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Efficient DCT-Domain Blind Measurement of Blocking Artifacts

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Abstract: It is well known that low bit rate block-based discrete cosine transform coded images exhibits visually annoying coding artifacts. It is of interest to be able to numerically assess the degree of blocking artifacts as it plays an important role in the design, optimization and assessment of image and video coding systems. A novel algorithm for image blocking artifact detection is presented in this paper. Experimental results illustrating the performance of proposed method are presented and evaluated. Our experiment results show that the proposed method of measuring blocking artifacts exhibits satisfactory performance as compared to other post-processing method's/techniques and is very efficient and stable since the signal need not be compressed/decompressed.

Keywords: Block discrete cosine transform, blocking artifacts, JPEG

1. Introduction

Transform coding is the heart of several industry standards for image and video compression. In particular, the block based discrete cosine transform (B-DCT) is the basis for the JPEG image coding standard [1], the MPEG video coding standard [2], and the ITU–TH. 261 [3] and H.263 recommendation's [4] for real time visual communication. BDCT coding has been successfully used in image and video compression applications due to its energy compacting property and relative ease of implementation. After segmenting an image in to blocks of size N×N, the blocks are independently DCT transformed, quantized, coded and transmitted. One of the most noticeable degradation of the block transform coding is the "blocking artifact". These artifacts appear as a regular pattern of visible block boundries.This degradation is the result of course quantization of the coefficients and of the independent processing of the blocks which does not take in to account the existing correlations among adjacent block pixels. In order to reduce blocking artifacts, measurement of blocking artifacts is very necessary. Several methods have been proposed to measure the blocking artifacts in compressed images [5-10]. In [5], a model was obtained that gives the numerical value depending upon the visibility of the blocking artifacts in compressed images and thus requires original image for comparison with reconstructed image. In [6] the blocky image is modeled as a non blocky image interfering with a pure blocky signal. This method can be implemented only in the pixel domain and thus requires iterative DCT/IDCT operations with heavy computational burden [7]. The weakness of [8] is to assume that the difference of the pixel value across block boundary is caused only by blocking artifacts. This assumption decreases computation complexity but the measured value does not confirm to truth, particularly for the two adjacent blocks with a gradual change in pixel value. In [9] and [10] the variation of pixel value across block boundary was modeled as a linear function. This method may give error nous results especially for the adjacent blocks with a large change of pixel value across the block boundary .In this paper we propose a blind but accurate measurement algorithm for blocking artifacts by taking into account that the change in pixel value across block boundary is large as compared to adjacent pixels as we move away across block boundary.

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2. Blocking Artifact Measurement System

Blocking artifacts are introduced in the horizontal and vertical directions. Let us consider two adjacent blocks c_1 and c_2. Here we study the case of horizontally adjacent blocks, for the vertical adjacent blocks same principles apply. Let the right half of c_1 and left half of c_2 form a block denoted as block b. Block b is the 8x8 block which contains the boundary pixels. If any blocking artifacts occur between c_1 and c_2 the pixel value in b will be abruptly changed. In this paper we propose a novel DCT- domain method for blind measurement of blocking Artifacts, by modeling the abrupt change in b. Assume that the change in pixel value across the block boundary is very large as compared to pixel value away from block boundary. Then the change in pixel value in block b can be modeled as a two dimensional function *f(x,y)* given by

$$f(x,y) = f(x) = \frac{x - \left[\frac{N-1}{2}\right] \pm 3.5}{2} \quad (1)$$

Where *x, y* =0… *N-1*. In (1), *f(x, y)* is not constant in the vertical direction. Also the change in *f(x, y)* is large as 'x' varies between 3 and 4 .

