INHERITABILITY-INSPIRED INTRA CODING OPTIMIZATION FOR AVS3

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ABSTRACT

AVS3 is an emerging video coding standard developed by Audio Video Coding Standard (AVS) Working Group of China. Many new coding tools were introduced into AVS3 and achieved promising coding performance improvement, however, with dramatical encoding time increase. Particularly, the complexity of intra prediction is nine times higher than that of the previous video coding standard, AVS2. In this paper, an inheritability-inspired intra coding optimization method is proposed. The proposed scheme fully explores the intrinsic prediction relationship of different prediction units firstly. Then adaptive early termination scheme of IPF process and elimination of partial intra modes are proposed to accelerate the intra coding. Experimental results show that the proposed method can achieve 30% encoding time saving on average with only 0.43% BD-rate increase in All Intra (AI) configuration compared with AVS3 reference software (HPM5.0).

Index Terms— AVS3, intra coding optimization, Intra-DT, IPF

1. INTRODUCTION

AVS3 is a new video coding standard developed by AVS working group to adapt the growing demand for Ultra High Definition (UHD) [1]. AVS3 was officially initiated in March 2018, and the target is to save 50% bitrate with almost the same subjective quality compared to its predecessor video coding standard, AVS2. Currently, AVS3 phase-1 (HPM4.0, reference software of AVS3[*]), which has been finalized in March 2019, can achieve almost 30% coding performance improvement compared to HEVC/H.265.

Intra coding is a vital module in the video coding framework, such as HEVC, AVS2, as well as AVS3. Newly adopted intra coding tools in AVS3 highly contribute to the coding efficiency while complicating the codec and hindering the application. Considering the great importance and high complexity of intra prediction, extensive researches have been done on the simplification of it since AVC/H.264. Statistic-based and content characteristic based fast intra decision methods were usually utilized to reduce the intra coding complexity. For statistic-based algorithm, [2][3][4] proposed a method to skip some prediction modes which are rarely used in the parent coding unit (CU) of the upper depth levels or spatially adjacent CUs. There are two disadvantages of this method, one is that the method ignores the varied texture in an image between the current block and their neighboring blocks which may lead to large performance loss, the other is that partition structure in different video coding standards may introduce more types of CU shape and size, which reduces the correlation between the current and adjacent blocks and harms the portability and robustness of the algorithm. For content characteristic based fast intra coding method, variance and gradient are often chosen as the feature. [5][6][7][8] proposed the method based on the gradient and variance to decide the intra prediction direction. Although some methods achieved a good trade-off between coding performance loss and complexity reduction, these methods were designed for previous standards (AVS2 and HEVC), which are unsuitable for the partition structure in AVS3. Moreover, none of these methods considered the relationship between different prediction units (PUs) belonging to the same CU. Based on this consideration, we design an algorithm to make full use of the correlation between these new features introduced into AVS3 and take intermediate information obtained from previously coded CU into account. The contributions of this paper mainly lie in the following aspects:

- An intrinsic relationship based intra modes pruning method for Intra Derived Tree (Intra-DT) is proposed. The correlation between different PUs in the same CU is explored and some intra modes are skipped.
- An intermediate information based fast IPF decision algorithm is proposed. The Intra Prediction Filter (IPF)

