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ノイズを考慮したシャドーアップ関数に基づく画像コントラスト強調

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あらまし　本論文では、ノイズを考慮したシャドーアップ関数に基づく画像コントラスト強調法を提案する。現在一般に用いられている撮像センサのダイナミックレンジは、現実シーンのダイナミックレンジと比べ極めて狭い。そのため、撮影される画像は低輝度あるいは高輝度領域におけるコントラストが低くなってしまう。その問題を解決するため、様々なコントラスト強調法が提案されている。しかしながら、従来の強調法には、コントラストの過強調により明るい領域の細部が失われてしまう問題がある。また、多くの強調法は、ノイズの影響を考慮していないため、画像中の暗い領域に含まれるノイズを増幅してしまう問題がある。提案法では、シャドーアップ関数を用いることにより、明るい領域の細部を失うことなしに、コントラストを強調する。さらに、ノイズを考慮したヒストグラムに基づくマッピング関数の設計が、ノイズの強調を抑制しつつ暗部のコントラスト向上できることを示す。生成される画像の品質とノイズに対する頑健性の観点から従来法との比較実験を行い、提案法の有効性が示される。

キーワード　コントラスト強調, 画像強調, ノイズ, シャドーアップ関数

Image contrast enhancement based on noise aware shadow-up function

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Abstract　This paper proposes a novel image contrast enhancement method based on a noise aware shadow-up function. Images taken by digital cameras have low contrast in dark or bright regions. This is due to a limited dynamic range which imaging sensors have. For this reason, various contrast enhancement methods have so far been proposed. However, conventional enhancement methods cause the loss of details in bright regions due to over-enhancement of contrast. In addition, most of conventional methods amplify noise in dark regions because they do not consider noise included images. The proposed method can enhance the image contrast without over-enhancement and noise amplification. In the proposed method, a shadow-up function is used for preventing over-enhancement and the loss of details in bright regions. In addition, a mapping function designed by using a noise aware histogram allows not only to enhance contrast of dark region, but also to avoid amplifying noise. Experimental results show the effectiveness of the proposed method by comparing the proposed ones with conventional ones.

Key words　Contrast enhancement, Image enhancement, Noise aware, Shadow-up function

1. Introduction

The low dynamic range (LDR) of modern digital cameras is a major factor preventing them from capturing images as well with human vision. This is due to a limited dynamic range which imaging sensors have. For this reason, images taken by digital cameras have low contrast in dark or bright regions. To overcome the problem, various contrast enhancement methods have so far been proposed.

The histogram equalization (HE) [1] is one of the most popular algorithms for contrast enhancement and there are various extended versions of the HE [3]〜[6]. However, these histogram-based methods cause the loss of cause the loss of details in bright regions due to over-enhancement of contrast. In addition, most of conventional methods amplify noise in dark regions because they do not consider noise in-

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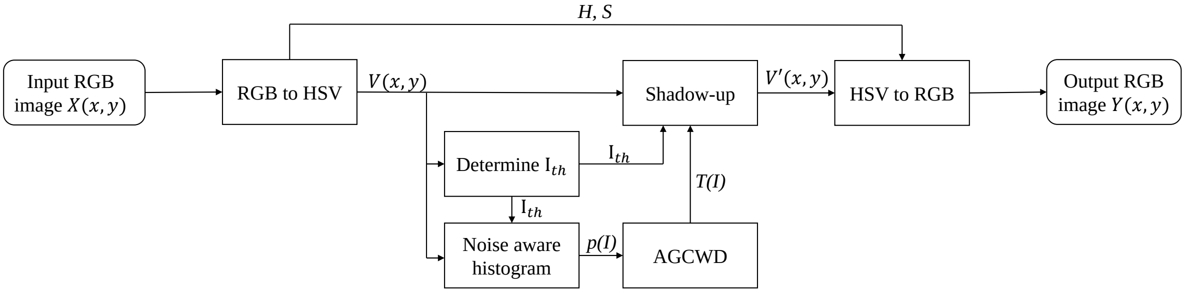


Fig 1: Flowchart of the proposed method. V and V' are intensities in the original and its enhanced image, respectively. I_{th} is threshold value used for Shadow-up function.

cluded images. On the other hand, contrast enhancement methods based on the retinex theory have also been studied. Although these methods can enhance the contrast while preserving details in bright areas, they also cause the noise amplifying as with histogram-based methods.

To avoid the noise amplification, some histogram-based contrast enhancement methods have been proposed. Low light image enhancement based on two-step noise suppression (LLIE) [8] uses both noise level function (NLF) and just noticeable difference (JND) in contrast enhancement for noise suppression. Although this method can reduce some noise, it does not preserve the details in bright areas as with histogram-based methods.

