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Region-based segmentation and classification of Mandibular First Molar Tooth based on Demirjian's method

Region-based segmentation and classification of Mandibular First Molar Tooth based on Demirjian's method

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Abstract. Dental age estimation is applied in various clinical and scientific disciplines such as pediatric dentistry, orthodontics, archaeology, palaeontology and forensic dentistry. Dental age assessment, particularly in forensic dentistry application for the purpose of human identification, has led to the fastest and cheapest procedure in the estimation process of the undocumented and unrecognized individuals. Traditionally, dental age assessment is done by applying the scoring system based on tooth development from the x-ray image. However, this method can be intricate and time consuming for massive incidents that involve a large number of victims such as a natural disaster. Thus, a number of experts are required during the identification process. Therefore, in this research, the application of digital image processing techniques is used to perform the segmentation and classification of the first molar tooth in every stage of its development. A region-based segmentation method known as Watershed Transform associated with several image enhancement algorithms is implemented. A marker image is automatically computed to control the operation of a watershed transform. Features are extracted based on the area of a segmented tooth, size of crown, the distance of left crown to root and distance of right crown to root. As a result, 94% and 92.8% of segmentation and classification accuracy are obtained.

1. Introduction

Age estimation is an important aspect in forensic medicine and odontology to identify not only deceased victims but living persons involved in crimes or accidents [1]. Teeth are one of the bone structures that can be used in estimating the age of a person based on its maturity. It is often used for clinical analysis as it provides a better index of maturation compared to others such as bone maturation index [2]. The maturation includes the initial mineralization of a tooth, the formation of crown, root development, eruption of the tooth and root apex maturation [3]. The development of teeth is distinctive to an individual as are the fingerprints. Therefore, human dentition helps in the individual's identification [4].

Conventionally, all of the parameters include in tooth maturation can be observed using the panoramic dental radiograph as it is the cheapest and fastest procedure in assessing the age of a person. In addition, the age assessment based on the radiological method is identified to be a non-destructive and simple method, and it has been employed to be used in daily dental practice [5]. Furthermore, the advanced use of radiography machine in assessing the age has the capability to provide the gross stage of dental development of the dentition [4]. However, in some situations such as mass disasters as well as the process of identifying the huge number of refugees may lead to an intricate procedure. Subsequently, this procedure requires a number of experts during the individual's identification, and examination expedites the procedure. Therefore, in this study, the application of digital image processing technique is implemented to overcome the limitations of the conventional method to stage the dental development which currently based on atlas.

2. Previous work

2.1. Clinical studies

The first publication on age assessment based on teeth was done by Edwin Saunders, a dentist [2] in 1837. The study was carried out on 1000 children. The author suggested that age estimation based on teeth is more reliable compared to the age estimation based on height [3][4]. There are three techniques that can be used for age estimation, which are Morphological, Biochemical and Radiological methods. The age assessment based on the radiological method is identified to be a non-destructive and simple method, and it has been employed in daily dental practice [5]. Furthermore, the advanced use of radiography machine in assessing the age has the capability to provide the gross stage of dental development of the dentition [4]. The advantages of this method resulting in promising research output in forensic odontology have introduced quite a number of publications in performing the age estimation using radiological images.

The radiological age determination is grouped into three phases which are prenatal, neonatal and post-natal, children and adolescents as well as adults [2]. Kraus and Jordan [6] were the researchers who did a study on prenatal, neonatal and post-natal, and they have studied about the early mineralization in various deciduous teeth and the permanent first molar. The result indicates that 10 stages of dental development were described. The formation of crown and root completion are the important parameters that can be utilized for this age group. Schour and Massler have published the numerical development charts based on the development of deciduous and permanent teeth for the children and adolescents starting from the age of 4 months to 21 years using dental radiographic images [7]. This approach allows for direct comparison with radiographs. Other methods which have applied the age determination in children and adolescents include Nolla's method [8][9] and Demirjian, Goldstein and Tanner method [9].