[*]ftp://47.93.196.121, AVS3 reference software

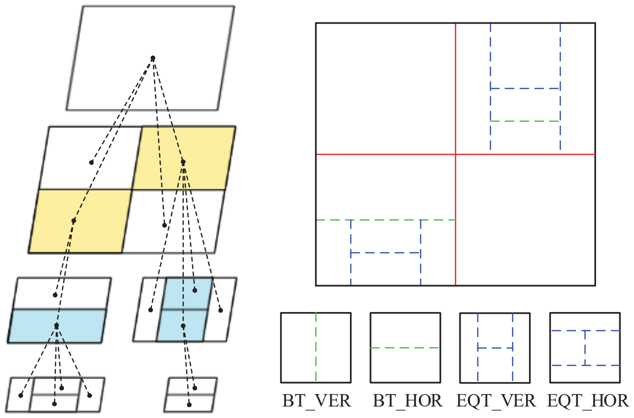


Fig. 1. Example of QTBT plus EQT partition scheme

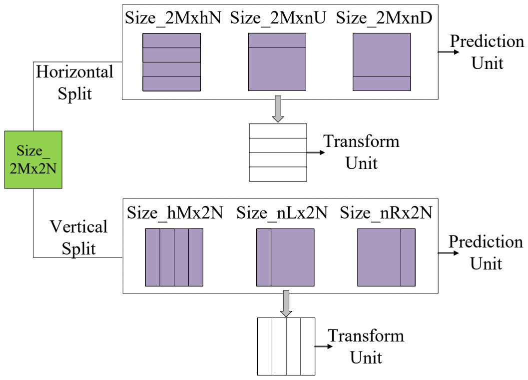


Fig. 2. Intra Derived Tree (Intra-DT)

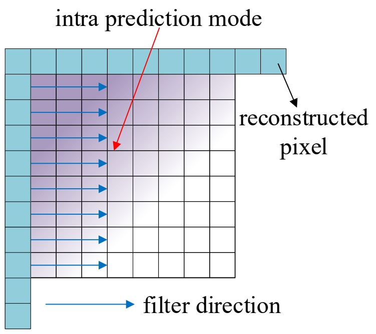


Fig. 3. Intra Prediction Filter

process can be early terminated adaptively based on the intermediate information.

The rest of this paper is organized as follows. Section 2 briefly introduces the intra coding of AVS3. The analysis and proposed method are described in Section 3 and Section 4 in detail. Experimental results are shown in Section 5. Finally, we conclude this paper in Section 6.

2. INTRA CODING IN AVS3

2.1. Block partition

The block-based hybrid video coding framework has been recognized as the core of the state-of-the-art video coding standards, such as H.265/HEVC and AVS2. To further improve the flexibility of block partition, AVS3 adopts a more flexible block partition scheme including quad tree nested binary tree (QTBT) and extended quad-tree (EQT) as shown in Fig. 1. The newly adopted partition scheme can improve the subjective and objective performance significantly.

2.2. Intra coding tools

Besides QTBT plus EQT block partition scheme, intra coding tools including Intra-DT and IPF are introduced to improve the prediction accuracy and get better subjective and objective quality. These coding tools bring promising coding performance, while improve the complexity of encoder dramatically.

As shown in Fig. 2, Intra-DT is a coding method which is applied only to intra CU and it can split a CU into two or four PUs horizontally or vertically according to the split type. Transform unit (TU) will also be forced to split according to the split direction. Intra-DT is suitable for rich texture areas and can maintain more detail of the current block. Another intra coding tool, IPF, aims to promote the accuracy of intra prediction by using the reference samples to refine the pixels of the current block, as shown in Fig. 3. The reference pixels are used to perform the refinement operation of the current block's pixels located on the top and left. IPF is only used on the PU with size equal to SIZE_2Mx2N which means that the Intra-DT derived PU doesn't use IPF. Besides intra-DT and IPF, implicit selection of transform (IST) [9] is designed to introduce more transform cores and achieve better energy compaction of the residual signals. For chroma coding, two step cross-component prediction mode (TSCPM) [10] is adopted, which assumes the linear correlation between luma sample and chroma sample in AVS3.

2.3. Intra coding process in HPM

Two-pass prediction process has been used in HPM5.0, as shown in Fig. 4. In the first pass, the PU with size equal to SIZE_2Mx2N will perform intra prediction firstly, followed by the Intra-DT derived PU. IPF is not performed in the first pass. In the second pass, IPF will be performed, only PU with SIZE_2Mx2N will be tested with IPF to decided whether to use IPF or not. Rough Mode Decision (RMD) is also applied in HPM5.0 to select five intra modes with minimum SATD

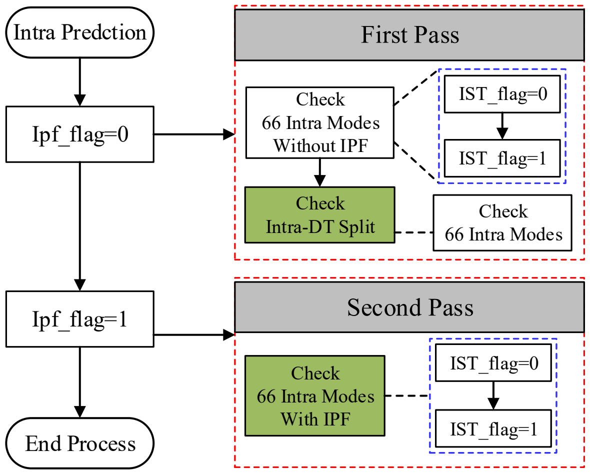


Fig. 4. Intra Prediction Process

Table 1. Test conditions

Sequences	BasketballDrive, RitualDance
Quantization Parameter (QP)	27, 32, 38, 45
Configuration	All Intra (AI)
Sequence Frame	600

