Overlapping interval differences-based fast Intra mode decision for H.264/AVC

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***Abstract*—An efficient and fast mode decision algorithm for H.264/AVC Intra prediction is proposed in this paper. Overlapping interval differences (OID) are calculated in the domain composed of samples of current block and reconstructed samples of neighboring blocks. The OID can represent the direction error of each prediction mode. Smaller direction error means that the corresponding prediction mode will be considered as the final selection with high probability by rate-distortion optimization (RDO). So this method adopts a subset of the candidate modes instead of all to implement the efficient and fast encoding. Experimental results show that the proposed scheme can reduce about 30% computational complexity with negligible degradation of video quality and compression efficiency. Compared with other approaches in the literature, the proposed algorithm also shows better performance.**

Keywords—H.264/AVC; Intra prediction; fast mode decision; overlapping interval difference; direction error

1. INTRODUCTION

The new generation of video coding standard is developed by Joint Video Team (JVT) composed of ITU-T Video Coding Experts Group (VCEG) and ISO/IEC Moving Pictures Experts Group (MPEG), which is named as Recommendation H.264 and also MPEG-4 Part 10: Advanced Video Coding (AVC) [1]. Scalable Video Coding is developed based on H.264/AVC, which is particularly suitable for network coding [9]. Many novel efficient coding techniques are adopted in H.264/AVC, such as various Intra prediction modes, variable block motion estimation, multiple reference frames, integer cosine transform (ICT), context-based arithmetic coding (CABAC). Meanwhile, the rate-distortion optimization (RDO) is employed to achieve the best coding performance with minimum rate-distortion (RD) cost. All these techniques assure that the coding efficiency of H.264/AVC has great improvement compared with previous video coding standards. Due to RDO technique needs to calculate all the available Intra and Inter coding modes, the computational complexity is dramatically increased. Researchers present many fast algorithms [2-7] about H.264/AVC encoding and decoding in recent years. This paper focuses on the fast Intra mode decision [2-6]. Methods in these literatures all show good performance without degradation of visual quality and compression efficiency. All these methods focus on the candidate modes early decision, so they have the common disadvantage. They all only consider samples of current block and neglect the effectiveness of samples of neighboring blocks used for prediction. Meanwhile, they do not care the Luma Intra 8×8 prediction types specified in High profile of H.264/AVC, which may play an important role in high-definition video.

In this paper, to make up for the disadvantage of existing algorithms mentioned above [2-6], an efficient and fast mode decision algorithm for H.264/AVC Intra prediction is proposed. Overlapping interval differences (OID) are firstly calculated in the domain composed of samples of current block and reconstructed samples of neighboring blocks. The OID can represent the direction error of each prediction mode. The prediction mode with minimum OID will be selected as the candidate mode. The two adjacent modes and DC mode are also enabled to obtain better coding performance. Thus, this method adopts a subset of the candidate modes instead of all to implement the efficient and fast encoding. Compared with the previous algorithms, this is the first time reported that the reconstructed samples of neighboring blocks are introduced into the heuristic differences between current block and reconstructed samples of neighboring blocks. So the direction can be detected more accurately, and the final selection prediction mode will be closer to what is decided by RDO.

The remainder of this paper is organized as follows. In Section 2, the Intra prediction technique of H.264/AVC is introduced. Section 3 describes the proposed fast Intra mode decision method in detail. The experimental results and conclusions are given in Sections 4 and 5, respectively.

2. INTRA PREDICTION OF H.264/AVC

Intra prediction in H.264/AVC can effectively reduce redundancy in the spatial domain. The current block is predicted by the reconstructed neighboring blocks. Luma Intra prediction has three types in High profile: Intra 4×4, Intra 8×8 and Intra 16×16, but only one for Chroma: Chroma 8×8. Assume that the number of RDO calculation for both Luma and Chroma components in a Marcoblock (MB) is $C8\times(M4\times16+M8\times4+M16)$, where $M4$, $M8$, $M16$ and $C8$ represent the number of prediction modes of Luma Intra 4×4, Intra 8×8, Intra 16×16 and Chroma 8×8, respectively. So total 4×(9×16+9×4+4)=736 different RDO calculations need to be performed. Thus, the huge computational complexity is obvious. Here, the distribution of three Luma Intra prediction types is tested firstly. Table 1 shows the results on ten standard test sequences with two resolutions (QCIF and CIF). The number of frames for each sequence is 300. All frames are encoded using Intra frame