Nolla's method has introduced the evaluation of the mineralization of permanent dentition in ten stages. This technique can be used to evaluate the development of each tooth of the maxillary and mandibular arch. The radiograph of the patient is matched with the comparative figure. After every tooth is assigned reading, a total is made from the maxillary and mandibular teeth, and then the total is compared with the table given by Nolla [8]. Demirjian et al. have introduced an age estimation method based on the scoring system [9]. In this method, seven mandibular teeth on the left side were divided into eight stages, and the maturity score was evaluated. Based on the existing methods of age estimation, Demirjian and Goldstein's method is simple, as it is an orthopantomogram-based method and it enables more reliable standardization and has good reproducibility and intra-examiner/inter-examiner reliability. However, the staging process of dental developmental may become difficult as the selection of the tooth developmental stage is quite subjective. As such, in this study, a new approach is applied in order to overcome one of the limitations in staging the dental development for the age assessment. The application of image processing and computer vision algorithm is implemented in this research.

2.2. Image processing analysis

There are several previous approaches that have produced good segmentation results for dental radiographic images. A semi-automatic approach which is based on a contour extraction method in order to overcome the limitation of fuzzy tooth contours caused by the low image quality, has been proposed in [10]. It involves three stages; image segmentation, pixel classification, and contour matching. Results showed that the proposed method is able to produce a promising object segmentation using small sets of data. However, further improvement is needed as the algorithm had difficulties working on the blurry image, occluded object and irregular shapes of teeth which eventually led to the over-segmentation problem. Another semi-automatic approach has been discussed in [11] which also involved three stages; morphological contour detector, Gaussian filtering, and an existing semiautomatic contour extraction method. Results affirmed that the proposed algorithm is able to achieve a precision rate of 0.7. However, the algorithm faced the same limitation as [10] when the blurry input image with the occluded object is used. A new advanced approach has been proposed in [12] where the authors presented a new semi-supervised fuzzy clustering algorithm known as SSFC-FS based on Interactive Fuzzy Satisficing. The algorithm was tested on 56 dental radiographic images and are proven to produce better clustering result compared to other methods such as Fuzzy C-Means, Otsu, eSFCM, SSCMOO, FMMBIS and another version of SSFC-FS with the local Lagrange method known as SSFC-SC.

A fully automated system for person identification using dental radiographic images requires prior segmentation of the images into sections containing a single tooth. The dental shape extraction based on the contours information is a common approach for features extraction. In [13], the authors used the integral intensity projection in segmenting upper jaw, lower jaw, and individual tooth separately followed by the shape extraction based on the fast connected component. The final stage includes the distance measurement using the Mahalanobis distance equation to measure the means of matching distance. Results showed that the algorithm has produced a better performance compared to their previous work which is based on semi-automatic contour extraction [14]. An improvement of contour extraction has been made in [15], where the use of point reliability measuring method and calculation of Hausdorff distance (HD) between the contours is applied. Experimental results showed that this approach is able to achieve 100% of accuracy for single tooth segmentation. Another fully automated segmentation approach which is based on thresholding method for the dental age assessment has been proposed in [16]. The main goal of this approach is to optimize the threshold value, T for the application of the mean, median and OTSU thresholding method. Choosing the right value of T will produce a good segmentation result where the foreground and background images can be effectively separated. Meanwhile, a fundamental study on region-based segmentation approach has been discussed in [17] where the comparison between canny and Sobel methods has been made in order to fulfil the requirement of Demirjian method for assessing all of the teeth types in quadrant 2 and quadrant 3. Besides, the application of pixel-based image segmentation associated with the mathematical morphological operation for the object extraction has been proposed in [18]. The results showed that the proposed method is able to produce the lowest mean absolute error (MAE) compared to other existing methods [19].

Other than that, a powerful tool method called Watershed Transform, which is based on the region segmentation method has been widely used in medical images. The original watershed method was first done by Lantuejoul in 1978 [20], and its applications have been widely described by Beucher and Meyer [21]. In this paper, a gradient image of panoramic dental radiograph is computed based on the convolution of the original image with a Sobel filter. Then, a mathematical morphological reconstruction together with the binary thresholding operation is performed in order to obtain the internal and external markers which act as a reference to a watershed algorithm. Several image preprocessing operations are applied to enhance object features. They include intensity adjustment and median filtering.

