Honeycomb Model Based Skin Color Detector for Face Detection

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***Abstract*—Skin color is an important feature for face detection and recognition in color images. In order to obtain the possible face regions in color images, the skin color models are always constructed by statistical analysis. Owing to low accuracy of the static models, researches have discussed several dynamic models to correct input image such as illumination compensation, white balance, edge points addition, etc. Unfortunately, it is possible that some objects whose color is the same as the definition exist, and the previous methods can not separate real skin item from skin color background. Thus, to enhance skin color separation, this paper presents a honeycomb model to recognize the real human skin and the skin color items. First, the possible skin color is estimated from the pixels of database, and the honeycomb structure is built in HSV color space according to the training samples. Then, the personal skin is captured in one of the honeycomb cells. The performance of the new skin color detector technique has been tested under complex lighting source and background environments. It is observed that the proposed model can effectively improve the segmentation results. Especially, the honeycomb model is capable of separating the human face which connected with other face or skin color background.**

***Index Terms*—Face detection, skin color detection, illuminant color, honeycomb model.**

I. Introduction

Skin color detection has been gaining popularity and importance in pattern recognition. Generally, it is the first step of computer vision tasks, such as detection, tracking, and recognition of face. Many literatures have indicated that skin color can be captured easily under suitable color space. Because of the human's skin color can be limited in a range of some specific color spaces even if the human races are different. Hence, several color spaces have been used for displaying the skin color distribution introducing normalized RGB, HSV, YCbCr, CIE-Lab color space, etc. Then, skin colors have often been detected by using a decision boundary classifier.

In the past few years, several algorithms have been reported skin color segmentation. It can be classified into three main classes, equations based, filter based, and training based classifiers. In equations defined based methods, researches constructed some equations to describe the boundary of skin color. Garcia *et al.* adopted some linear equations to determine the bounding planes [1]. Yang *et al.* used a closed curve to delineate the skin cluster region [2]. Chi *et al.* included the skin color between two quadratic equation [3]. In filter based methods, researchers used different filters to model the skin color, such as single Gaussian classifier [4] and mixtures of Gaussian [5]. In training based methods, the defined skin color has been used for training a network, such as neural network [6], Bayesian classifier [7], and multilayer perceptron [8].

Due to low accuracy of the static models, researches have discussed several dynamic models to correct input image such as illumination compensation [9], white balance [10], edge points addition [11], etc. However, the existing methods only focus on determining a optimum boundary to obtain a little group of colors as the skin color. In other words, a typical method only classified each pixel to either skin or non-skin under the transformed color space [12]. In actual cases, although the colors which are located in the little area of special color space are very similar, a single human face is always a subset of the determined skin color. Thus, as a result the different skin color objects will connect or overlap to a single object in skin color segmentation if we do not classify or group the determined skin color.

In this paper, we propose an advanced classifier for separating different kind of skin colors in the decision boundary. The developed classifier avoids using complicated approach to define a little area as the skin color, because each color in decision area is able to be found on someone's face. Hence, we first find out the little area in YCbCr domain quickly. Then a honeycomb model based on HSV domain captures the skin colors of one human in a honeycomb cell. Moreover, we specially proposed a new noise filter to improve the qualities of images.

II. Observation and Motivation

In previous skin color detection, only one range is designed as human skin color. These approaches do not have detailed classification to different kind of skin colors. Hence, they will judge the connected skin color objects as a candidate face. For example, we can get the segmented face region from simple background image as shown in Figs.1(a) and (b). However, the face which is in the skin color background

(a) (b) (c) (d)

Fig. 1. Two example of typical skin color segmentation: (a) a face in normal background, (b) skin color segmentation of (a), (c) a face in skin color background, and (d) skin color segmentation of (c).

(a) (b)

Fig. 2. Each color in the red block of (a) is overlapped with the green spots of (b).

can not be segmented by this method. We demonstrate this counterexample in Figs.1(c) and (d). On the other hand, some colors which have appeared in human skin may appear in other non-skin object. For example, in Fig. 2, the colors in a jacket (inside the red block) are the same with some skin colors of a face (green points). Hence, a severe boundary definition also can not divide only face region from skin color background in any case.