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coding with RDO and CABAC enabled. The quantization parameter is 28. All these experiments are implemented on JM16.0 provided by JVT [8]. From the results, we can obtain the following inferences. The Intra 4×4 is well suited for coding parts with detailed information, while Intra 16×16 is fit for smooth regions. Most of the Macroblocks of a sequence are partitioned into Intra 4×4 or Intra 8×8, only small parts with motionless background are coded with Intra 16×16. Meanwhile, two options named *FastCrIntraDecision* and *I16RDO* are introduced into JM16.0. Through these two ways, the RDO procedure of Chroma 8×8 is separated from Luma component and the optimal prediction mode of Intra 16×16 is early obtained by the sum of absolute differences (SAD) instead of RDO. Then only 4+9×16+9×4+1=185 different RDO calculations need to be considered for a MB. Both techniques can effectively save the coding time with little loss of visual quality and compression efficiency. Therefore, this paper only focuses on reducing the complexity induced by the optimal prediction mode selection procedure of Luma Intra 4×4 and Luma Intra 8×8. Fig.1 illustrates the Intra prediction and the corresponding nine different prediction modes for a 4×4 Luma block. The nine prediction modes contain one DC mode and eight different direction predictions. Lowercase letters a ~ p denote the current pixels, and uppercase letters A ~ M represent the reconstructed samples of neighboring blocks used for prediction. While for an 8×8 Luma block, the prediction modes are the same as those of Luma Intra 4×4. Only the rule used to construct predicted pixels is different because of different block size. According to the current pixels and samples of neighboring blocks, how to get the approximately optimal prediction mode without exhaustive search based on RDO is the main contribution of this paper.

Table 1. The distribution of Intra prediction types

QCIF	I4MB	I8MB	I16MB
Akiyo	42.24%	47.00%	10.76%
News	66.72%	22.56%	10.71%
Foreman	57.56%	37.08%	5.36%
Stefan	84.84%	10.33%	4.83%
Coastguard	52.14%	46.50%	1.36%
CIF	**I4MB**	**I8MB**	**I16MB**
Table	27.43%	66.25%	6.32%
Silent	41.55%	49.80%	8.65%
Foreman	46.10%	41.91%	11.99%
Mobile	75.84%	2.27%	1.88%
Container	32.91%	44.65%	22.44%

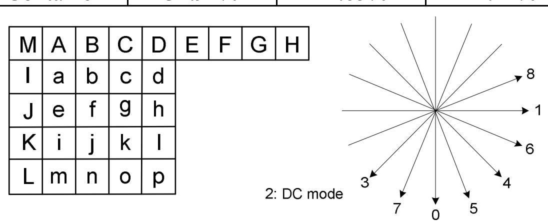


Fig.1. Intra 4×4 prediction modes in H.264/AVC

3. FAST INTRA MODE DECISION ALGORITHM

In order to reduce the computational complexity of Intra prediction in H.264/AVC, an efficient and fast mode decision algorithm is proposed. According to the rules that available information can be made use of as much as possible with the least computational load, we alternately calculate the average of sum of absolute difference between two interval pixels in the domain which is comprised of samples of current block and reconstructed samples of neighboring blocks. These differences are named overlapping interval differences (OID), which can represent the intrinsic characteristics of each Intra prediction mode. The following will give a detailed analysis on the fast mode decision algorithm.

3.1. Fast Intra 4×4 Mode Decision

For a 4×4 Luma block, Fig.2 shows the details of nine prediction modes, including eight direction predictions and one DC mode. The DC mode is a special mode since it does not represent a prediction direction, so the proposed algorithm only considers the other eight direction prediction modes. The OID of each prediction direction is firstly calculated, which can represent the direction error of current prediction mode. Smaller direction error means that the corresponding prediction mode will be selected as the optimal prediction mode with high probability by RDO. In order to obtain better coding efficiency, the two adjacent modes and DC mode are also enabled. For example, if the optimal prediction mode is mode 6, then the two adjacent modes are mode 1 and mode 4. The precise mathematical expressions of OID for each direction prediction mode will be discussed in detail as follows.

