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Picture Quality Control by Priority Among Multiple Video Sources

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ABSTRACT

When the multiple video sources are transmitted together through the channel of fixed bandwidth, an efficient picture quality control is necessary. This paper presents a joint picture quality control method to satisfy the user requirement by priority among the video sources. The better picture quality is assigned to the source of higher priority compared to lower priority. We obtain the bitrate for each source to have a required distortion level among the sources by using an approximate distortion-bitrate model for simple implementation. It is shown by simulation that the proposed bandwidth allocation method can keep almost the user-required picture quality among the sources in comparison to an independent bandwidth allocation method.

Keywords: multiple program, picture quality distribution, priority control

1. INTRODUCTION

The video source can be transmitted through the conventional media by the video compression schemes such as MPEG-1, MPEG-2[1], and H.264[13]. In the environments of satellite, terrestrial, and cable TV broadcasting channels, the several compressed video sources can be transmitted together within one channel. For example, digital NTSC video source can be compressed to 3-6 Mb/s while still providing acceptable picture quality. Hence, it is possible to transmit 3-6 NTSC sources over a conventional terrestrial TV channel of 19Mb/s and 5-12 sources over a cable TV channel of 27-38Mb/s[2]. Thus, the total bandwidth of a channel should be divided to each video effectively. The bandwidth for each video can be allocated by independent method which divides total bandwidth by only considering the spatial resolution. However the independent allocation method does not distribute the picture quality of each video as the level of user requirement. That is, if the bitrates are independently allocated to the sources without considering the video characteristics then the distortion of complex texture sequence is greater than that of simple texture sequence. So, the subjective picture quality variation can be enlarged according to the video contents among the sources.

To overcome the problems, the joint bandwidth allocation method is required to handle the picture quality among multiple video sources[2-4]. For this, the video characteristics of each source should be considered by the rate-distortion model or rate-quantization model. Some papers[2,3,5] have proposed to keep the uniform picture quality among video sources, it can also take the additional advantage of the constant picture quality within each sequence. Another paper[14] has proposed a systematic approach for bitrate control that utilizes the concept of

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object priority corresponding to the application of MPEG-4 visual object coding.

Also, in the condition of special case such as video-on-demand, the picture quality should be handled for satisfying the priority, user-required picture quality. The source of higher priority has lager picture quality than one of lower priority. This priority can be set by depending on user requirement such as better service quality with higher expense.

In this paper, we propose the bitrate allocation method for user-required picture quality among sources on the condition of the fixed total bitrate. For the bitrate allocation, the relationship of distortion and bitrate should be first defined. In the literature[5-10], the relationship of distortion and bitrate has been presented. The relationships show the direct linear relationship between distortion and bitrate, the relationship between the quantization parameter and the distortion, and the relationship between the percentage of '0' in quantized transform coefficients and the distortion has been used.

We first assume the model of distortion and bitrate can be satisfied by the modified Gaussian model for MPEG video coding. Then we obtain the bitrates of the pictures within the sources to satisfy the user-required distortion level by adaptively using the model parameters and the coded results of previous pictures.

2. DISTORTION-BITRATE MODEL

The distortion after reconstruction of video signal is largely dependent on the assigned bitrate. Thus the relationship between distortion and bitrate is directly formed. This section presents the conventional distortion-bitrate models and investigates the approximate model for MPEG video coding from computer simulation.

For the memoryless Gaussian video signal with zero mean, distortion(Mean Square Error between the original and reconstructed pixels) and bitrate (bits per pixel) is related by following equation[11].

$$D = \sigma^2 \cdot 2^{-2R} \tag{1}$$

$$\log D = \log \sigma^2 - 2\log 2 \cdot R \tag{2}$$

where, D is a distortion(MSE), R is a bitrate, and σ^2 is a variance of the signal.