Besides, few investigators have adopted edge detection to separation skin color object. Nevertheless, it is very hard to realize a perfect edge detection for face detection. The edges of the adjacent skin color can not be clearly defined by the edge detection. For example, Berbar *et al*. combined face color image and edge detection result to remove edge points between face regions and background [11]. However, this method is hard to deal with the case of skin color background or to connected face. Therefore, in order to content skin color object separation, we will propose a powerful classifier for separating different kind of skin colors to increase detection ratio.

III. The Proposed Methodology

In this paper, we proposed a cascade structure to combine the advantages of YCbCr and HSV transform. The cascade structure is shown in Fig. 3. We first adopt YCbCr transform to find out skin color as typical methods. Then, the possible pixels are classified in HSV color space. Therefore, the pixels will be grouped to R_1, R_2, ..., R_n by honeycomb model and collected to face candidates as shown in Fig. 3. The YCbCr and HSV classifiers are described in Sec.III-A and Sec.III-B respectively. After the classification, the noise filter is introduced in Sec.III-C

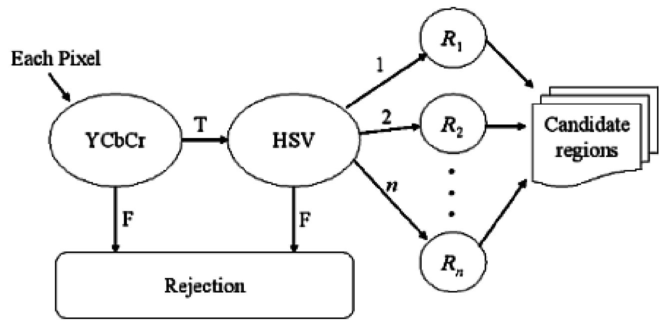


Fig. 3. The proposed cascade structure for skin color segmentation.

A. YCbCr Classifier

The advantage of YCbCr color space is fast computation, because it is a linear transform. Fig. 4 shows the skin color distribution in YCbCr color spaces, based on skin patches (952,024 pixels) collected from 286 human face in the 1999 Champion Database [13]. In this statistics, we only consider the general skin color in face. The eyes, mouth, and ears parts are not collected. Hence, the skin colors can be limited in a very narrow area in the (Cb/Y)-(Cr/Y) subspace [9] as shown in Fig. 5(a). In this paper, we use linear equation based method to delineate the skin cluster region. Fig. 5(b) shows