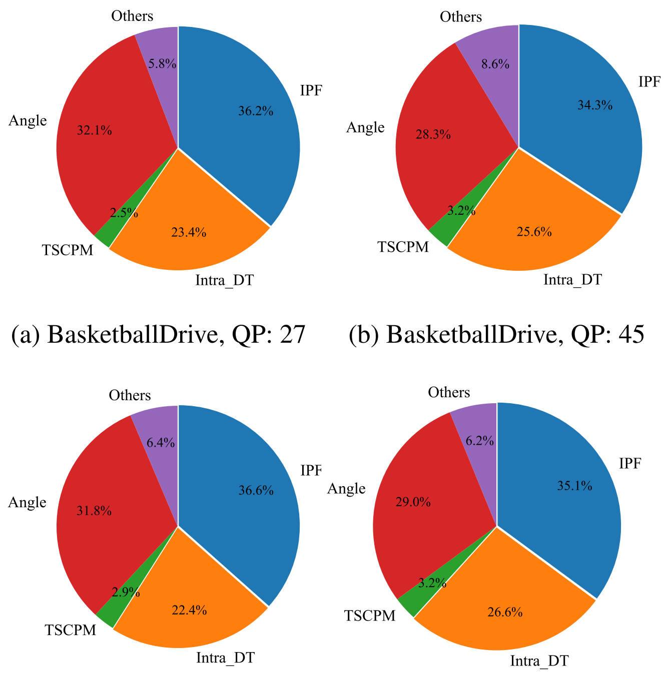
cost from the pre-defined 66 intra modes and the selected five intra modes are used to generate a full RDO candidate list in intra prediction.

3. ANALYSIS OF INTRA CODING IN AVS3

To reduce the computational complexity of intra prediction in AVS3, we statisticed and analyzed the coding time distribution of main coding tools firstly. Then, we investigated the relationship among intra modes, PU and two-pass intra prediction to find the appropriate intra coding optimization method.

3.1. Motivation

To investigate the coding time distribution in HPM, two video sequences are tested with HPM5.0. The test condition is shown in Table 1. The analysis results are summarized in Fig. 5, in which show the coding time distribution among different intra prediction coding tools. The part marked with *Others* in Fig. 5 represents entropy coding and in-loop filters. *Angle* denotes the time of intra prediction with the PU size equal to SIZE_2Mx2N. It should be noted that the coding time distribution of intra prediction does not include IST since IST is a tool used in transform module. From Fig. 5, it



(a) BasketballDrive, QP: 27 (b) BasketballDrive, QP: 45

(c) RitualDance, QP: 27 (d) RitualDance, QP: 45

Fig. 5. Time proportion of intra coding tools.

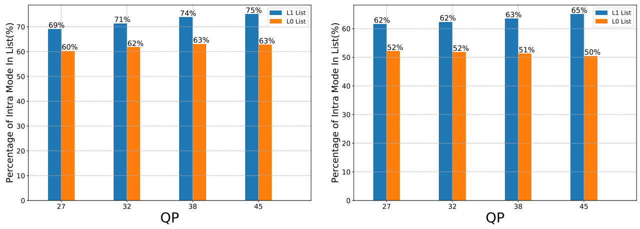
can be seen that Intra-DT and IPF occupy about 60% encoding time. *Angle* also occupies 30% encoding time. Besides luma component, the coding time of TSCPM only takes up a small proportion.

The complexity of exhaustive Rate-Distortion Optimal (RDO) process increased by dozens of time, hence the optimization of intra coding is meaningful and necessary to AVS3. To reduce the encoding complexity of Intra-DT and IPF, we firstly analyze the relationship between intra mode and different PUs. The effects of the result obtained in the first pass on the second pass are investigated subsequently.