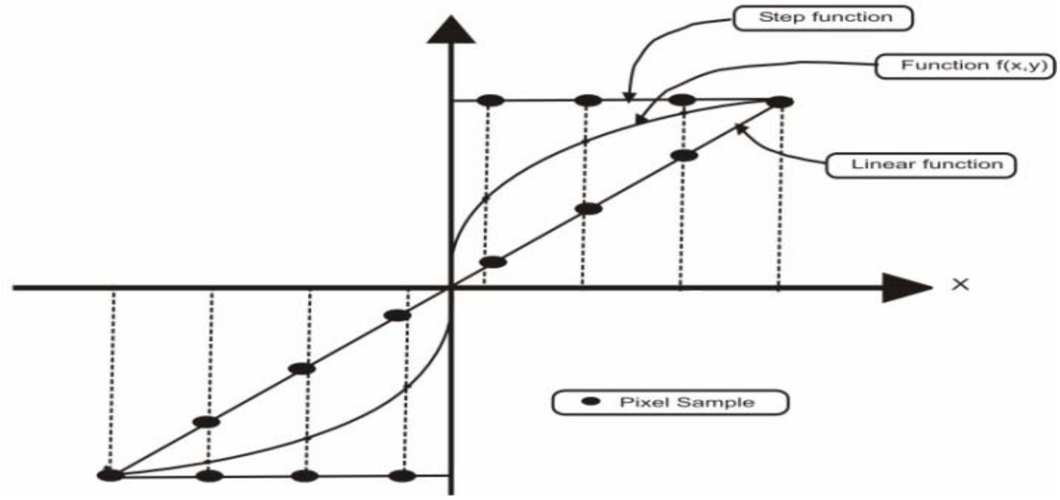

Fig.1 Illustration of replacing the step function with a function f(x, y) in the 1-D case

Where

$$f(x) = \frac{x - \left[\frac{N-1}{2}\right] - 3.5}{2} \qquad for\ x = 0,1,2,3 \quad (2)$$

and

$$f(x) = \frac{x - \left[\frac{N-1}{2}\right] + 3.5}{2} \qquad for\ x = 4,5,6,7 \quad (3)$$

Thus the eight pixels values on the function *f(x,y)* can be obtained as

$$k = [\,f(-3.5), f(-2.5), f(-1.5), f(-.5),$$
$$f(.5), f(1.5), f(2.5), f(3.5)\,]$$

The 2-D 8x8 block *f* can be constituted by simply stacking the vector *k* row by row, i.e., Note that the block *f* is anti-symmetric horizontally and constant in the vertical direction. Therefore the, 8x8 DCT transform of *f* has only four non -zero elements in the first row.

$$f = \begin{bmatrix} k_0 & k_1 & k_2 & k_3 & k_4 & k_5 & k_6 & k_7 \\ . & . & . & . & . & . & . & . \\ . & . & . & . & . & . & . & . \\ k_0 & k_1 & k_2 & k_3 & k_4 & k_5 & k_6 & k_7 \end{bmatrix}_{8\times 8}$$

Fig.2 JPEG compressed test images with Q=7 , from top-left to bottom-right: “pentagon,” “lena,” “peppers,” and “elaine,”.

The blocking artifacts between blocks c_1 and c_2 can be regarded as a 2-D step function in the block b given by

$$s(x,y) = \begin{cases} -\dfrac{1}{N}, x = 0,....,7; \quad y = 0...,3 \\ \dfrac{1}{N}, x = 0,....,7; \quad y = 4...,7 \end{cases} \tag{4}$$

Let Δm the slope of *f(x, y)* and β be the amplitude of s*(x, y)*.Then, block b can be modeled as

$$b(x,y) = \mu + \Delta m.f(x,y) + \beta.s(x,y) + r(x,y) \tag{5}$$

Where μ is the average value of b representing local brightness and $r(x, y)$ represents the white Gaussian noise with zero mean [11-12]. Figure 2 show's a 1-D model of the pixel value difference across the block boundary. Let the difference between two pixels in horizontal direction be denoted by

$$m(x, y) = b(x, y) - b(x, y-1) \tag{6}$$

Let the slope of left half of 'b' is Δm_L given by

$$\Delta m_L = \frac{1}{N}\sum_{x=0}^{N-1}\left[\frac{2}{N-2}\sum_{y=1}^{N/2-1} m(x, y)\right] \tag{7}$$

Let the slope of me right half of 'b' is ΔmR

$$\Delta m_R = \frac{1}{N}\sum_{x=0}^{N-1}\left[\frac{12}{N(N-2)}\sum_{y=N/2}^{N-1} m(x, y)\right] \tag{8}$$