3. Proposed framework

In this study, the digital panoramic radiographs of 678 Malay children (332 males and 346 females) with known chronological age and gender were retrospectively selected. The selection criteria are as follows; Malay ethnicity, age between 5 and 14 years, no medical evidence or pathology affecting tooth development visible on the panoramic radiographs, and presence of a complete set of left mandibular permanent teeth includes erupted and unerupted tooth. The aim of this study is to perform the segmentation and classification of mandibular 1st molar present in panoramic dental images for age estimation. Figure 1 shows the flowchart of the proposed methodology where the overall framework includes the pre-processing, segmentation and classification. Figure 2 shows the image of panoramic dental radiograph where the region inside the bounding box represents the 1st molar of left mandible. This object is noted as the object of interest for later processing. According to the Atlas [9], which is currently being used in clinical practice, eight stages of dental development (A-H) are taken into consideration for age estimation. This will require the human observers to rate the image according to the atlas shown in figure 3. Based on the rating, an individual's chronological age is estimated by directly converting the scores according to a table proposed by Demirjian [9].

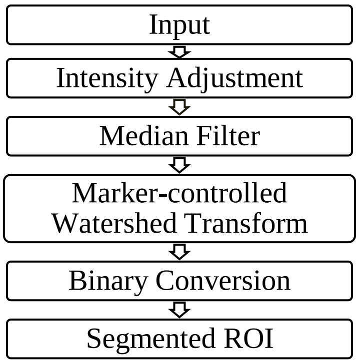

Figure 1. Flowchart of methodology

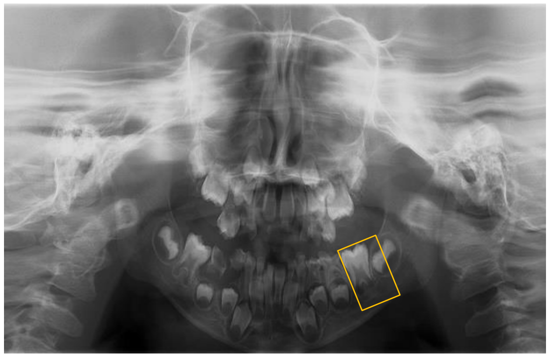

Figure 2. Mandibular first molar tooth present in panoramic dental radiograph

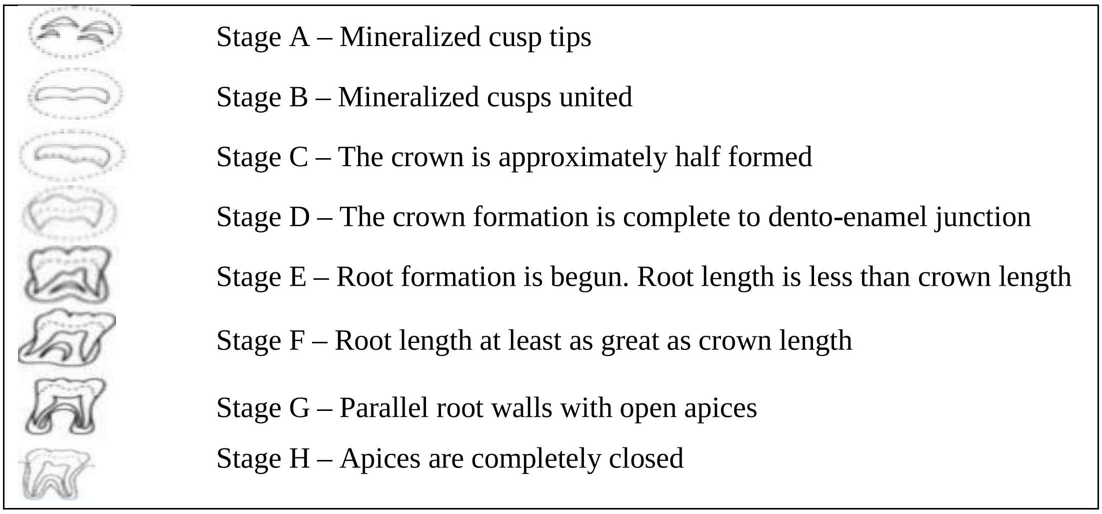

Figure 3. Sample of dental development of first Molar. (a) Stage E and (b) Stage G.

