s}(i,j) - s(i,j)|$$

  - Best Prediction Mode

$$\theta^*_{inter,refi} = arg\min_{(sc,m,n)}\sum_{i=0}^{15}\sum_{j=0}^{15}|\hat{s}_{refi,sc}(m+i,n+j) - s(i,j)|$$

$$\theta^*_{intra} = arg\min_{\theta} D(\theta)$$

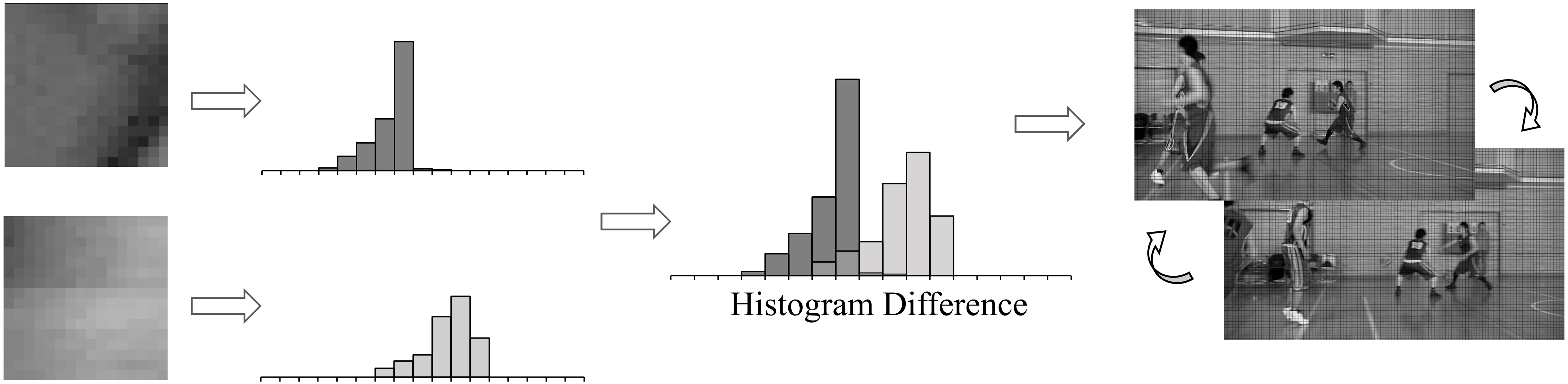
$$\theta^* = arg\min_{\theta}\{D(\theta^*_{intra}), D(\theta^*_{inter,0}), D(\theta^*_{inter,1})\}$$



Intra-frame & Inter-frame Analysis

- Pixel Distribution Characteristics
  - Histogram Statistics

$$B(k) = \sum_{i=0}^{15}\sum_{j=0}^{15} \mathbb{I}(s(i,j) = k) \qquad H(f_1, f_2) = \frac{1}{\Gamma}\sum_{k=0}^{\Gamma} |B(f_1, k) - B(f_2, k)| \qquad \Gamma = 2^{bitdepth - 1}$$



Bitrate Allocation Optimization

- Relevance Modeling
  - Frame similarity in histogram statistic

$$H(f_1, f_2) = \frac{1}{\Gamma}\sum_{k=0}^{\Gamma} |B(f_1, k) - B(f_2, k)|$$

  - Inter-frame prediction selection rate

$$R(f) = 1 - \frac{1}{N}\sum_{i=0}^{N-1} \mathbb{I}\left(\theta_{f,i}^{*} = \theta_{f,i,intra}^{*}\right)$$

  - Key-frame dependency rate

$$P(f) = \frac{1}{N}\sum_{i=0}^{N-1} \mathbb{I}\left(\theta_{f,i}^{*} = \theta_{f,i,inter,0}^{*}\right)$$

Bitrate Allocation Optimization

- Quantization Parameter Derivation

$$\mathrm{QP}(Layer) = \begin{cases} \mathrm{QP}_{base} + \Delta\mathrm{QP}(Layer) & , Layer \neq 0 \\ \mathrm{QP}_{base} + \Delta\mathrm{QP}(Layer) + \Delta\mathrm{IQP} & , Layer = 0 \end{cases}$$