The slope Δm in block 'c 'can be computed by averaging Δm_L and Δm_R

$$\begin{aligned}\Delta m &= \frac{\Delta m_L + \Delta m_R}{2} \\ &= \frac{1}{N}\sum_{x=0}^{N-1}\left[\frac{1}{N-2}\sum_{y=1}^{N/2-1} m(x, y) + \frac{6}{N(N-2)}\sum_{y=N/2}^{N-1} m(x, y)\right]\end{aligned} \tag{9}$$

Once μ and Δd are calculated the next part $\hat{b}(x, y)$ composed of $s(x, y)$ and $r(x, y)$ can be obtained by

$$\begin{aligned}\hat{b}(x, y) &= \beta.s(x, y) + r(x, y) + \mu \\ &= b(x, y) - \Delta m.f(x, y)\end{aligned} \tag{10}$$

Using β the blocking artifact can be measured/estimated quantitatively.

3. Fast Dct Domain Algorithm

Denote the BDCT of c_1, c_2 and b by C_1, C_2 and B. Let us define two matrices q_1 and q_2 as follows:-

$$q_1 = \begin{bmatrix} O & O_{4\times4} \\ I_{4\times4} & O \end{bmatrix}, q_2 = \begin{bmatrix} O & I_{4\times4} \\ O_{4\times4} & O \end{bmatrix}$$

Where I is identity matrix and O is zero matrix

$$\therefore \hat{b} = c_1 q_1 + c_2 q_2 \tag{11}$$

In DCT domain equation can be written as

$$\hat{B} = C_1 Q_1 + C_2 Q_2 \tag{12}$$

The 8x8 BDCT transform of the block $c_k(x, y)$ is defined as

$$\begin{aligned}C_k(u,v) &= c_u c_v \sum_{x=0}^{7}\sum_{y=0}^{7} c_k(x, y) \\ &\times \cos\left(\frac{\pi(2x+1)u}{16}\right) \times \cos\left(\frac{\pi(2y+1)v}{16}\right)\end{aligned} \tag{13}$$

Where k=1, 2

$$\text{and } c_u = c_v = \begin{cases} \sqrt{1/8} & for \quad u = 0, v = 0 \\ \sqrt{2/8} & otherwise \end{cases} \tag{14}$$

Assume that the variation in pixel value of c_k is modeled by $\Delta m_k . f(x, y)$ Here Δm_k represents the slope of 2-D function *f(x, y)* in c_k. For $u = 0, v = 1$ Substituting $\Delta m.\ f(x, y)$ for $c_k(x,y)$ in (13) gives

$$C_k(0,1) = \sqrt{2}/8\sum_{y=0}^{7}\Delta m_k\left(y-\left(\frac{N-1}{2}\right)\right) \times \cos\left(\frac{\pi(2y+1)}{16}\right) \quad (15)$$

$$C_k(0,1) = \eta\Delta m_k$$

Where η = -18.2241 according to park. [10] Then, by averaging the slopes of 2-D function *f(x,y)* in C_1 and C_2 we estimate Δm as

$$\Delta m = \frac{\Delta m_1 + \Delta m_2}{2} = \frac{C_1(0,1)+C_2(0,1)}{2\eta} \quad (16)$$

The value Δm can be obtained from the above equation (16) with less computational complexity. Let us denote the first row of the 8x8 BDCT transform of *f(x,y)* by $\hat{k} = [k_o, k_1, \ldots\ldots, k_7]$.In order to calculate β we first compute the rest block $\hat{B}$ by subtracting μ and *f(x,y)* from B as given below.

$$\hat{B} = \begin{cases} B(i,j) - \Delta m.k_j, & i=0 \ and \ j=1,\ldots,7. \\ 0, & i=0 \ and \ j=0 \\ B(i,j), & otherwise \end{cases} \quad (17)$$

Note that the 8x8 DCT transform of the 2-D step function defined in (4) has only four none zero elements in the first row. Let the vector v= [v_o,v_2,…….,v_7] be the first row of the 8x8 DCT transform of the 2-D step function, Then v_o=v_2=v_4=v_6=0. By the unitary property of the DCT transform, we have

$$\| v \|_2 = \sqrt{\sum_{i=0}^{N-1} v_i^2} = \sqrt{\sum_{x=0}^{N-1}\sum_{y=0}^{N-1} s^2(x,y)} = 1 \quad (18)$$

Hence the Parameter β can be computed as follows'

$$\beta = \sum_{j=o}^{7} v_j \hat{B}(0,j) = v_1\hat{B}(0,1) + v_3\hat{B}(0,3) + v_5\hat{B}(0,5) + v_7\hat{B}(0,7) \quad (19)$$

Because of the sparseness of DCT coefficients in the DCT block, the proposed method is far more efficient than the conventional IDCT-DCT methods such as [6]. It should be noted that if the magnitude of the blocking artifact $|\beta|$ is very small as compared to the original variation of pixel values across the block boundary then the blocking artifacts may not observed.