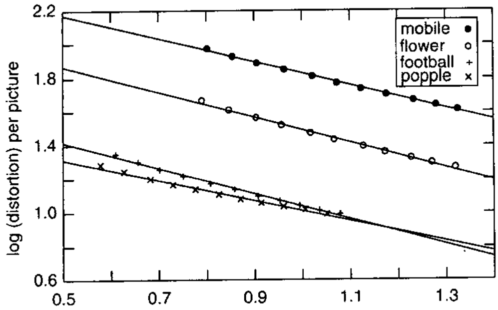
For MPEG video coding, Eq.(1) should be modified in order to consider the motion compensated prediction and quantization. We assume that the relationship in picture-types for each sequence can be approximated by the following model in the practical range of bitrates,

$$D = 10^{m-nR} \tag{3}$$

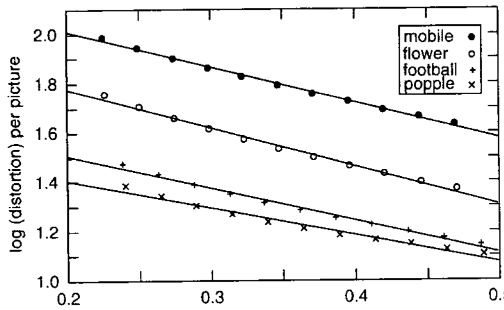
$$\log D = m - n\ R \tag{4}$$

where D is the distortion (Mean Square Error), R is the bitrate in bits per pixel, and m, n are model parameters which are dependent on the characteristics of the test video sequences.

By computer simulation, we investigated the distortion-bitrate relationship of MPEG-2 video coding. The sequence was the interlaced 60 fields per second of 704 pixels×480 lines for luminance component and 352×240 for chrominance component from each of the four test sequences, "Flower Garden", "Football", "Mobile & Calendar", and "Popple". The coding procedure was based on the TM5[12], where a GOP (group of pictures) consisted of 15 pictures without B-pictures. We varied the bitrates from 4.0~8.0Mb/s at 0.4Mb/s intervals. Fig. 1 shows the distortion (Mean Square Error between the original and reconstructed pixels for both luminance and chrominance components) averaged over 60 pictures with respect to the bitrates in bits per pixel for I-picture and P-picture of the test sequences. Also m, n model parameters are summarized in Table 1. We notice in Table 1 that the term n is less dependent on test



(a) I-picture



(b) P-picture

Fig. 1. Observed relationship of distortion and bitrate for the bitrates from 4.0Mb/s to 8.0Mb/s.

sequence. However, the value of the term n for P-picture is about two times larger than I-picture, since P-picture is coded by motion compensated prediction. Thus we notice that the

Table 1. Comparison of observed m, n values for sequence

Test sequence	I-picture		P-picture	
	m	n	m	n
Flower Garden	2.23	0.74	2.08	1.55
Football	1.79	0.75	1.77	1.32
Mobile & Calendar	2.51	0.68	2.29	1.44
Popple	1.62	0.60	1.62	1.10

term n can be approximated to a constant for each picture-type, independent of the sequence. We choose average value n for each picture-type, $\bar{n}=0.7$ for I-picture and $\bar{n}=1.4$ for P-picture, less dependent on test sequence as in Eq(2) of Gaussian source.

3. PICTURE QUALITY CONTROL FOR USER REQUIREMENT

When the total bitrate for multiple sources is fixed, it is required to divide the fixed total bitrate among each source in order to satisfy the user requirements on the picture quality. A model of our multiple video encoder system is shown in Fig. 2. The system consists of video encoders, a multiplexer and a central controller monitors for bitrate allocation. The central controller monitors the status of each encoder and

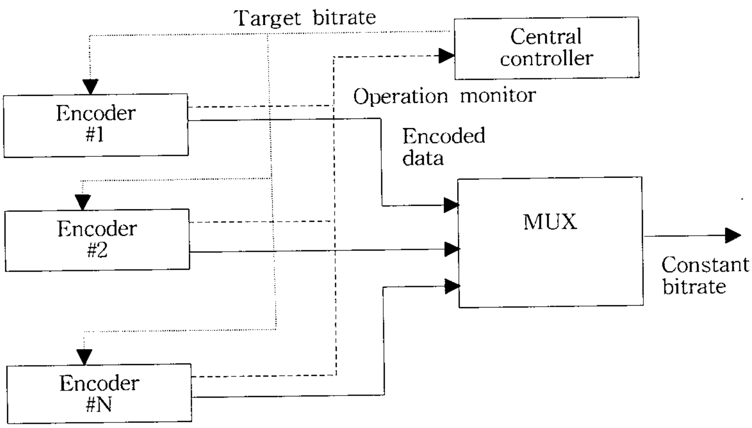


Fig. 2. Block diagram for multiplexing of multiple video encoder.

calculates the bitrate allocation according to the control algorithm. The video encoder operates at a target bitrate that is defined and dynamically updated by the central controller. The output from each encoder is multiplexed by the multiplexer and sent to the communication line. Using the distortion-bitrate model presented in section 2, we propose the bitrate allocation method for distortion distribution among the sources, and investigate the effects of this model.