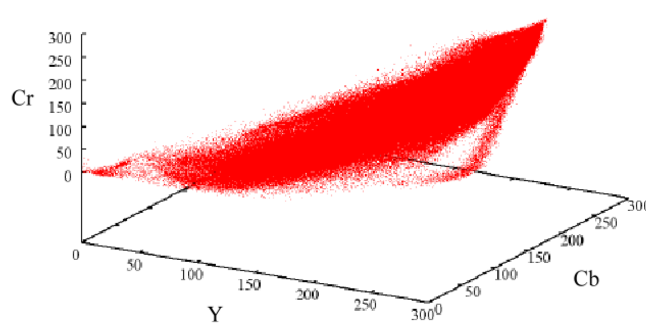
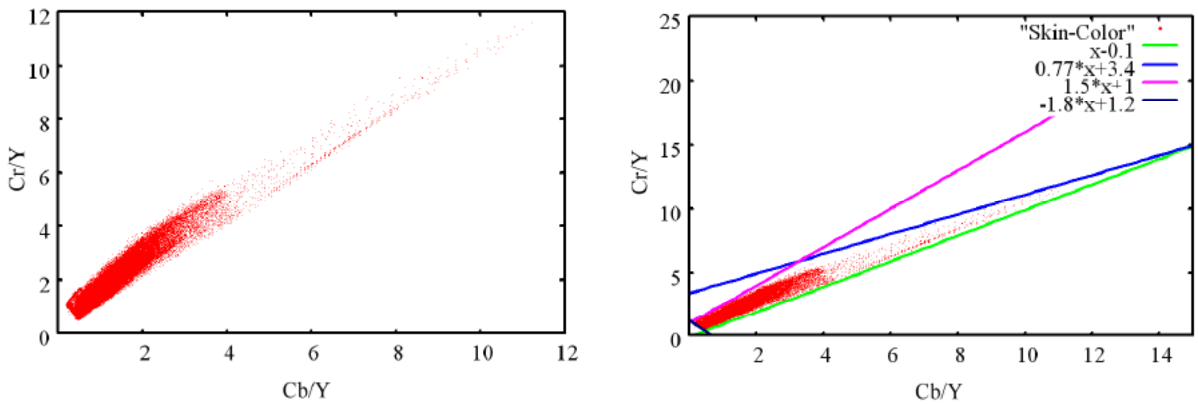
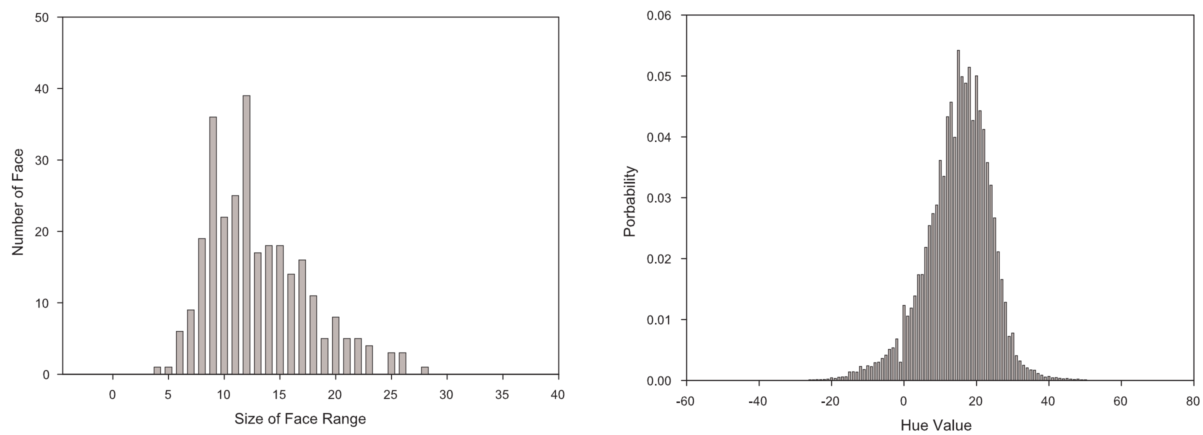


Fig. 4. The skin color distribution in YCbCr color space.



(a) (b)

Fig. 5. (a) The skin color distribution in (Cb/Y)-(Cr/Y) subspace, and (b) the segmentation by linear functions.



(a) (b)

Fig. 6. (a) The range analysis of single face, and (b) the skin color distribution in hue domain.

the definition of skin color, and the classifier can be designed easily by the following four equations:

$$f(x) = 1.5x + 1, \quad (1)$$
$$f(x) = x - 0.1, \quad (2)$$
$$f(x) = 0.77x + 3.4, \quad (3)$$
$$f(x) = -1.8x + 1.2, \quad (4)$$

where $f(x) =$ Cr/Y and $x =$ Cb/Y. Thus, the skin color pixels can be defined as follows:

$$S_Y(i,j) = \begin{cases} 1, & \text{falls within the locus,} \\ 0, & \text{otherwise,} \end{cases} \quad (5)$$

where i and j are the length and width of the input image respectively.

B. HSV Classifier

HSV color space is a preferred model for color classification because of its similarities to the way humans tend to perceive color [14]. We have observed that the hue value of a single face can be limited in a little range of skin colors, we can separate a single face from many skin color objects by a suitable range. Hence, using multiple range method can classify the skin color objects. In this paper, we model the multiple range by a honeycomb model. The cells of the honeycomb is classified to $R_x = \{R_1, R_2, ..., R_n\}$ in the following expression:

$$R_x = \{H(i,j)|h(q-1) < H(i,j) < h'(q-1)\}, \quad (6)$$

where

$$H(i,j) = \begin{cases} \text{Hue value of point } (i,j), & S_Y(i,j) = 1, \\ 0, & \text{otherwise,} \end{cases} \quad (7)$$

and

$$q = 0, 1, 2, \ldots, n, \quad (8)$$
$$h'(q) = h(q) + \alpha, \quad (9)$$
$$h(q+1) = h(q) + (\alpha/2). \quad (10)$$