4. Discussion

In the proposed method several (“lena,”, “pepper’s,” **“**pentagon,” and “Elaine,”) 512 x512 images are coded at different bit rate. Fig. 3 shows the comparative results of the blocking artifact measurement done by proposed method and method in [10]. In addition to that the results are also compared with true blocking artifact which is measured by measuring the original pixel variation across the block boundary As shown in fig. 3 the measured β (average) of the proposed method is more close to true blocking artifact as compared to the method in [10]. It should be noted that at low Q factor the blocking artifact is relatively small but as the Q factor increases the blocking artifact (Horizontal, vertical as well as average) also increases.

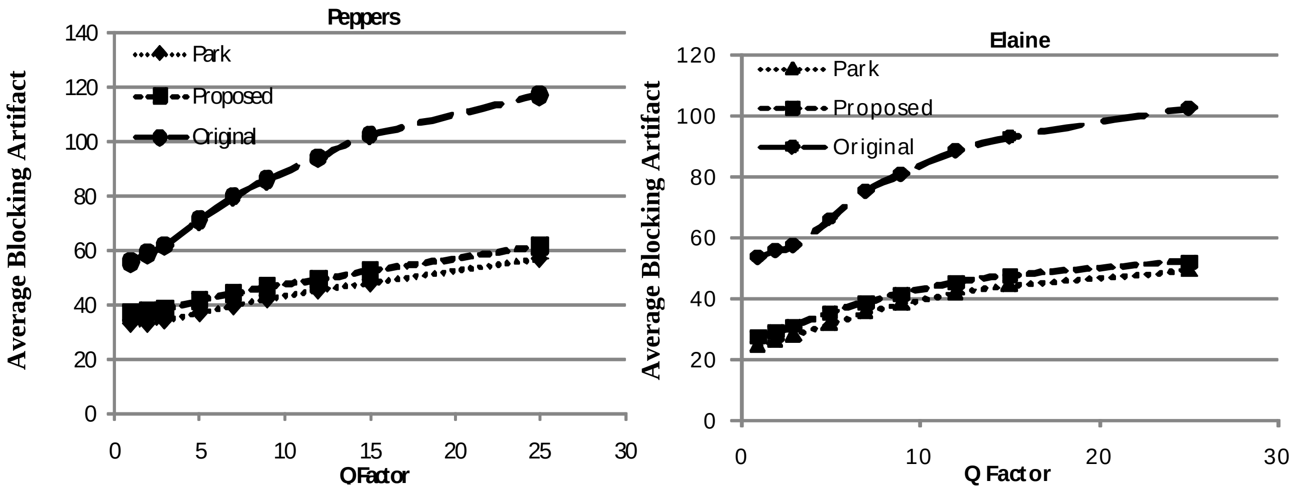

Fig. (4) shows the average deviation $|\Delta m|$ for different values of Q factor .The average deviation is different for different images and is maximum in case of " lena," and is minimum for "pentagon," image. The deviation is small for low values of Q but as the Q factor increases the deviation is large. The results indicate that the proposed method measures blocking artifacts more accurately than the method in [10]