Because of such a situation, this paper proposes a novel image contrast enhancement method based on a noise aware shadow-up function. The proposed method can enhance the image contrast without over-enhancement and noise amplification. In the proposed method, a shadow-up function is used for preventing over-enhancement and the loss of details in bright regions. In addition, a mapping function designed by using a noise aware histogram allows not only to enhance contrast of dark region, but also to avoid amplifying noise.

We evaluate the effectiveness of the proposed method in terms of the quality of enhanced images by a number of simulations. In the simulations, the proposed method is compared with conventional contrast enhancement methods. Experimental results showed that the proposed method can produce high quality images without over-enhancement, and the proposed method outperforms conventional ones in terms of the noise robustness.

2. Related works

The histogram equalization (HE) [1] is one of the most popular algorithms for contrast enhancement [2] and various extended versions of the HE have been proposed [3]～[6]. Brightness preserving bi-histogram equalization (BBHE) [3] enhances the contrast by using partitioned histogram based on the mean value of an image. Similarly, dualistic sub-image histogram equalization (DSIHE) [4] uses histograms which are partitioned by the median value of an image. Contrast accumulated histogram equalization for image enhancement [6] enhances the image by using visual importance estimation and histogram reformulation. Efficient contrast enhancement using adaptive gamma correction with weighting distribution (AGCWD) [5] aims to prevent over-enhancement and under-enhancement caused by the HE by using an adaptive gamma correction and a modified probability dustribution. However, there are still issues that the over-enhancement and the loss of contrast in bright areas are caused by these histogram-based methods. Some noise hidden in the darkness is also amplified.

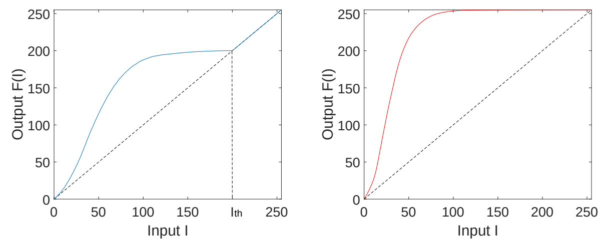
On the other hand, contrast enhancement methods based on the retinex theory have also been studied. For example, retinex-based perceptual contrast enhancement in images using luminance adaptation [7], which utilizes the characteristic of human eye sensitivity, allows not only to enhance the contrast, but also to preserve details in bright areas. However, as well as histogram-based methods, the noise is not considered.

Because of such a situation, some histogram-based contrast enhancement methods preventing the noise amplification have been proposed. In the methods, shrinkage functions are used for preventing the noise amplification. Low light image enhancement based on two-step noise suppression (LLIE) [8] uses both noise level function (NLF) and just noticeable difference (JND) for contrast enhancement with noise suppression. Although this method can reduce some noise, it does not preserve the details in bright areas as with histogram-based methods.

In this paper, we consider not only the noise but also the highlights. Our purpose enhances contrast with noise suppression, and moreover preserve details in bright regions.

3. Proposed method

Here, we propose a novel contrast enhancement method with a noise aware shadow-up function. For color images,



(a) AGCWD with Shadow-up finction.

(b) AGCWD without Shadow-up finction.

Fig 2: Examples of mapping curves.

we use value $V(x,y)$ at pixel(x,y), in the HSV color space, as luminance $l(x,y)$ in accordance with [9]. The outline of the proposed method is shown in Fig. 1.

3.1 Shadow-up function

To avoid the loss of details in bright areas due to over-enhancement, a shadow-up function is used for contrast enhancement [10], [11]. The function, which consists of the non-linear part and the linear part as shown in Fig. 2, is given by

$$f(I) = \begin{cases} T(I), \text{ if } I < I_{th} \\ I, \text{ otherwise} \end{cases}, \tag{1}$$

where $I \in [0, 255]$ is the intensity of luminance V, $T(I)$ is a monotonically increasing function, and I_{th} is the upper limit for the nonlinear part. By using eq. (1), the contrast is enhanced when I is less than the threshold value I_{th}. On the other hand, the contrast is maintained when I is greater than I_{th}.