In this paper, we assume $\alpha = 13$, $n = 7$, and $h_0 = -8$. The variable α is the size of the ranges from $h(q)$ to $h'(q)$. It means that $(n-1)$ ranges are defined to find isolated face region. This assumption is demonstrated in Figs. 6(a) and 6(b), based on skin patches (952,024 pixels) [13]. Fig. 6(a) shows the probability density function (PDF) of single face range

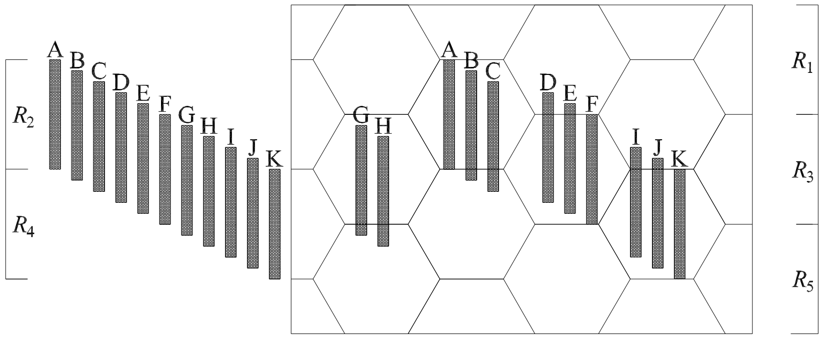


Fig. 7. The proposed honeycomb model.

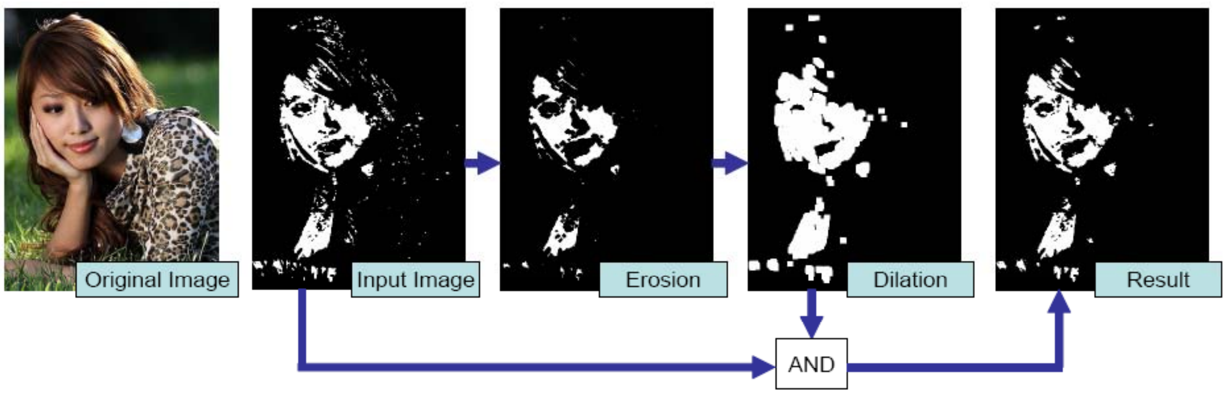


Fig. 8. Construction of small region filter.

size, and the maximum probability is concentrated at 9 and 12. Hence, we define $\alpha = 13$ in this paper. Besides, the PDF of skin color in Hue domain is shown in Fig. 6(b). The probability which is larger than 0.005 can be collected from -5 to 30. Thus, we can obtain 7 ranges by Eqs. (3) and (4). The definition range is from -8 to 43. Therefore, each single face must be captured in one of the honeycomb cells at least. For example, Fig.7 shows the proposed honeycomb model. As can be seen, there are 11 face distributions which fall in 2 neighboring cells uniformly. The proposed honeycomb can capture most pixels of each face distribution. Face A to C are captured in R_2; face D to H are captured in R_3; face I to K are captured in R_4. Therefore, the proposed honeycomb model can classify the statistic skin color to 7 kind of skin colors for human face.

C. Noise Filter

In this section, we describe the proposed new low pass filter. The target of this filter is to remove the small-scale regions without interfering large-scale regions. Because the large-scale regions may have some rough boundary, these boundaries and small-scale regions are both high frequency signal in frequency domain. Typical low pass filter always take high frequency away directly. It not only causes the structure of large-scale region to destroy, but also take a lot of computation in frequency domain transform. Thus, we construct the small-scale regions filter by binary morphological dilation "$\oplus$" and erosion "$\ominus$" operations [15].