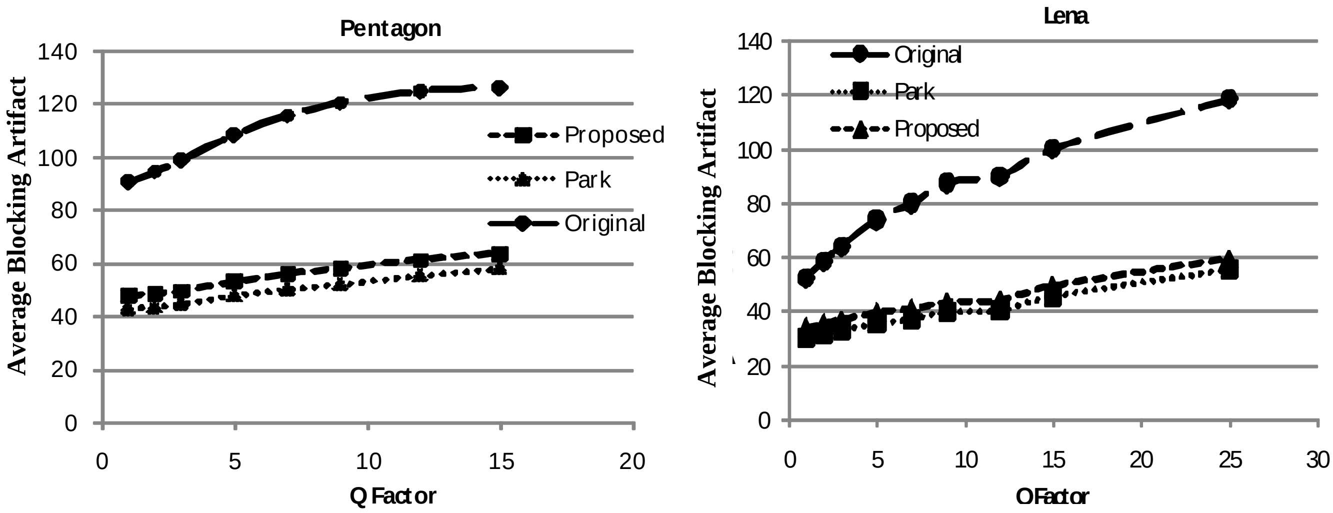

Fig.3. Average blocking artifact comparison of different detection methods.

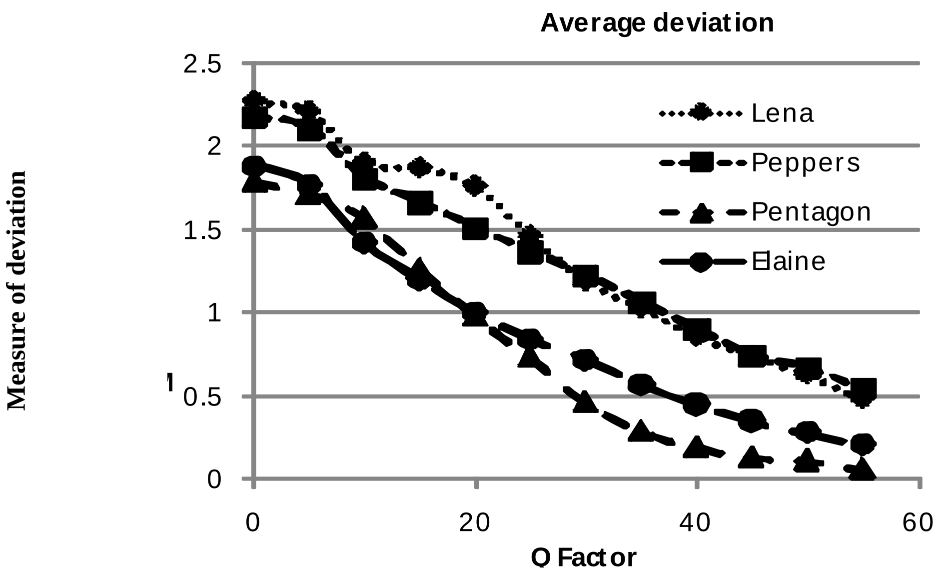

Fig. 4. Average deviation comparison for different images.