Mode 0: *Vertical Prediction Mode*

For the vertical prediction of a 4×4 Luma block as shown in Fig.2, the upper four samples A, B, C and D are used to predict the pixels with the same vertical coordinate, respectively. It means that the pixels are highly correlated in the same column. The OID can be defined as equation (1), where x and y represent the horizontal and vertical coordinates of pixel $p(x, y)$. Here we adopt the difference between two interval pixels to further reduce the computational operations. Three or more interval pixels will obviously reduce the prediction performance. According to the prediction rules specified by H.264/AVC [1], the OID for other seven direction prediction modes can be clearly denoted by equation (2) ~ (8).

$$Diff_0 = \frac{1}{12} \times \sum_{x=0}^{3} \sum_{y=0}^{2} \left| p(x, y-1) - p(x, y+1) \right| \quad (1)$$

Mode 1: Horizontal Prediction Mode

$$Diff_1 = \frac{1}{12} \times \sum_{x=0}^{2} \sum_{y=0}^{3} \left| p(x-1, y) - p(x+1, y) \right| \quad (2)$$

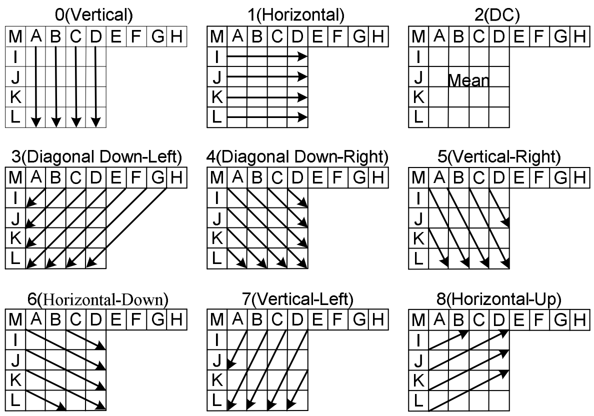


Fig.2. Intra 4×4 prediction for Luma block

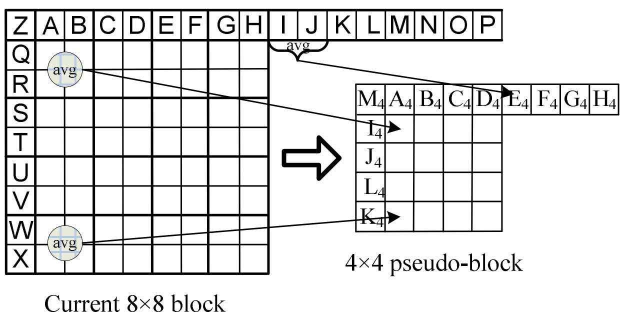


Fig.3. Construct 4×4 pseudo-block

Mode 3: *Diagonal Down-Left Prediction Mode*

$$Diff_3=\frac{1}{9}\times\begin{Bmatrix}|C-(p(1,0)+p(0,1))/2|+|D-p(1,1)|\\ +|p(2,0)-p(0,2)|+|E-p(2,1)|+|p(3,0)-p(1,2)|\\ +|p(2,1)-p(0,3)|+|F-p(2,2)|+|p(3,1)-p(1,3)|\\ +|G-(p(3,2)+p(2,3))/2|\end{Bmatrix}\quad(3)$$

Mode 4: *Diagonal Down-Right Prediction Mode*

$$Diff_4=\frac{1}{9}\times\begin{Bmatrix}|B-(p(2,0)+p(3,1))/2|+|A-p(2,1)|\\ +|p(1,0)-p(3,2)|+|M-p(1,1)|+|p(0,0)-p(2,2)|\\ +|p(1,1)-p(3,3)|+|I-p(1,2)|+|p(0,1)-p(2,3)|\\ +|J-(p(0,2)+p(1,3))/2|\end{Bmatrix}\quad(4)$$

Mode 5: *Vertical-Right Prediction Mode*

$$Diff_5=\frac{1}{12}\times\begin{Bmatrix}|M+A-p(0,0)-p(1,2)|+|A+B-p(1,0)-p(2,2)|\\ +|B+C-p(2,0)-p(3,2)|+|M-p(0,1)|\\ +|p(0,1)-p(1,3)|+|A-p(1,1)|+|p(1,1)-p(2,3)|\\ +|B-p(2,1)|+|p(2,1)-p(3,3)|\end{Bmatrix}\quad(5)$$