3.1 Bitrate Allocation by Using Approximated Model Parameters

The total bitrate R_t for all the video sources is fixed, which is given by

$$R_t = \sum_{i=1}^{N} R_i \tag{5}$$

where R_t is the bitrate in bits per pixel for the i-th video source. For the priority control in the picture quality, the requirement is

$$\alpha_i D_i = \alpha_j D_j, \quad \text{for} \quad 1 \le i, j \le N \tag{6}$$

where D_i is the distortion of the i-th video source and α_i is the factor of distortion ratio for i-th video source to the other sources, which means D_i will be relatively small in comparison to the other sources if α_i is large. As special case, the distortion will be uniformly distributed among all the sources if $\alpha = 1$. Using the distortion-bitrate model of Eq. (3), Eq. (6) can be rewritten by

$$\alpha_i \cdot 10^{m_i - n_i R_i} = \alpha_j \cdot 10^{m_j - n_j R_j}, \quad \text{for} \quad 1 \le i, j \le N \tag{7}$$

that can be presented for the term of R_i as follows:

$$R_i = \frac{n_j R_j + (m_i - m_j) + (\log\alpha_i - \log\alpha_j)}{n_i} \tag{8}$$

Substitution of Eq. (8) into Eq. (5) yields

$$\begin{aligned} R_t &= \sum_{i=1}^{N} \frac{n_j R_j + (m_i - m_j) + (\log\alpha_i - \log\alpha_j)}{n_i} \\ &= n_j R_j \sum_{i=1}^{N} \frac{1}{n_i} + \sum_{i=1}^{N} \frac{(m_i - m_j) + (\log\alpha_i - \log\alpha_j)}{n_i} \end{aligned} \tag{9}$$

From exchanging the variable j to i in Eq. (9), we can obtain the following bitrate R_i

$$R_i = \frac{R_t - \sum_{j=1}^{N} \frac{(m_j - m_i) + (\log\alpha_j - \log\alpha_i)}{n_j}}{n_i \sum_{j=1}^{N} \frac{1}{n_j}} \tag{10}$$

In order to use Eq. (10), we should know the real values of model parameters m, n. The real values can be known from the several coded results (distortions and bitrates) of the same picture. It introduces the picture delay and processing complexity. For simple implementation, we select the value $\bar{n}$ which is not dependent on the video sequence and m is updated by the coding result of the previous picture of the same picture-type within same video source. Thus, for the P-picture, the target bitrate of k-picture of i-th source can be obtained as follows:

$$R_i(k) = \frac{R_t(k)}{N} - \frac{1}{N} \sum_{j=1}^{N} \frac{(m_j(k-1) - m_i(k-1)) + (\log\alpha_j - \log\alpha_i)}{\bar{n}} \tag{11}$$

where the total bitrate $R_t(k)$ itself can be updated for each picture by the complexity measure and the virtual buffer fullness as in the TM5, $m_i(k-1)$ is calculated by Eq. (4) from the average distortion $D_i(k-1)$ and the bitrate $R_i(k-1)$ of the (k-1)-th P-picture, respectively, which is given by

$$m_i(k-1) = \log D_i(k-1) + \bar{n} R_i(k-1) \tag{12}$$

Also a buffer control method can be added to prevent the buffer overflow and underflow of each source. For a constant bitrate channel, it is possible to determine upper bounds on encoder and decoder buffer sizes such that if the encoder's output rate is controlled to ensure no encoder buffer overflow or underflow, then the decoder buffer will also never underflow or overflow[15]. So, we set the upper bound of each coder's bitrate to 2 R_t/N. For better buffer control, our bit allocation algorithm can combined with special buffer control methods such as in[16,17]