3.2. The relationship between intra mode and different PUs

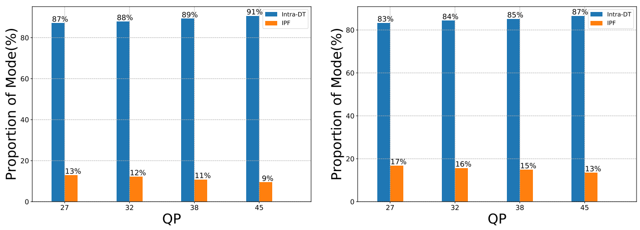
To visualize the intra mode correlation among different PUs in the same CU, we conducted some tests. The proportion of intra modes of Intra-DT derived PU ultimately falling into $L0$ and $L1$ is shown in Fig. 6. In this figure, the vertical direction is the hit ratio, which is calculated by comparing whether the optimal intra mode falls into the pre-defined set (i.e. $L0$ or $L1$). $L0$ is the intra mode candidate list used in the PU with size equal to SIZE_2Mx2N. $L1$ is the intra mode candidate list to be used for Intra-DT derived PU. The hit ratio, Γ, can be formulated as follows.

$$\Gamma = \frac{N_{IM}}{N_{PU}} \quad (1)$$



(a) BasketballDrive (1080p) (b) RitualDance (1080p)

Fig. 6. The percentage of optimal intra mode of Intra-DT derived PU falling in L0 or L1 List.



(a) BasketballDrive (1080p) (b) RitualDance (1080p)

Fig. 7. The percentage of Intra-DT/IPF mode is selected as the best mode when the first pass selects Intra-DT.

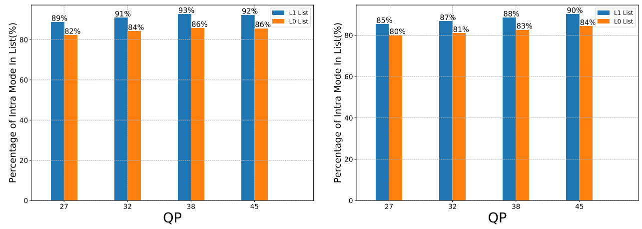
where N_{PU} is the total number of PU, N_{IM} represents the number of optimal intra mode falling into pre-defined set.

Hit ratio is a crucial measurement, since the coding performance loss will be smaller with the hit ratio increasing. It can be inferred that the intra mode decision process of Intra-DT derived PU can be assisted by the intra mode information of PU with size equal to SIZE_2Mx2N from Fig. 6.

3.3. The relationship of two-pass intra prediction

To explore the relationship between the first pass and the second pass of intra prediction, we performed some experiments and statistics. The statistic results are shown in Fig. 7 and Fig. 8. When Intra-DT is selected as the optimal mode after the first pass, the proportion of optimal mode (Intra-DT/IPF) after the second pass is exhibited in Fig. 7. The X-axis is the QP set and Y-axis denotes the proportion of optimal mode. It can be seen that IPF has a low probability of being selected as the optimal mode when Intra-DT is selected as the optimal mode after the first pass. With this consideration, IPF process can be early terminated if Intra-DT is selected as the optimal mode after the first pass.

Fig. 8 shows the proportion of optimal intra mode falling into $L0$ and $L1$. The vertical direction of this figure denotes hit ratio, which has similar meaning with equation 1. The numerator is the optimal intra mode of IPF falling into pre-defined set (i.e. $L0$ or $L1$) and the denominator is the total number of PU. $L0$ is the intra mode candidate list of the PU



(a) BasketballDrive (1080p) (b) RitualDance (1080p)

Fig. 8. The percentage of optimal intra mode in L0 or L1 List.

with size equal to SIZE_2Mx2N of the first pass. $L1$ is the intra mode candidate list to be used for IPF. It can be seen that both the hit ratio of $L0$ and $L1$ are in a high level. Therefore, the intra prediction process of the second pass can be simplified by the intra mode of the first pass.

4. INHERITABILITY-INSPIRED INTRA CODING OPTIMIZATION

Based on the analysis and observations in Section 3, an inheritability-based fast intra coding optimization method is proposed. The overall workflow of the proposed method is shown in Fig. 9. The proposed method consists of two parts, the optimization of Intra-DT and IPF. The method is described as follows.