Mode 6: *Horizontal-Down Prediction Mode*

$$Diff_6=\frac{1}{12}\times\begin{Bmatrix}|M+I-p(0,0)-p(2,1)|+|I+J-p(0,1)-p(2,2)|\\ +|J+K-p(0,2)-p(2,3)|+|M-p(1,0)|\\ +|p(1,0)-p(3,1)|+|I-p(1,1)|+|p(1,1)-p(3,2)|\\ +|J-p(1,2)|+|p(1,2)-p(3,3)|\end{Bmatrix}\quad(6)$$

Mode7: *Vertical-Left Prediction Mode*

$$Diff_7=\frac{1}{12}\times\begin{Bmatrix}|B+C-p(1,0)-p(0,2)|+|C+D-p(2,0)-p(1,2)|\\ +|D+E-p(3,0)-p(2,2)|+|C-p(1,1)|\\ +|p(1,1)-p(0,3)|+|D-p(2,1)|+|p(2,1)-p(1,3)|\\ +|E-p(3,1)|+|p(3,1)-p(2,3)|\end{Bmatrix}\quad(7)$$

Mode8: *Horizontal-Up Prediction Mode*

$$Diff_8=\frac{1}{12}\times\begin{Bmatrix}|J+K-p(0,1)-p(2,0)|+|K+L-p(0,2)-p(2,1)|\\ +|L+L-p(0,3)-p(2,2)|+|K-p(1,1)|\\ +|p(1,1)-p(3,0)|+|L-p(1,2)|+|p(1,2)-p(3,1)|\\ +|L+L-p(1,3)-p(3,2)|\end{Bmatrix}\quad(8)$$

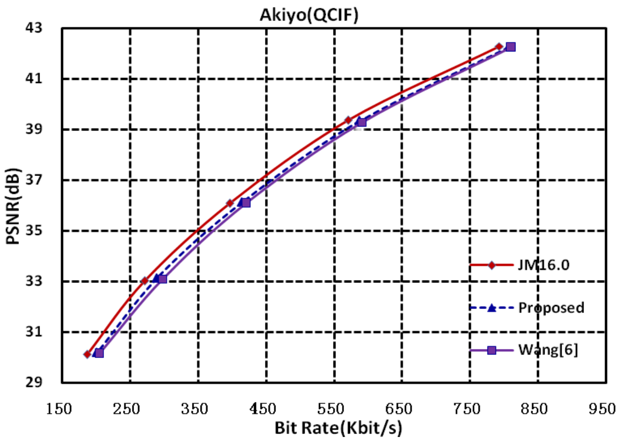
3.2. Fast Intra 8×8 Mode Decision

H.264/AVC uses the Luma Intra 8×8 prediction in High profile. All the prediction modes are the same as those of Luma Intra 4×4, so the proposed OID approach can be also applied here. But due to the different block size, we must pre-process the current 8×8 Luma block at first as shown in Fig.3. The current 8×8 block is used to construct a 4×4 pseudo-block by average operation, so do the neighboring available samples. Equation (9) can express this process accurately, where $p(i, j)$ represents the pixels of current 8×8 block and its neighboring samples at the position (i, j), and $p_4(x, y)$ for the constructed pixels with the coordinates (x, y). Now, the same procedure as part 3.1 can be performed to obtain the approximately optimal prediction mode for Luma Intra 8×8 prediction. Also four candidate modes instead of nine are used to RDO calculation. So the proposed algorithm only calculates 4+4×16+4×4+1=85 different RDO calculations for a MB, thus the coding complexity can be effectively reduced.