Bitrate Allocation Optimization

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- Quantization Parameter Derivation

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$$\Delta\mathrm{IQP} = \mathrm{round}(\alpha \times \left(R(f_{16}) \cdot R(f_8) \cdot P(f_8)\right) + \beta \times \left(H(f_8, f_{16}) - H(f_0, f_8)\right) + \alpha \times \frac{H(f_0, f_{16})}{R(f_{16})})$$

Bitrate Allocation Optimization

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- Quantization Parameter Derivation

$$QP(Layer) = \begin{cases} QP_{base} + \Delta QP(Layer) & , Layer \neq 0 \\ QP_{base} + \Delta QP(Layer) + \Delta IQP & , Layer = 0 \end{cases}$$

$$\Delta IQP = \mathrm{round}\left(\alpha \times \left(R(f_{16}) \cdot R(f_8) \cdot P(f_8)\right) + \beta \times \left(H(f_8, f_{16}) - H(f_0, f_8)\right) + \alpha \times \frac{H(f_0, f_{16})}{R(f_{16})}\right)$$

tendency to depend on key-frames for inter-frame prediction

continuity-dependent effect of key-frames

key-frame bit allocation adjustment

midpoint offset of texture movement

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Experimental Performance

- Simulation Setup
  - Platforms:

    Encoder:

    - uAVS3e (*https://github.com/uavs3/uavs3e.git*) SHA: cd295084
    - Speed level 1; Default RA configuration; Follows AVS3 Common Test Condition

    Processor:

    - Intel(R) Core(TM) i9-10900K CPU @ 3.70GHz
    - 4 slots of 16G DDR4 RAM / 512 G SSD / No GPU limitation
    - Windows 10 20H2 / Visual Studio 2017 15.9.7

    Auxiliary Tools:

    - FFmpeg release version 4.0
    - Bjontegaard Metric implementation for Excel (xlsm) - *Tim Bruylants, ETRO, Vrije Universiteit Brussel, 2013*

Experimental Performance

- Dataset

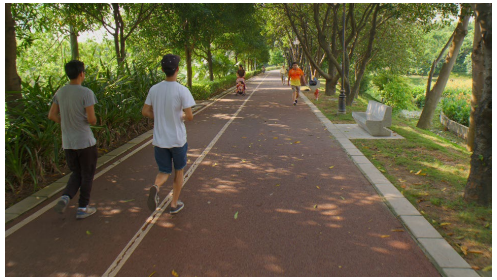
BasketballDrive
1920×1080
8bit 30fps

Cactus
1920×1080
8bit 30fps

RitualDance
1920×1080
10bit 60fps

MarketPlace
1920×1080
10bit 60fps

Campfire
3840×2160
10bit 30fps



ParkRunning3
3840×2160
10bit 50fps

DaylightRoad2
3840×2160
10bit 60fps

Tango2
3840×2160
10bit 60fps

Experimental Performance

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- QP Configurations

Sequence Name	Width	Height	D*	FPS	Frames	BaseQP	ΔIQP	IQP
BasketballDrive	1920	1080	8	30	60	27,32,38,45	6.06	33,38,44,51
Cactus	1920	1080	8	30	60	27,32,38,45	4.91	32,37,43,50
RitualDance	1920	1080	10	60	120	27,32,38,45	6.11	33,38,44,51
MarketPlace	1920	1080	8	60	120	27,32,38,45	3.82	31,36,42,49
Campfire	3840	2160	10	30	60	27,32,38,45	3.24	30,35,41,48
ParkRunning3	3840	2160	10	50	100	27,32,38,45	5.15	32,37,43,50
DaylightRoad2	3840	2160	10	60	120	27,32,38,45	3.29	30,35,41,48
Tango2	3840	2160	10	60	120	27,32,38,45	5.51	33,38,44,51

* D: bit depth, maximum number of valid bits for each pixel in each channel, $MaxBitDepth$