4.1. Intrinsic relationship based intra mode pruning of Intra-DT

Based on the observations of statistical results in Section 3.2, an intrinsic relationship based intra mode pruning method for Intra-DT derived PU is presented.

In the proposed method, when the PU conducts intra prediction, the RMD process can be skipped by selecting intra modes in $L0$. To further improve the hit ratio, MPM list of the current PU is established. The intra modes in MPM list will be checked whether in $L0$ or not. Mode not included in $L0$ will be added to $L0$. The SATD cost of the intra mode in $L0$ will be calculated. $L1$ consists of four intra modes with minimum SATD cost in $L0$. Subsequently, $L1$ will be used as the full RDO candidate list. The light blue part in Fig. 9 shows the algorithm.

4.2. Intermediate information based fast IPF optimization

Based on the aforementioned statistical results in Section 3.3, an intermediate information based fast IPF optimization method is proposed, as shown in the light yellow part of Fig. 9. The proposed method consists of two parts as follows.

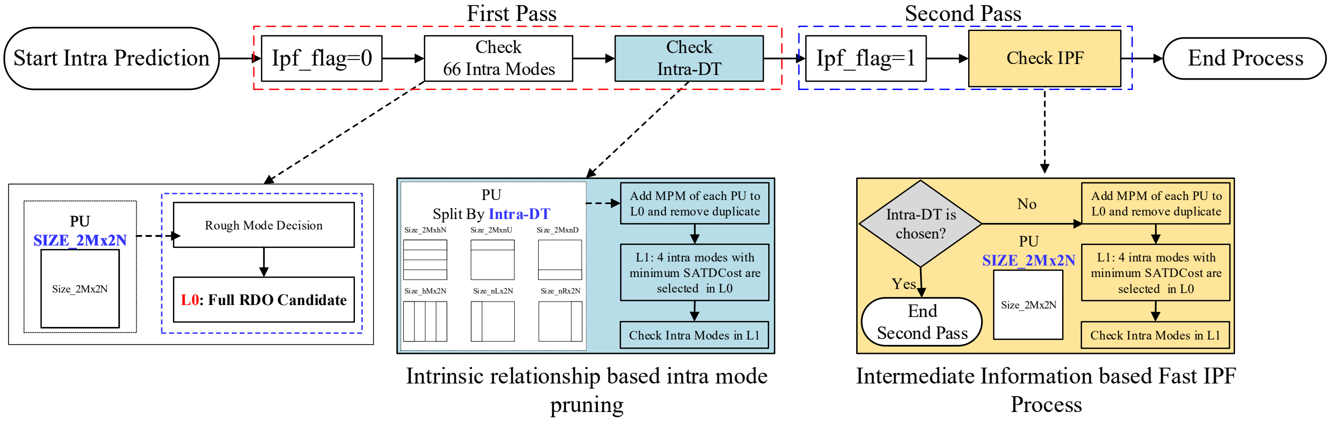


Fig. 9. Flowchart of Proposed Method. $L0$ is the full RDO candidate list used in first pass.

(1) IPF early termination
Based on the observation of Fig. 7, IPF can be skipped when Intra-DT is selected as the optimal mode in the first pass.

(2) Intra mode decision in advance
Intra mode decision in advance is based on the intermediate information obtained in the first pass. Compared with the first pass without IPF, the second pass is only different in that IPF uses reference pixels to refine the predicted pixels. The textural direction and pixel variation are concurrent. Therefore, the intra mode decision process of the second pass with IPF can be assisted by the intermediate information obtained in the intra prediction process of the first pass without IPF. The designed strategy of intra mode decision in advance of IPF is similar to section 4.1. The intra modes in MPM of the current block will be checked and added to $L0$. $L1$ consists of four intra modes with minimum SATD cost in $L0$. $L1$ is the full RDO candidate list used in the second pass.