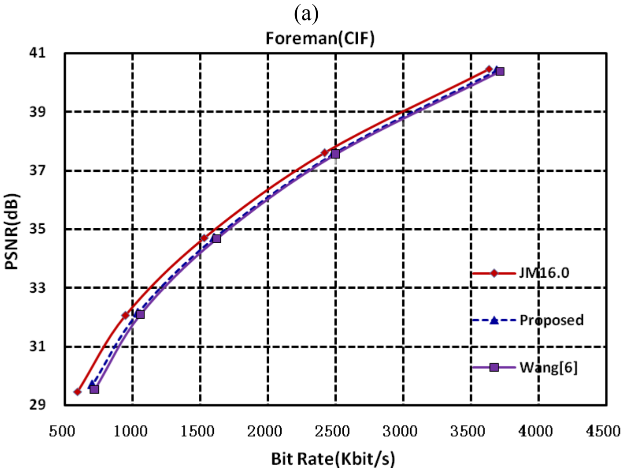
$$p_4(x,y)=\begin{cases}p(-1,-1), & x=y=-1\\ \frac{1}{2}\sum_{i=2x}^{2x+1}p(i,-1), & y=-1\ and\ x\neq y\\ \frac{1}{2}\sum_{j=2y}^{2y+1}p(-1,j), & x=-1\ and\ x\neq y\\ \frac{1}{4}\sum_{i=2x}^{2x+1}\sum_{j=2y}^{2y+1}p(i,j), & others\end{cases}\quad(9)$$

4. EXPERIMENTAL RESULTS

This study can achieve the complexity reduction and retain the coding performance. The proposed fast Intra prediction algorithm has been successfully implemented on JM16.0. All frames employ the Intra coding with RDO and CABAC enabled. Quantization parameters (QP) used in experiments are 24,28,32,36 and 40. The number of frames for each sequence is 300. The Bjontegaard's method is used to calculate the average change of PSNR and BR [10].



(a)



(b)

Fig.4. RD curves under JM16.0 and two fast Intra 4×4 prediction algorithms. (a) Akiyo in QCIF; (b) Foreman in CIF

Table 2. Evaluation results for QCIF sequences

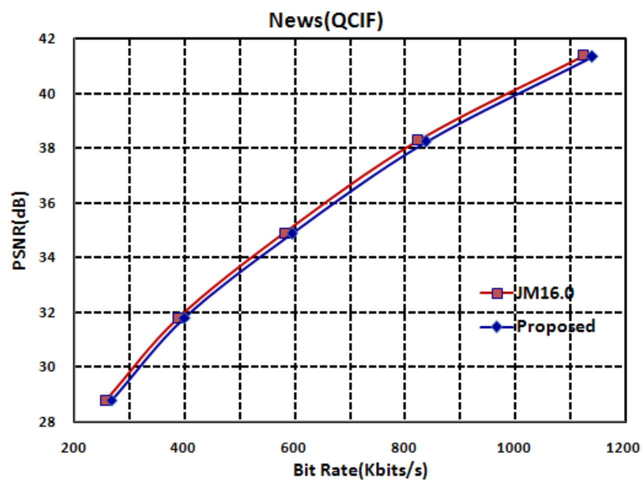
QCIF Sequences	[6]			The proposed algorithm		
	△PSNR [dB]	△BR [%]	△Time [%]	△PSNR [dB]	△BR [%]	△Time [%]
Akiyo	-0.463	5.30	-26.51	-0.286	3.32	-26.81
Foreman	-0.289	3.96	-28.45	-0.209	2.87	-28.69
Mobile	-0.259	2.33	-31.70	-0.203	1.82	-31.85
Container	-0.454	5.71	-27.63	-0.415	5.20	-27.96
Mother	-0.609	8.58	-26.41	-0.386	5.52	-26.96
Average	-0.415	5.18	-28.14	-0.300	3.75	-28.45

Table 3. Evaluation results for CIF sequences

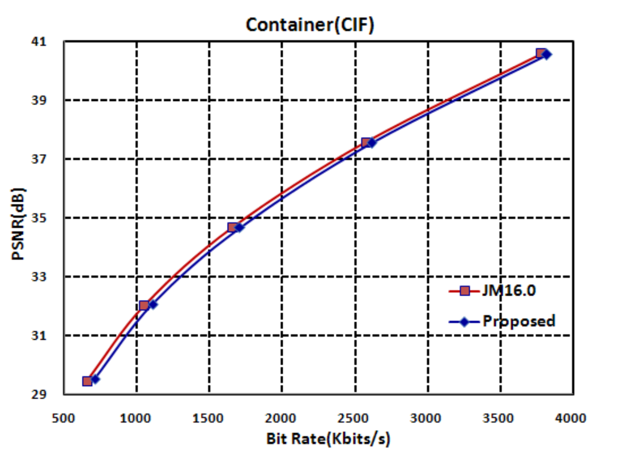
CIF Sequences	[6]			The proposed algorithm		
	△PSNR [dB]	△BR [%]	△Time [%]	△PSNR [dB]	△BR [%]	△Time [%]
News	-0.682	8.14	-27.31	-0.456	5.55	-28.26
Silent	-0.347	6.14	-28.88	-0.273	4.47	-29.72
Stefan	-0.459	4.76	-30.19	-0.304	3.14	-30.65
Table	-0.367	5.43	-28.76	-0.311	4.63	-29.23
Coastguard	-0.253	3.70	-30.81	-0.353	5.16	-31.08
Average	-0.422	5.63	-29.19	-0.339	4.59	-29.79