5. Conclusion

Table I Measure of Blocking Artifacts of JPEG-Coded Lena Image

Q Factor	Original			Method in [10]			Proposed		
	β_h	β_v	β_{av}	β_h	β_v	β_{av}	β_h	β_v	β_{av}
1	58.46	46.45	52.46	39.35	21.41	30.38	44.10	23.89	34.00
2	64.90	52.45	58.68	40.41	22.78	31.59	45.39	25.23	35.31
3	70.85	57.23	64.04	41.84	23.94	32.89	46.76	26.51	36.64
5	80.94	67.08	74.01	45.16	26.16	35.83	49.90	29.05	39.48
7	88.75	71.55	80.15	46.43	28.24	37.33	51.09	30.71	40.90
9	98.11	77.31	87.71	49.61	30.08	39.84	53.92	32.49	43.21
12	100.8	79.77	90.02	50.60	30.38	40.49	55.28	32.76	44.02
15	111.2	89.35	100.30	55.80	35.49	45.65	60.94	37.64	49.29
25	136.7	100.63	118.67	69.34	41.68	55.51	75.21	43.75	59.48

Table II Measure of Blocking Artifacts of JPEG-Coded Peppers Image

Q Factor	Original			Method in [10]			Proposed		
	β_h	β_v	β_{av}	β_h	β_v	β_{av}	β_h	β_v	β_{av}
1	53.00	54.05	55.10	35.00	29.47	32.32	40.68	33.34	37.01
2	60.31	56.85	58.60	35.94	29.97	32.95	40.69	33.97	37.33
3	63.32	59.33	61.33	37.05	31.01	34.03	41.73	34.94	38.33
5	72.56	69.11	70.83	40.00	33.77	36.89	45.01	37.82	41.42
7	82.88	76.07	79.47	43.05	36.08	39.56	47.60	39.98	43.79
9	89.38	81.96	85.67	45.47	38.82	42.14	49.91	42.64	46.28
12	97.43	90.09	93.76	48.64	41.69	45.17	53.01	45.33	49.17
15	104.87	99.03	101.95	51.17	44.64	47.91	55.75	48.42	52.08
25	121.79	111.53	116.6	61.76	51.92	56.84	66.82	55.67	61.24

Table III Measure of Blocking Artifacts of JPEG-Coded Pentagon Image

Q Factor	Original			Method in [10]			Proposed		
	β_h	β_v	β_{av}	β_h	β_v	β_{av}	β_h	β_v	β_{av}
1	90.93	90.66	90.79	43.57	42.63	43.10	48.51	47.17	47.84
2	96.52	92.95	94.73	44.08	43.49	43.78	49.19	48.18	48.68
3	100.4	97.94	99.20	44.95	44.61	44.78	50.08	49.48	49.78
5	109.1	108.3	108.7	48.10	47.85	47.97	53.57	52.97	53.27
7	115.2	116.22	115.73	50.00	50.47	50.24	55.90	56.14	56.02
9	118.4	122.67	120.58	51.78	52.35	52.07	58.34	58.03	58.18
12	123.3	126.2	124.78	55.96	54.80	55.38	63.36	60.21	61.28
15	123.3	129.37	126.38	57.93	58.13	58.03	63.90	63.62	63.76
25	127.8	130.0	128.9	59.1	58.9	59.00	64.7	64.3	64.5

Table IV Measure of Blocking Artifacts of JPEG-Coded Elaine Image

Q Factor	Original			Method in [10]			Proposed		
	β_h	β_v	β_{av}	β_h	β_v	β_{av}	β_h	β_v	β_{av}
1	55.05	50.95	48.00	26.89	22.17	24.53	29.87	24.65	27.26
2	57.31	54.53	55.92	28.05	23.75	25.90	31.42	26.50	28.96
3	59.30	55.88	57.59	29.95	25.83	27.89	33.22	28.92	31.07
5	67.32	65.19	66.26	33.63	29.41	31.52	37.45	32.78	35.11
7	76.77	74.13	75.45	37.05	33.81	35.43	40.45	36.87	38.66
9	81.52	80.51	81.01	40.05	36.14	38.09	43.81	38.90	41.35
12	89.42	87.59	88.51	44.03	39.26	41.65	47.96	42.42	45.19
15	94.58	91.51	93.05	46.46	41.88	44.17	50.08	44.66	47.37
25	106.7	98.13	102.45	52.21	46.04	49.13	55.89	48.20	52.05

In this paper we proposed a DCT-domain blind measurement of blocking artifact's which is stable and can be applied to a wide variety of images in both pixel and DCT domain. Experimental results indicate that the proposed method gives better results as compared to the method in [10] and is more accurate. The proposed method can be used to improve the performance (accuracy) of existing algorithms reducing the blocking artifacts. Due to its low computational cost, the technique can be integrated in to real- time image/video applications.

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