3.2 Effects of Approximate Model Parameters

Now we consider the effect of the approximation of $\bar{n}$ on Eq. (10) in video variation such as scene change. Under the distortion-bitrate model of Eq. (4), $D_i(k)$, a distortion of temporally k-th picture for i-th source, is given by

$$\log D_i(k) = m_i(k) - n_i(k)R_i(k) \tag{13}$$

In order to find the effect of approximation, we consider the stationary sources in which the pictures of same picture-type in each source have same values of m and n in Eq. (4), i.e., $m_i(k-1) = m_i(k) = ... = m_i$. $n_i(k-1) = n_i(k) = ... = n_i$. Eq. (13) can be rewritten as

$$\log D_i(k) = m_i - n_i R_i(k) \tag{14}$$

By replacing m_i with the distortion-bitrate pair of (k-1)-th picture, Eq. (14) is given by

$$\log D_i(k) = \log D_i(k-1) + n_i R_i(k-1) - n_i R_i(k) \tag{15}$$

Then, substitution of Eqs. (11) and (12) into Eq. (15) yields

$$\log D_i(k) = \log D_i(k-1) + n_i R_i(k-1) - n_i \frac{R_t(k)}{N}$$
$$+ \frac{n_i}{N}\sum_{j=1}^{N}\frac{(\log D_j(k-1) - \log D_i(k-1)) + (\log\alpha_j - \log\alpha_i)}{\bar{n}}$$
$$+ \frac{n_i}{N}\sum_{j=1}^{N}(R_j(k-1) - R_i(k-1)) \tag{16}$$

From the constraint of constant total bitrate,

$$R_t(k) = R_t(k-1) = \sum_{j=1}^{N} R_j(k-1),$$

$$\log D_i(k) = \log D_i(k-1)$$
$$+ \frac{n_i}{N}\sum_{j=1}^{N}\frac{(\log D_j(k-1) - \log D_i(k-1)) + (\log\alpha_j - \log\alpha_i)}{\bar{n}}$$
$$= \frac{\bar{n} - n_i}{\bar{n}}\log D_i(k-1) + \frac{n_i}{N}\sum_{j=1}^{N}\frac{\log D_j(k-1)}{\bar{n}}$$
$$+ \frac{n_i}{N}\sum_{j=1}^{N}\frac{(\log\alpha_j - \log\alpha_i)}{\bar{n}} \tag{17}$$

Eq. (17) shows the relationship of distortion between (k-1)-th and k-th pictures, so from this equation, we can find the variations of distortion among the sources, i.e., the distortion ratios.

In order to satisfy the Eq. (6), requirement for distortion distribution among the sources, the distortion ratio among the sources should be converged to the desired value, from (k-1)-th picture to k-th picture. That is,

$$\sum_{j=1}^{N}\left(\frac{\alpha_i}{\alpha_j} - \frac{D_j(k-1)}{D_i(k-1)}\right)^2 > \sum_{j=1}^{N}\left(\frac{\alpha_i}{\alpha_j} - \frac{D_j(k)}{D_i(k)}\right)^2 \tag{18}$$

This can be satisfied if the following condition is satisfied between any two sources of N sources. For $1 \le i \ne j \le N$,

$$\left(\frac{\alpha_i}{\alpha_j} - \frac{D_j(k-1)}{D_i(k-1)}\right)^2 > \left(\frac{\alpha_i}{\alpha_j} - \frac{D_j(k)}{D_i(k)}\right)^2, \quad 1 \le i \ne j \le N \tag{19}$$

By considering only two sources i, j, Eq. (17) can be presented by

$$\log D_i(k) = \frac{\bar{n} - n_i}{\bar{n}}\log D_i(k-1) + \frac{n_i}{2}\frac{\log D_i(k-1) + \log D_j(k-1)}{\bar{n}}$$
$$+ \frac{n_i}{2}\frac{(\log\alpha_j - \log\alpha_i)}{\bar{n}}$$

$$= \frac{2\bar{n} - n_i}{2\bar{n}} \log D_i(k-1) + \frac{n_i}{2\bar{n}} \log D_j(k-1) + \frac{n_i}{2\bar{n}} (\log\alpha_j - \log\alpha_i) \quad (20)$$