In the two-dimensional Euclidean space Z^2, Binary dilation of a binary image $A(i,j)$ by a binary structure element $B(u,v)$ is denoted by

$$A(i,j) \oplus B(u,v) = \{Z | [(\hat{B})_z \cap A] \subseteq A\}, \tag{11}$$

where

$$\hat{B} = \{w | w = -b, \text{for } b \in B\}, \tag{12}$$

$$(A)_z = \{c | c = a + z, \text{for } a \in A\}. \tag{13}$$

Binary erosion of $A_x(i,j)$ by $B(u,v)$ is defined

$$A(i,j) \ominus B(u,v) = \{Z | [(B)_z \cap A] \subseteq A\}. \tag{14}$$

Note that we define the size of structure element is 0.01% of image resolution. Hence, $u, v = 0, 1, 2, ..., k$, where

$$k = \left\lfloor \frac{\sqrt{(i \times j) \times 0.01\%}}{2} \right\rfloor \times 2 + 1. \tag{15}$$

The small region filter is constructed as follows:

$$SmallRegionFilter = \{[A(i,j) \ominus B_0(u,v)] \oplus B_1(u,v)\} \textbf{ AND } A(i,j), \tag{16}$$

where

$$B_0(u,v) = \begin{cases} 1, & \text{if} D(u,v) \leq D_0, \\ 0, & \text{if} D(u,v) > D_0, \end{cases} \tag{17}$$

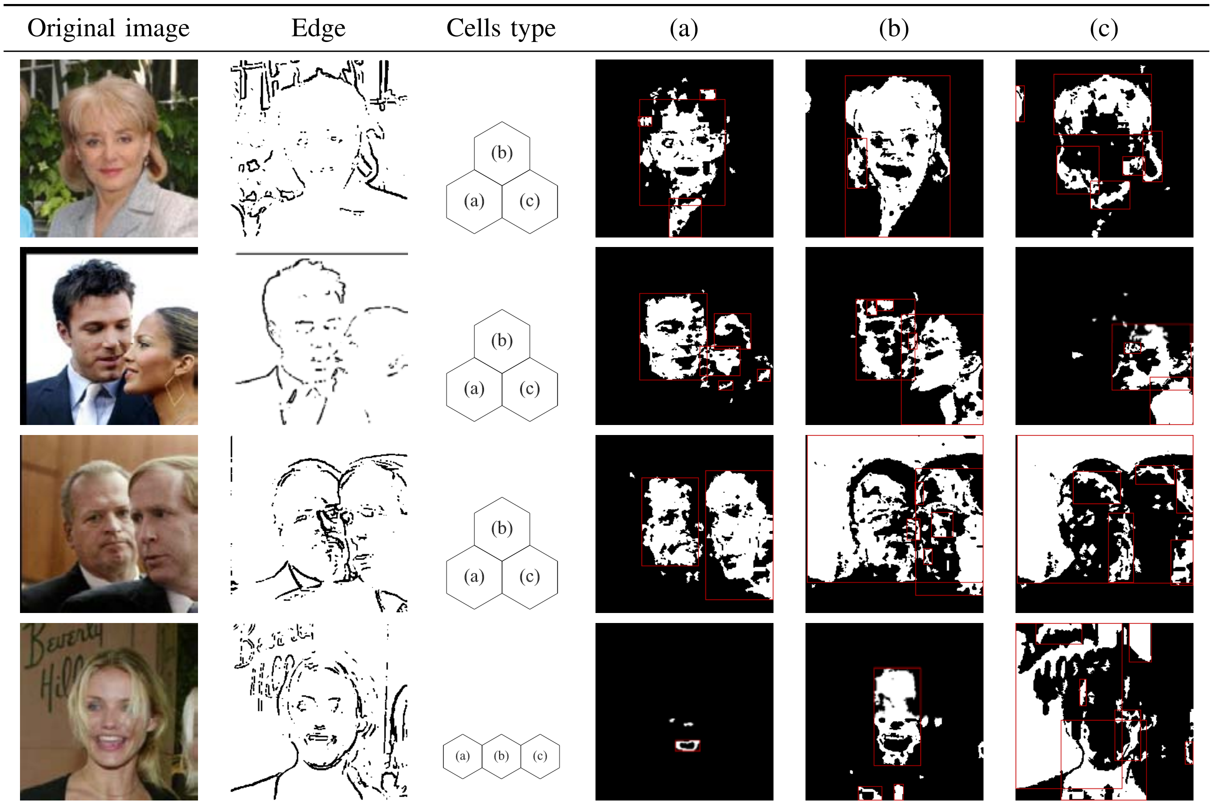


Fig. 9. Skin color classification results from LFW database.