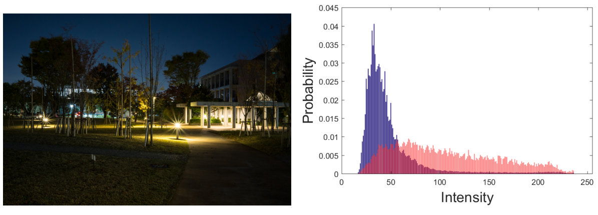
To determine a proper threshold value I_{th} for each input image, we take into account the luminance distribution of the image. Let $H = \{(x,y) : l_{th} < l(x,y) < l_{max}\}$, where l_{th} is the th percentile of luminance $l(x,y)$ of the input image, and l_{max} is the maximum of $l(x,y)$. The threshold value I_{th} is calculated as follows:

$$I_{th} = 255 - \frac{1}{|H|} \sum_{(x,y)\in H} l(x,y), \tag{2}$$

The threshold value I_{th} become smaller for a brighter image, while I_{th} become larger for a darker image.

3.2 Determining $T(I)$ via noise aware histogram

Function $T(I)$ can be designed by using one of conventional histogram-based enhancement methods. In the conventional methods, adaptive gamma correction with weighting distribution (AGCWD) [5] provides high quality images and it has a low computational cost. For this reason, we adopt AGCWD for determining $T(I)$. However, AGCWD usually causes the noise amplification because it does not consider noise characteristics. To overcome the problem, noise aware histograms are applied to AGCWD in this paper.



(a)

(b)

Fig 3: Histograms in *Night campus*. (a)Original image. (b)Original histogram(blue) for (a) and noise aware histogram(red) for (a).

3.2.1 Noise aware histogram

In Fig. 3(a), image "*Night campus*" contains large flat regions in grass and night sky, and the flat regions have the highest probability in the original histogram in Fig. 3(b). The highest probability causes results in some over-enhancement of contrast.

To deal with this problem, we consider local contrast and noise level of the input image. First, we estimate local contrast c by using a Gaussian filter as follows [12]:

$$c(x,y) = \sqrt{\frac{(g_\sigma * l^2)(x,y)}{(g_\sigma * l)^2(x,y)}}, \tag{3}$$

where $*$ is the convolution operator, and g_σ is a Gaussian filter with standard deviation σ. Second, the noise level in $n(I)$ is modelled as follows:

$$n(I) = \frac{I + \sigma(I)}{I}, \tag{4}$$

where $\sigma(I)$ is the standard deviation of noise.

In general, noise in a low light image can be represented by the generalized signal dependent noise model. NLF for the generalized signal dependent noise model is given by

$$\sigma(I) = \sqrt{I^{2\gamma} \cdot \sigma_u^2 + \sigma_w^2}, \tag{5}$$

where γ is the exponential parameter, and σ_u^2 and σ_w^2 are variances of zero-mean Gaussian distributions u and w, respectively. The parameters γ, σ_u^2, and σ_w^2 are estimated according to [13].

By using eqs. (3) and (4), we compute the noise aware histogram of an input image as follows:

$$p(I) = \frac{|B_I|}{|S|}, \tag{6}$$

where

$$S = \{(x,y) : c(x,y) > n(l(x,y)); l(x,y) < I_{th}\}, \tag{7}$$

$$B_I = \{(x,y) \in S : l(x,y) = I\}. \tag{8}$$

S is the set of pixels having higher contrasts than the noise level, and B_I is the subset of S which contains the pixels whose intensity is I. Fig. 3(b) shows the noise aware histogram calculated from Fig. 3(a). It makes noise less visible, and avoids over-enhancement in large uniform areas.

3. 2. 2 AGCWD

AGCWD consists of the adaptive gamma correction and the weighting distribution (WD) function. The adaptive gamma correction is formulated as follows:

$$T(I) = I_{max}(I/I_{max})^{1-cdf_w(I)}, \tag{9}$$

where cdf_w is the modified cumulative distribution function (CDF) based on the weighting distribution function. The WD function with adjusted parameter α is formulated as follows:

$$pdf_w(I) = pdf_{max}\left(\frac{pdf(I) - pdf_{min}}{pdf_{max} - pdf_{min}}\right)^{\alpha}, \tag{10}$$

where pdf_{max} and pdf_{min} are the maximum and minimum values of the probability density function pdf, respectively. In this paper, pdf is given as $pdf(I) = p(I)$. From eq. (10), the modified CDF cdf_w is calculated as follows:

$$cdf_w(I) = \sum_{I=0}^{I_{max}} pdf_w(I)/\Sigma pdf_w, \tag{11}$$

where the sum of pdf_w is calculated is given by

$$\Sigma pdf_w = \sum_{I=0}^{I_{max}} pdf_w(I). \tag{12}$$

3. 3 Proposed procedure

The proposed procedure for enhancing an input image is summarized as follows (see Fig. 1).