5. EXPERIMENTAL RESULT

We conducted some experiments on the AVS3 reference software HPM5.0 to evaluate the performance of the proposed method. These experiments comply with the common test condition (CTC) [11] of AVS3. The testing platform is Linux Redhat 7.3 64bit with Intel Xeon E5-2697A. Since we focus on the performance of intra coding, experiments are carried out on all-intra (AI) configuration. The coding efficiency is measured with Bjøntegaard delta rate(BD-BR), Bjøntegaard delta Peak Signal-to-Noise Rate (BD-PSNR) [12] and time saving (TS). TS is defined as the following equation:

$$TS = \frac{T_{anchor} - T_{proposed}}{T_{anchor}} \times 100\% \qquad (2)$$

where T_{acnhor} represents the encoding times of original HPM5.0 reference software and $T_{proposed}$ denotes that of the proposed method. A negative value is desired by TS, the bigger TS is, the better time saving can get In the case of equivalent performance.

Table 2 shows the performance of the proposed method. The fast Intra-DT and IPF method can get 11.06% and 18.48% time saving with 0.15% and 0.34% performance loss. The overall proposed method can get nearly 31% time saving with 0.43% performance loss. The proposed algorithm can achieve steady efficiency trade-off for all sequences.

6. CONCLUSION

In this paper, an effective inheritability-inspired intra coding optimization method was presented. Based on the analysis and observation results, the algorithm skipped some redundant calculation in intra prediction process. The proposed method reduced the complexity of Intra-DT and IPF by using intrinsic relationship of different PUs and intermediate information of the first pass in intra prediction process. The algorithm balance coding performance and time saving well, and only use the intermediate information derived in the previous coded process. Experimental results demonstrate that our proposed algorithm can save 30% encoding time on average with negligible performance loss.

7. ACKNOWLEDGEMENT

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Table 2. Experimental results of the proposed method, Anchor: HPM5.0

Class	Sequences	Intra-DT			IPF			Overall		
		BD-BR	**BD-PSNR**	TS	**BD-BR**	**BD-PSNR**	TS	**BD-BR**	**BD-PSNR**	TS
Class A	Tango2	0.20%	-0.003 dB	11.96%	0.61%	-0.010 dB	19.86%	0.70%	-0.011 dB	29.67%
	ParkRunning3	0.04%	-0.002 dB	9.42 %	0.27%	-0.015 dB	17.76%	0.27%	-0.015 dB	26.94%
	Campfire	0.18%	-0.004 dB	12.28%	0.33%	-0.008 dB	18.27%	0.45%	-0.011 dB	30.37%
	DaylightRoad2	0.19%	-0.003 dB	11.73%	0.39%	-0.007 dB	19.11%	0.48%	-0.009 dB	30.81%
UHD 4K		0.15%	-0.003 dB	11.29%	0.40%	-0.010 dB	18.73%	0.48%	-0.011 dB	29.39%
Class B	Cactus	0.12%	-0.004 dB	11.46%	0.31%	-0.011 dB	18.22%	0.37%	-0.013 dB	29.91%
	BasketballDrive	0.11%	-0.003 dB	10.91%	0.21%	-0.006 dB	18.43%	0.29%	-0.008 dB	31.25%
	MarketPlace	0.06%	-0.003 dB	9.81%	0.41%	-0.017 dB	16.65%	0.42%	-0.017 dB	26.62%
	RitualDance	0.15%	-0.008 dB	11.85%	0.50%	-0.025 dB	17.88%	0.56%	-0.028 dB	29.92%
1080P		0.11%	-0.004 dB	10.98%	0.36%	-0.014 dB	17.78%	0.41%	-0.016 dB	29.31%
Class C	City	0.08%	-0.005 dB	9.61%	0.22%	-0.013 dB	18.46%	0.27%	-0.017 dB	33.62%
	Crew	0.23%	-0.008 dB	10.58%	0.31%	-0.011 dB	18.38%	0.45%	-0.016 dB	31.15%
	vidyo1	0.22%	-0.011 dB	11.83%	0.34%	-0.017 dB	19.16%	0.52%	-0.026 dB	31.76%
	vidyo3	0.25%	-0.014 dB	11.77%	0.20%	-0.011 dB	19.81%	0.39%	-0.021 dB	32.77%
720P		0.19%	-0.010 dB	10.91%	0.27%	-0.013 dB	18.94%	0.40%	-0.020 dB	32.27%
Average		0.15%	-0.006 dB	11.06%	0.34%	-0.012 dB	18.48%	0.43%	-0.016 dB	30.29%

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