Similarly,

$$\log D_j(k) = \frac{2\bar{n} - n_j}{2\bar{n}} \log D_j(k-1) + \frac{n_j}{2\bar{n}} \log D_i(k-1) + \frac{n_j}{2\bar{n}} (\log\alpha_i - \log\alpha_j) \quad (21)$$

From Eqs. (20) and (21), distortion ratio between i and j sources can be presented as

$$\frac{D_j(k)}{D_i(k)} = \left(\frac{\alpha_i}{\alpha_j}\right)^E \cdot \left(\frac{D_j(k-1)}{D_i(k-1)}\right)^F \quad (22)$$

where

$$E = \frac{n_i + n_j}{2\bar{n}} \quad (23)$$

$$F = \frac{2\bar{n} - (n_i + n_j)}{2\bar{n}} \quad (24)$$

Substitution of Eq. (22) into Eq. (19) yields,

$$\left(\frac{\alpha_i}{\alpha_j} - \frac{D_j(k-1)}{D_i(k-1)}\right)^2 > \left(\frac{\alpha_i}{\alpha_j} - \left(\frac{\alpha_i}{\alpha_j}\right)^E \cdot \left(\frac{D_j(k-1)}{D_i(k-1)}\right)^F\right)^2 \quad (25)$$

$$\left(1 - \frac{\alpha_j}{\alpha_i}\frac{D_j(k-1)}{D_i(k-1)}\right)^2 > \left(1 - \left(\frac{\alpha_j}{\alpha_i}\frac{D_j(k-1)}{D_i(k-1)}\right)^F\right)^2 \quad (26)$$

Therefore, to satisfy the inequality of Eq. (26), F should be in range of

$$-1 \le F \le 1 \quad (27)$$

that can be rewritten by using Eq. (24) as follows:

$$0 < \frac{n_i + n_j}{2} < 2\bar{n} = \bar{n} + \bar{n} \quad (28)$$

We notice from Eq. (28) that if the sum of approximate n values is greater than one half of the exact sum, then the distortion ratio converges to the desired ratio.

4. SIMULATION RESULTS

We compare the performance of the proposed bandwidth allocation method in the distortion and the bitrate with that of an independent bandwidth allocation method. The sequence is the interlaced 60 fields per second of 704 pixels ×480 lines for luminance component and 352×240 for chrominance component from each of the four test sequences, "Flower Garden", "Football", "Mobile & Calendar", and "Popple". The coding procedure is based on the TM5[12], where a GOP (group of pictures) consists of 15 pictures without B-pictures. The total bitrate for four test sequences is fixed as a constant bitrate 24.0Mb/s. In the independent bandwidth allocation method, the bitrate for each sequence is allocated equally at the constant bitrate 6.0Mb/s.

Fig. 3 shows the PSNR (Peak Signal to Noise Ratio) and the bitrate per picture of the sequence for the independent bitrate allocation method. Since the bitrate for each sequence is allocated as same value, the PSNRs among the sequences vary extensively according to the video characteristics.

Fig. 4 shows the simulation results of the proposed bitrate allocation method for different priorities. The priority parameters are set as $\alpha=1$ for "football" and "popple" sequences, $\alpha=10^{-0.2}$ for "mobile & calendar" and "flower garden" sequences. That is, we want that "football" and "popple" sequences have larger PSNR of 2dB picture quality than "mobile & calendar" and "flower garden" sequences. As shown in Fig. 4, the proposed method satisfies the user requirement that picture quality between "football" and "popple" sequences, between "mobile & calendar" and "flower garden" sequences is almost same, and the picture quality between sequences of different priorities is different by PSNR 2dB.

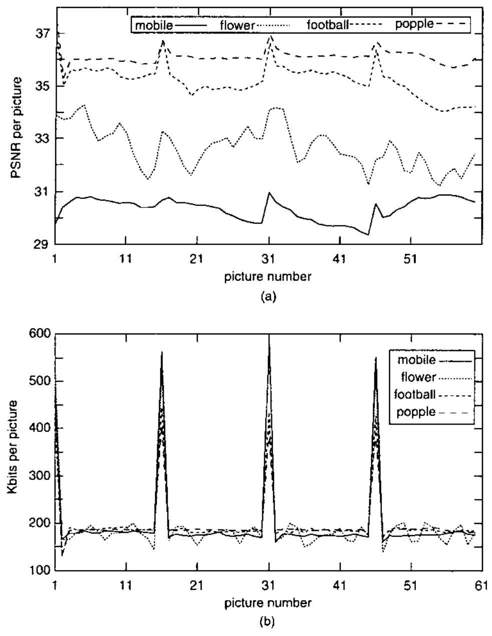


Fig. 3. Performance of an independent bitrate allocation method; (a) PSNR per picture, (b) bitrate per picture.