3.1. Image preprocessing

In this stage, the region of interest (ROI) is cropped to a dimension of 256 x 256. Then, the intensity adjustment and median filter are applied. This operation is used to enhance the image by highlighting the foreground and suppressing the background image. This will be beneficial for later processing. In addition, a median filter is used to remove an impulsive noise while preserving the object edges where a kernel filter with a size of 9 x 9 is applied. Based on this filter, middle pixel value from a series of pixels n is extracted and later to be sorted in ascending order of pixel, y. Then, the middle value is calculated by dividing the total number in the series y by two.

3.2. Image segmentation

Object segmentation is done using the marker-controlled watershed transform. This method has been widely used in processing the medical images as it has the capability in producing a complete division

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of the image. The concept of watershed comes from the field of topography, where it creates the line that determines where a drop of water will fall into a particular region. In mathematical morphology, grayscale images are considered as topographic relieves. In the topographic representation of a given image I, the intensity value of each pixel stands for the elevation at this point. The operation of the watershed transform on its own will lead to the over-segmentation problem [22]. In order to overcome this limitation, the watershed transformation required to pass through several pre-processing operations. In this study, an introduction of marker image to the watershed transformation has led to a robust and flexible segmentation of objects with closed contours, where the boundaries are expressed as ridges. This marker image is created in order to control the transformation process before obtaining good partitioning objects. The image is in a binary image consisting of either single marker points or larger marker regions, where each connected marker is placed inside an object of interest. Figure 4 shows the steps of marker computational, where the morphological image reconstruction is applied before the Watershed transformation. Reconstruction is a morphological transformation involving two images that are called marker and mask. In this proposed framework, a structuring element of 'disk' structure with a radius of 5 is applied. Morphological image processing contains two essential operations which are erosion and dilation. The erosion followed by dilation operation results in the opening image, while vice versa produces a closing image. Dilation and erosion are operations that thicken and thin the objects in the image, respectively. The dilation of image *f* by structuring element *B* denotes as$f \oplus B$, where it can be defined as follows:

$$(f \oplus B)(x,y) = max\left\{f(x-x_1, y-y_1) + B(x_1,y_1) \middle| \begin{matrix}(x-x_1, y-y_1) \in Z, \\ (x_1,y_1) \in Z\end{matrix}\right\} \quad (1)$$

While the erosion of image f by structuring element B denotes as$f \ominus B$, where it is defined as follows:

$$(f \ominus B)(x,y) = min\left\{f(x+x_1, y+y_1) - B(x_1,y_1) \middle| \begin{matrix}(x+x_1, y+y_1) \in Z, \\ (x_1,y_1) \in Z\end{matrix}\right\} \quad (2)$$

The opening and closing image *f* by structuring element *B* and image reconstruction can be computed respectively, as follows:

$$f \circ B = (f \ \Theta \ B) \oplus B \quad (3)$$

$$f \bullet B = (f \oplus B) \ \Theta \ B \quad (4)$$

$$R(f) = \beta\left(\theta_1, (f \oplus B)\right), \ 0 \leq l \leq n \quad (5)$$

where β is the reconstruction operation, and θ_1 is the image obtained from the closing operation. The *l* and *n* indicate the time and the size of structuring element *B*, respectively.

The reconstruction of an opening image is used to restore the original shape of the object that remains after erosion while the reconstruction of opening-closing is used to restore the remaining object after dilation. Figure 5 shows the output images for both reconstruction operations. Next, the connected components of pixels with a constant intensity value, t whose external boundary pixels all have a value less than t were computed. These connected components are called regional maxima. Figure 6 (Top) shows the regional maxima superimposed with the original image. In binary image, pixels that are set to 1 are identified as regional maxima while all other pixels are set to 0. Therefore, the resultant image from this morphological operation is labelled as a marker image. Based on this regional maxima, watershed boundary or ridge lines can be computed using the Euclidean distance where the distance transform assigns a number that is the distance between every pixel in binary and the nearest nonzero pixel. The resulting ridge lines will isolate the foreground object and preserve the object of interest. Then, the watershed transform concept is then applied to the gradient image obtained early in the process where the regional maxima and watershed ridge lines are assigned. Figure 8 (Below) shows the segmented region of interest, which represents the mandibular first molar tooth.