(1) Calculate value $V(x, y)$ from an input image $X(x, y)$.

(2) Determine a threshold value I_{th} by eq. (2).

(3) Calculate a noise aware histogram $p(I)$ by using eq.(3) to eq. (8).

(4) Calculate $T(I)$ by using eq. (9) to eq. (12).

(5) Calculate the enhanced luminance $V'(x, y)$ according to eq. (1).

(6) Obtain the enhanced image $Y(x, y)$ by transforming H, S, and V' into the RGB color space.

4. Simulation

We evaluated the proposed method in terms of the quality of enhanced images and noise robustness.

4. 1 Simulation condition

We carried out two simulations, called Simulation 1 and Simulation 2, to compare the proposed method with state-of-art contrast enhancement methods, AGCWD [5], LLIE [8], and CAHE [6]. The simulations were run on a PC with Intel (R) Core (TM) i7 CPU (3.40GHz) and 8.00GB RAM running a Windows 10 OS and MATLAB 2016b. We used four images, i.e. *Night campus*, *Corridor*, *Water* and *Toy*, taken by digital camera SONY α7 II for the simulations (see Fig. 4(a)). We adopted the 88th percentile as l_{th} because it outperformed the cases of $th = 12, 25, 50,$ and 75.

4. 2 Simulation results

4. 2. 1 Simulation 1 (Visual comparison)

In Simulation 1, the above-mentioned images, i.e. original ones, were used as input image X of each method. Next, we compared the resulting images, subjectively.

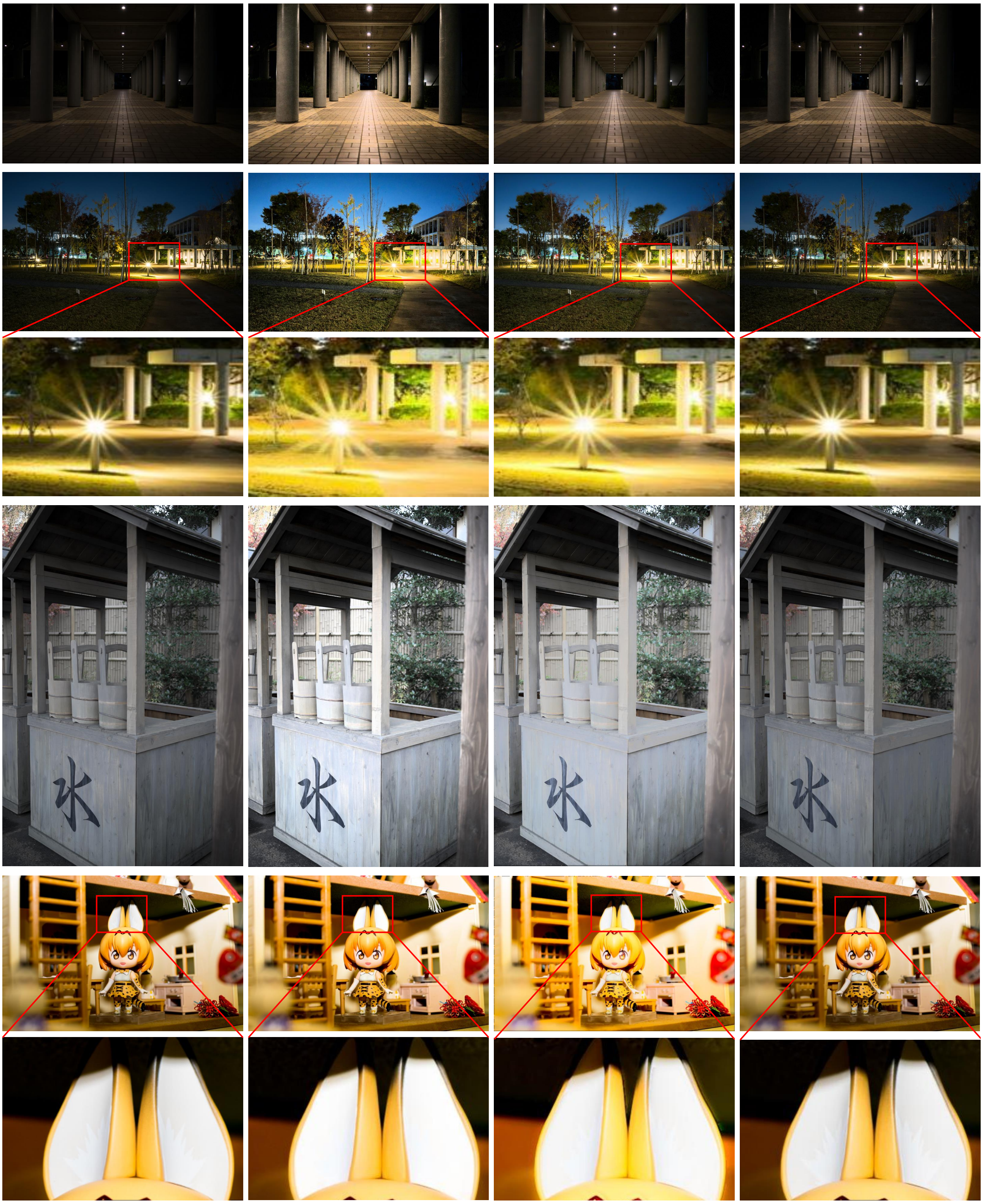
Figure 4 illustrates input images and enhanced ones produced by each method. From Fig. 4(b), it is confirmed that AGCWD clearly reproduces dark areas with detail, and over-emphasizes bright areas. Further, we can see some noise from pillar in *Corridor*, and some unnatural sight in closed to streetlight in *Night campus*. Besides, while LLIE successfully reduces noise for *Night campus* and *Corridor*, the wood grain and some edges in *Water* are lost, as shown in Fig, 4(c).