Fig. 5 shows the simulation results for another priority condition. The "mobile & calendar" sequence is highest priority, then priority is lower down in the order of "flower garden", "football", "popple" sequences. The priority parameter is set as α=1 for "mobile & calendar" sequence, $\alpha=10^{-0.1}$ for "flower garden" sequence, $\alpha=10^{0.2}$ for "football" sequence, and $\alpha=10^{-0.3}$ for "popple" sequence. We can find that there is about PSNR 1dB difference between the ordered sequences with different priorities.

5. CONCLUSIONS

For the multiplexing system of multiple video sources, it is required to adjust the bitrate among the sources under the condition of fixed total bandwidth. In this paper, we investigate the approximate model of distortion and bitrate for the video source, and then we propose an adaptive bitrate allocation method based on the model for the user-required picture quality

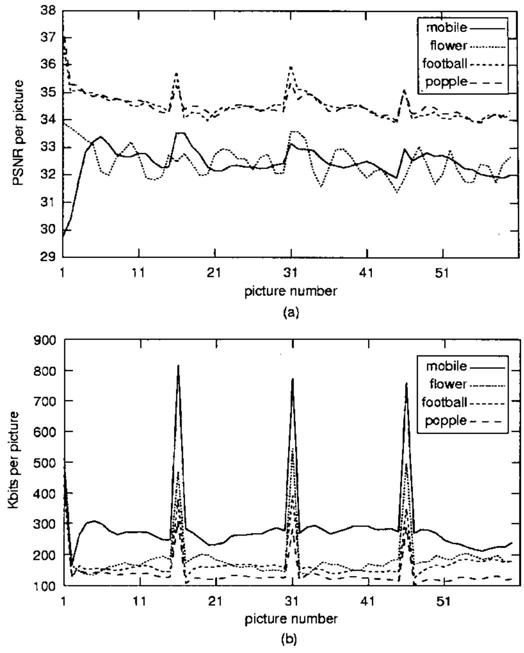


Fig. 4. Performance of the proposed bitrate allocation method, $\alpha=1$ for "football" and "popple" sequences, $\alpha=10^{-0.2}$ for "mobile & calendar" and "flower garden" sequences; (a) PSNR, (b) bitrate.

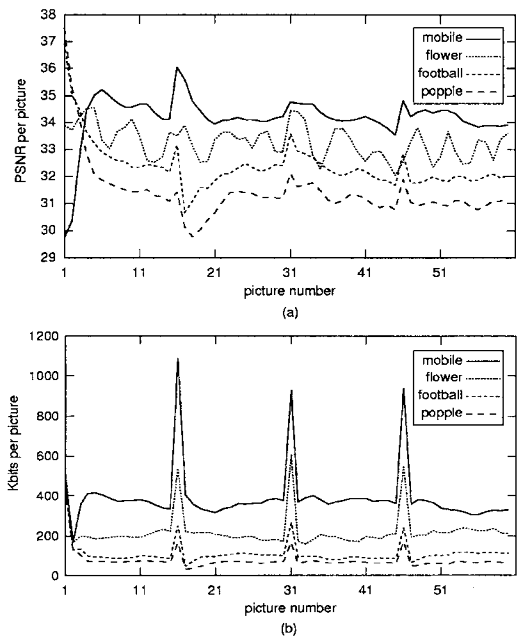


Fig. 5. Performance of the proposed bitrate allocation method, $\alpha=1$ for "mobile & calendar" sequence, $\alpha=10^{-0.1}$ for "flower garden", $\alpha=10^{-0.2}$ for "football", and $\alpha=10^{-0.3}$ for "popple"; (a) PSNR, (b) bitrate.

among the sources. By adaptively using the approximate model and the coded results of the sequences, we can see that the picture qualities among the sources are set to the level of user requirements.

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