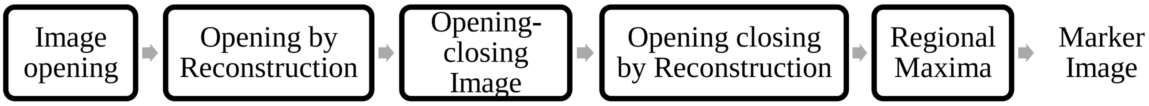
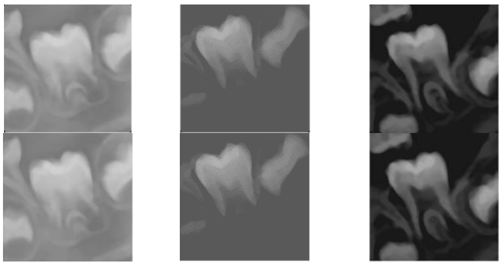
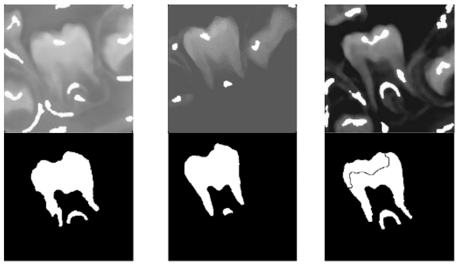


Figure 4. Process of computing the marker image



(a) (b) (c)

Figure 5. (Top) Opening-by-Reconstruction of original images. (Below) Opening-closing by Reconstruction applied on top images



(a) (b) (c)

Figure 6. (Top) Regional Maxima of Opening-Closing by Reconstruction. (Below) Watershed segmented region

4. Results analysis

The important characteristics of panoramic dental radiographs obtained from dental X-ray machine include density and contrast of the object that can be seen in the image. The density indicates the degree of darkening of an exposed x-ray on the object of interest where the illumination transition is from white to black. Density is usually influenced by exposure factors and object density. A tooth with a metal implant has a high density and will cause the bright region to appear inside the object of interest in a dental radiograph. Contrast represents the difference in densities which indicates the blackness between various regions on image. High contrast is best for caries detection while low contrast is best for a periapical or periodontal evaluation. The contrast of the image varied with other subjects. This is due to subject variability as every patient may have different tooth density, thickness and composition. Therefore, in this proposed method, a preprocessing algorithm is applied to enhance the original image which includes the intensity adjustment and median filtering for the purpose of optimizing the illumination and sharpen the edge of the image.

Watershed transform without marker initialization produced the over-segmentation result. Therefore, in the segmentation stage, an output from the preprocessing algorithm is fed into the segmentation algorithm where the marker image is computed prior to the watershed transformation. Initially, the gradient image associated with edge detector using a Sobel filter is computed where this method created an image emphasizing edges. In this analysis, the kernel filter of 3 x 3 neighbourhoods has been used. The structuring element of "disk" with a radius of 5 gave an optimal object delineation and produced good segmentation results as it is able to mask the small area of the object such as the root apex. The algorithm also has a capability to segment the beginning of root formation of 1st molar where it occurs in stage E of its developmental. Another structuring function of "sphere" with a radius of 5 has been tested using the proposed algorithm. As a result, the algorithm only able to segment 4 earlier stages of dental development which are stage A to D. Therefore, the selection of the optimal structuring element function affects the good segmentation output. In addition, based on the promising results obtained, it is shown that a watershed transform is a powerful tool for segmenting object with complex regions. Features extraction includes the measurement of crown, distance of the left crown to root, distance of the right crown to root and the area of the segmented object. Table 1 shows the mean, μ and standard deviation, σ of the extracted features for all stages. By assuming a normal distribution of all of the extracted features, the probability distribution of measured features in every stage of development can be estimated. Figure 7 shows the normal distribution of all extracted features. Based on the distribution of all features (a), (b), (c) and (d), a minimal difference of mean seen in every stage. However, the positive trend of distribution is shown and has proven that every stage of development shows the increment of white pixel. Among these four features, the area shows the significant difference in mean value where the difference of mean area in every stage is clearly seen in figure 7 (d) compared to others. Next, the extracted features are classified using the SVM classifier where the accuracy of 92.8 is obtained.