Table 4. Evaluation results for QCIF and CIF sequences

Format	Sequences	△PSNR[dB]	△BR[%]	△Time[%]
QCIF	Akiyo	-0.190	2.39	-33.38
	Foreman	-0.131	1.89	-34.86
	Mobile	-0.192	1.72	-37.06
	Container	-0.239	3.11	-34.20
	Mother	-0.172	2.82	-33.27
	Average	-0.185	2.39	-34.55
CIF	News	-0.223	2.92	-34.62
	Silent	-0.124	2.38	-35.76
	Stefan	-0.159	1.68	-36.59
	Table	-0.133	2.08	-35.40
	Coastguard	-0.152	2.30	-37.23
	Average	-0.158	2.27	-35.92



(a)



(b)

Fig.5. RD curves comparison between JM16.0 and the proposed algorithm. (a) News in QCIF; (b) Container in CIF

4.1. *Fast Intra 4×4 Evaluation*

To compare with the previous methods fairly, only the fast Intra 4×4 algorithm is enabled to evaluate the coding efficiency, because they all do not care the Luma Intra 8×8 prediction types. We have realized several algorithms [2, 4, 6], and the approach in [6] gives the relatively good results beside our method. Table 2 and 3 show the comparison results for QCIF and CIF sequences, respectively, where △PSNR indicates the peak signal-to-noise ratio (PSNR) increments, △BR denotes the bit rate (BR) increments and △Time represents the total coding time saving by referring to JM16.0. The average loss of PSNR and increment in BR are both less than [6]. So it is obvious that the proposed scheme can obtain a better performance. For the computational complexity, the additional equations (1-9) only require little memory. And the time complexity can be represented by △Time, we can obtain that both algorithms have the similar time complexity and are faster than JM16.0 from Table 2 and 3. Fig.4 shows the RD curves comparison with "Akiyo" and "Foreman" sequences. The results also indicate that the reported method can successfully achieve the coding process with negligible loss of PSNR and increments of BR.

4.2. *Fast Intra 4×4 and Intra 8×8 Evaluation*

In order to evaluate the proposed algorithm more comprehensive, both fast Intra 4×4 and Intra 8×8 techniques for Luma component are enabled to compare with reference software JM16.0. Table 4 shows the experimental results. The average loss of PSNR is about 0.185 dB for QCIF sequences and 0.158 dB for CIF sequences. The average bit rate increases by 2~3%. The time complexity reduction is about 35%. Fig.5 shows the RD curves comparison with "News" and "Container" sequences, which can indicate that the proposed scheme can retain almost the same coding efficiency by referring to JM16.0.

All these experimental results testify the excellent performance of the proposed algorithm, because the neighboring available decoded samples are introduced into the direction detection.

5. CONCLUSIONS

This paper presents an efficient and fast mode decision algorithm for H.264/AVC Intra prediction. In order to make use of more available information with less computational load, the overlapping interval differences (OID) are calculated to estimate the direction error which can decide the final prediction mode. Thus, a subset of the candidate modes is enabled to achieve great computation reduction. The reconstructed samples of neighboring blocks are firstly introduced into the fast Intra prediction algorithm, so the final mode is selected more accurately. In a word, the proposed method not only accelerates the Intra encoding but also maintains the video quality. Experimental results also show that the proposed scheme reduces about 30% computational complexity with negligible degradation of visual quality and compression efficiency. Compared with other approaches in the literature, the proposed algorithm also shows better coding performance.

ACKNOWLEDGMENT

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