Experimental Performance

- Simulation Results

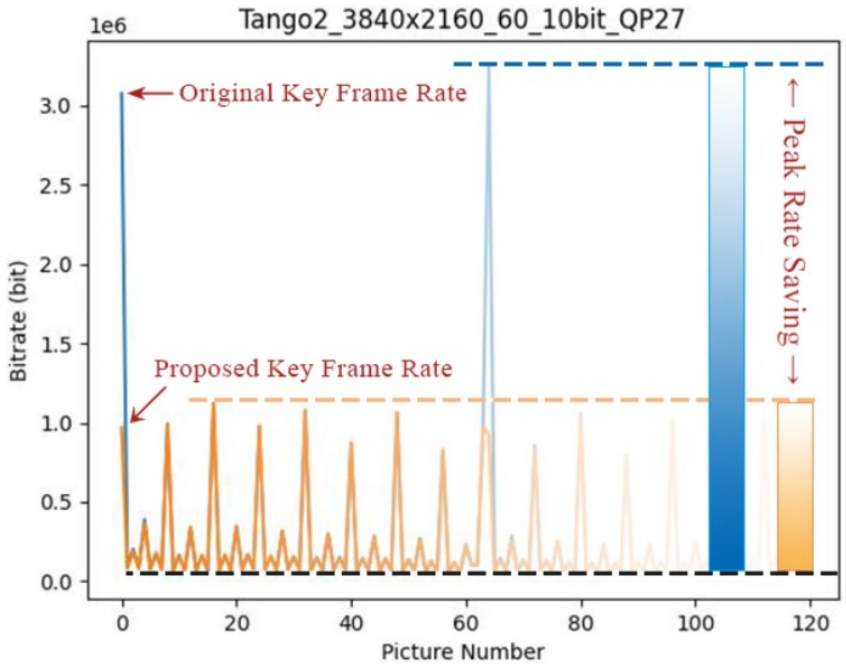
Sequence Name	Y	U	V	W
Tango2_3840x2160_60_10bit	-3.14%	0.84%	-1.18%	-2.35%
ParkRunning3_3840x2160_50_10bit	-3.69%	0.31%	0.81%	-3.02%
Campfire_3840x2160_30_10bit	-0.24%	-2.71%	1.01%	-0.54%
DaylightRoad2_3840x2160_60_10bit	-0.33%	8.66%	8.15%	1.71%
Cactus_1920x1080_30	1.04%	11.83%	10.84%	2.77%
BasketballDrive_1920x1080_30	-1.39%	3.22%	0.52%	-0.71%
MarketPlace_1920x1080_60	-1.82%	9.57%	11.44%	0.04%
RitualDance_1920x1080_60_10bit	1.39%	7.70%	5.61%	2.29%
Overall Performance	**-1.02%**	**4.93%**	**4.65%**	**0.02%**

$$W = \frac{1}{8} \times (6 \cdot Y + U + V)$$

Experimental Performance

- Simulation Results

Sequence	Original Bitrate (kb)			Propsed Bitrate (kb)			ΔR
	Max	Min	Δ	Max	Min	Δ	
BasketballDrive	732.67	16.64	716.03	397.78	16.46	381.32	46.75%
Cactus	1280.07	9.04	1271.03	731.96	9.00	722.96	43.12%
RitualDance	360.26	15.52	344.74	221.74	15.45	206.28	40.16%
MarketPlace	747.51	4.57	742.95	481.88	4.50	477.38	35.74%
Campfire	3498.94	266.34	3232.60	2459.87	266.23	2193.63	32.14%
ParkRunning3	5346.96	156.11	5190.85	3433.85	156.63	3277.22	36.87%
DaylightRoad2	3428.55	26.85	3401.70	1949.02	26.48	1922.54	43.48%
Tango2	1289.28	22.56	1266.72	567.45	22.91	544.54	57.01%
Average	**2085.53**	**64.70**	**2020.83**	**1280.44**	**64.71**	**1215.74**	**41.91%**



Outline

Conclusion & Outlook

- This paper proposes an adaptive quantization parameter offset model, which achieves a significant reduction in bitrate fluctuations without affecting the overall compression performance.

- Mentioned results indicate that the dependency of keyframes in the Random Access structure is not irreplaceable. Excessive keyframe bitrate may not necessarily lead to positive effect in the evolving coding standards.

- This paper may hopefully provide new inspiration for bitrate allocation schemes. Its effectiveness in realistic bitrate control frameworks is under evaluation.

Thanks

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