Table 1. Mean and standard deviation of extracted features for all stages

	Crown Distance		Left crown-root		Right crown-root		Area	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
A	1.02	0.11	1.15	0.10	1.15	0.10	9054.68	137.17
B	1.15	0.08	1.21	0.08	1.21	0.08	9988.12	49.92
C	1.29	0.09	1.35	0.04	1.35	0.04	9558.62	551.12
D	1.43	0.07	1.41	0.04	1.41	0.04	11142.45	495.59
E	1.45	0.05	1.45	0.03	1.45	0.03	12266.92	790.69
F	1.70	0.06	1.56	0.09	1.56	0.09	13094.26	180.22
G	1.71	0.05	1.61	0.06	1.61	0.06	14145.94	409.97
H	1.83	0.04	1.76	0.03	1.76	0.03	14166.01	419.80

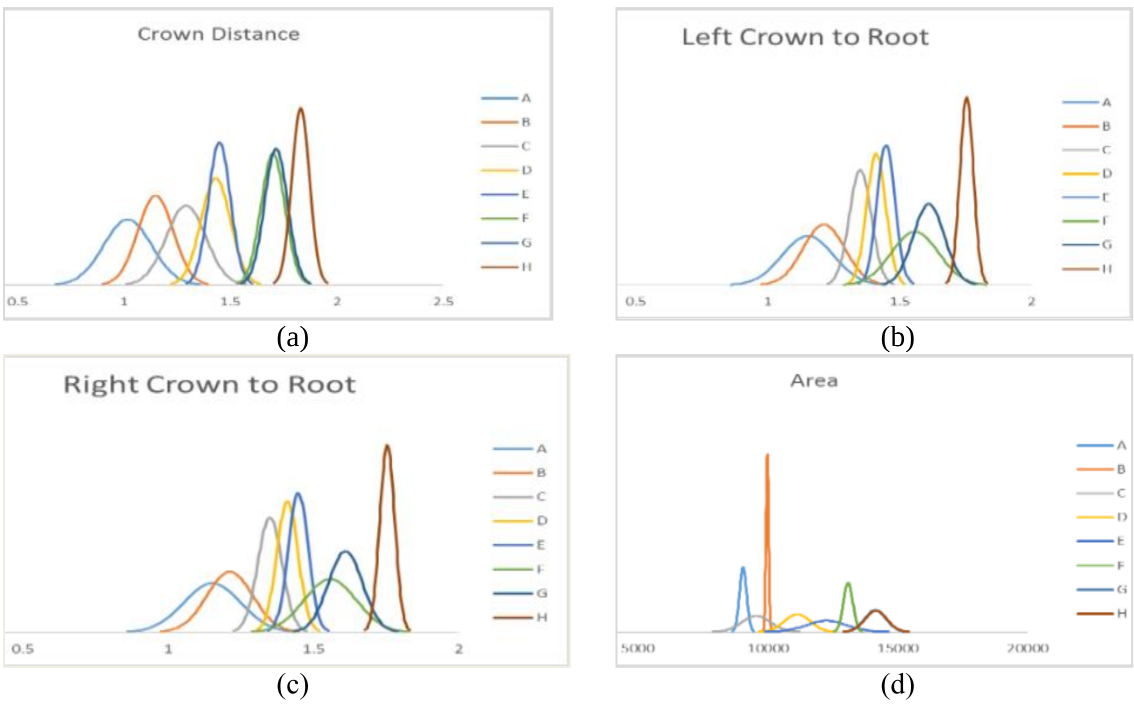


Figure 7. Normal Distribution of extracted features.

5. Conclusion

Dental age assessment which based on atlas method has been utilized as the fastest and cheapest procedure to estimate the age of unrecognized individuals as a part of forensic human identification. Traditionally, the assessment was done manually by the experts, and it required a number of human observers to rate the teeth based on the atlas. This can be an intricate procedure when a large number of forensic identifications is needed. In this research, the region-based segmentation method called watershed transform associated with two sequential preprocessing algorithms has produced a good segmentation output. It is also proven that the algorithm has a capability to automatically segment regions with an acute angle such as root apex. Next, all of the extracted features are classified using the SVM classifier. The overall performance of the proposed automated system to segment the first molar tooth on panoramic radiographs has successfully produced a segmentation and classification accuracy of 94% and 92.8%, respectively.

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