TABLE I
SKIN COLOR CLASSIFICATION RESULTS.

Database	No. of Images	CCR(%) without white balance	FAR(%) without white balance	CCR(%) with white balance	FAR(%) with white balance
Champions	295	90.85	9.15	95.93	4.07
LFW	5000	91.36	8.64	94.78	5.22

$$B_1(i,j) = \begin{cases} 1, & \text{if} D(u,v) \leq D_1, \\ 0, & \text{if} D(u,v) > D_1, \end{cases} \tag{18}$$

AND is logic AND operation, $D_0 = (k-1)/2$, $D_1 = (\sqrt{2}k)/2$, and $D(u,v)$ is the distance from point (u,v) to the center of mask. Fig. 8 shows the process of the small-scale regions filter. We can observe that the results located at right hand side, the boundary of large-scale regions are identical with original ones. By this simple filter, we can reduce a large amount of face candidates for face detection. Consequently, the proposed filter can save a lot of memory and computation of face detection processing and be used for high performance processing.

IV. Experimental Results

In order to analyze the effectiveness of the proposed method, the extensive experiments are performed on two face image databases. Champions 1999 database [13] consists of 297 color images. All the images are single face inside and placed in monotonous background. This data set is suitable to evaluate the performance of single honeycomb cell. LFW (Name Labeled Faces in the Wild) database [16] contains 13233 images which include 13000 color images and 233 gray images which consist of over 5749 people. This database collects the photo of 5749 famous people. Most of people in this database are put in complex background such as a crowd of people, another person, skin color wall, etc. Thus, this data set is sufficient to verify the performance of multiple range skin color segmentation. In our experiment, we pick up 5000 color images randomly to test the proposed method.

Before the experiments, the automatic white balance processing is used first for correcting the old photos in the databases. The automatic white balance is implemented in eEO iMAGING photo processing software [17]. Fig. 9 shows the examples of the capturing results by honeycomb cells. The first column is the original image and the second column is the result of edge detection. Obviously, the edge is not a perfect line to delimit a face. Hence, the connected skin color region can not be separated by the edge information. The last three column show the result of capturing result of honeycomb cells. In order to compare the connected and overlapping cell, the first three rows list the results made by three connected honeycomb cells and the last row shows the result of three neighbor cells. The diagram of the select cells is shown in third column. The first photo shows a blonde lady. We can see that cell (b) found out the face with hair. It is a familiar result in previous methods. However, in our approach, the cell (a) and (c) can separate the face and hair respectively. The second and third ones are the two examples of connected faces. As can be seen, cell (b) segmented the skin color of both two people. It may couple together such as the result of third example. Nevertheless, the powerful honeycomb model can separate these face in the cell (a) and (c). The last row shows the results of three neighbor cells. Note that cell (a) is connected with cell (b); cell (b) is connected with cell (c); cell (a) is not connected with cell (c). Obviously, each detected skin color dose not reappear in other cell. Cell (a) found out mouth pixels; cell (b) detected the face pixels; and cell (c) captured the background. Finally, the complete experimental results are shown in Table I. We utilized CCR (Correct Classification Rate) and FAR (False Accept Rate) to evaluate the performance of proposed method. As can been seen, the CCR in Champions database is 95.93% and in LFW database is 94.78%. Therefore, the proposed skin color classifier has reliable performance in discriminating face region from skin color background and other objects.

V. Conclusion

In this paper, we proposed a novel classifier to segment skin color to several parts from the general definition. The statistics of skin color distribution were obtained in YCbCr color space. Then, the statistical skin color was classified into varied honeycomb cells for different items. It is worth stressing that our approach can avoid the problem of coupled skin color object. Experimental results show that the honeycomb model performs with 95% accuracy. With the high detection ratio of face candidate detection, the proposed method can affect the result of face detection directly and positively.

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