From *Corridor* in Fig. 4(d), it is confirmed that those in the image enhanced by the proposed method are more clearer than details in the image enhanced by LLIE. In *Night campus*, the proposed method dose not enhance bright area, so we can see the clear burst/sun star, and slightly enhance in sky and grass. In *Water*, the main part is similar to original image, because our proposed method is based on luminance adaptation, and the plant behind of main part is enhanced.

From *Toy* in Fig. 4, we are interested in what happens when inputting images with correct exposure time. We can use EV values to know correct exposure times for professional cameras, but we cannot be sure whether the exposure is correct when most of the smart phones and compact digital camera take photo by auto mode, The proposed method did not enhance *Toy* that had the correct exposure time, and the details in the red boxes are shown in Fig. 4. Because the input image is a correct exposure time image, the proposed method did not enhance image and kept details as shown in the red boxes. AGCWD also provided a good result, but we can observe the ears which lost the details and showed all white. The white balance of the results for LLIE was changed and some over-enhancement happened.

4. 2. 2 Simulation 2 (Noise robustness)

To evaluate noise robustness against each enhancement method, noisy images were generated as shown in Fig. 5(a) by adding Gaussian noise to the original ones shown in Fig. 4(a). The mean and variance of the noise were zero and 0.005, respectively. Peak Signal-to-Noise Ratio(PSNR) values between enhanced images without any noise and enhanced noisy ones. Larger PSNR values indicate less affects



(a) Original image (b) AGCWD [5] (c) LLIE [8] (d) Proposed method

Fig 4: Experimental Results under different contrast enhancement methods.The second and sixth columns are enlarged views of the previous one. From top to bottom: *Corridor*, *Night campus*, *Water*, and *Toy*.

due to the noise.

Table 1 provids the objective evaluation results. LLIE and the proposed method were clearly better than AGCWD and CAHE. The proposed method was slightly better than LLIE except *Corridor*, although LLIE has a good performance in low light condition. CAHE did not perform well in this simulation. On the average, the proposed method can be applied to a variety of different scenarios. Therefore, the proposed method effectively enhances contrast in various environments while considering the noise and preserving the details.

(a) Noisy image (b) AGCWD [5] (c) LLIE [8] (d) CAHE [6] (e) Proposed method

Fig 5: Experimental Results under different contrast enhancement methods for noisy images.

Table 1: PSNR value comparison for noisy images.

Methods	AGCWD [5]	LLIE [8]	CAHE [6]	Proposed
Corridor	23.43	**29.75**	20.05	25.54
Night campus	15.96	19.18	14.09	**23.04**
Water	18.26	20.38	17.95	**22.51**
Toy	34.02	17.60	31.69	**34.78**
Average[dB]	22.92	21.73	20.95	**26.47**

5. Conclusion

In this paper, we have proposed a novel image contrast enhancement method based on a noise aware shadow-up function. The proposed method can enhance image contrast without over-enhancement and noise amplification. To prevent over-enhancement, the proposed method utilizes a Shadow-up function. In addition, the use of noise aware histogram enables us to avoid amplifying noise. Experiment results showed that the proposed method successfully enhances contrast while preserving details of highlight regions and suppressing some noise in dark regions.

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