Non-Cooperative Iris Segmentation: A Survey

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Abstract*— *With the advancement in information technology, human identification based on iris pattern has registered rapid strides in the recent times. Present day research has been focusing on finding a solution to provide secure and reliable identification and verification in human related problems. There has been a paradigm shift in the study of human identification from cooperation to non-cooperation on the part of the subjects. The purpose of this paper is to present a survey to facilitate the researchers, who are in the beginning stage of their investigation in iris recognition, to understand the current trends and the implemented methodologies of the non-cooperative iris segmentation. As the non-cooperation deals with the various heterogeneous factors such as obstruction, occlusions by eyelids and eyelashes and affected with so many noise factors, the segmentation of the iris from the eye image is becoming the ultimate challenge. Most of the authors have concentrated on the identification of eyelids and eyelashes which are quite normal under the non-cooperative situation. In this paper, the following categories of iris segmentation and their implementation are analyzed with: (1) Both the pupil and iris as (i) circular model and their improvements (ii) noncircular model and (2) active contour models.

Index Terms: Biometrics, Iris, Segmentation, Computer Vision, Non-cooperation, Pattern Recognition.

1. INTRODUCTION

Biometric systems have emerged as an elegant solution to provide secure and reliable identification and verification. Since the people cannot change their physical characteristics as they lose their password or identity cards, biometric methods are being considered as the most promising method for the human identification. The verification process may always expect the cooperation from the subject whereas the identification it may not be the case. Situations where the cooperation is not expectable from the individual such as criminal activities etc., are the greater challenges for the researchers. The use of iris biometric system has been highly supported by both public and private sectors in order to replace or improve the traditional security systems. Iris provides a better solution for these challenges since the acquisition device can be fixed somewhere else which is not required to reveal to the humans. The challenging part of the iris recognition in the non-cooperative situation is segmentation. In this paper, an exhaust search over the researchers who are concentrating on the non-cooperative iris segmentation has been summarized their work.

2. IRIS SEGMENTATION

Flom and Safir [1] obtained a patent during 1987 for the iris biometric system for highly controlled condition which includes the size of the pupil, an adjustable light source for illuminating the eye at the selected value. According to their conclusion the probability of similarity in the iris pattern between two distinct persons are only at 1 in 1072. The concepts which are included in the patent were unimplemented. In order to implement an automated algorithm to identify the human using iris biometric, Flom approached Daugman and Daugman proposed the first commercial prototype. Earlier Daugman proposed an integro-differencial operator [2] by assuming both the pupil and iris boundary as circular form to identify the iris and pupil boundary using the parameters radius r, circle center coordinates x0 and y0. The equation of the integro-differencial operator is

$$\max_{r,x_0,y_0}\left|G_\sigma(r)*\frac{\partial}{\partial r}\oint_{r,x_0,y_0}\frac{I(x,y)}{2\pi r}ds\right|$$

Where I(x,y) is the input iris image, $G_\sigma(r)$ is the smoothing function.

Wildes [3] proposed an iris localization system by applying the edge detection algorithm with the help of the intensity of the image followed by the circular Hough transform. The efficiency of his method is dependency of threshold values on the edge map construction.

Based on these two methodologies, most of the researchers in this field have developed their algorithms which are well suitable for the cooperative situation. The major works adopted on the iris segmentation in the non-cooperative situation are focused in this work. The following section will describe the non-cooperative iris segmentation survey.

3. NON-COOPERATIVE IRIS SEGMENTATION

Proenca has introduced for the very first time a non-cooperative iris segmentation methodology [4] which could give better result for the heterogeneous and noisy iris image.

When there are no enough sources to differentiate the sclera and iris region, the failure of the integro-differential operator has been noticed by Proenca. In order to improve the image contrast and better result by overcoming the so called drawback they applied two preprocessing optimizations, namely equalization and Binarisation.

In order to achieve an accurate and robust iris segmentation, Proenca evaluated the Tuceryan's [5] methodology – a moment based texture segmentation algorithm. Proenca proposed a methodology which begins the process with image feature extraction followed by Fuzzy clustering which can classify each pixel and will produce the intermediate image. By applying this intermediate image as an input to the Canny edge detector the edge map is being

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ehp[constructed. Finally, the circular Hough Transform has been applied to get the expected segmented iris image. The feature extraction and clustering algorithm which was carried out by the authors are given as follows.

Feature Extraction: By performing several tests, Proenca concluded that the coordinates of the pixel position and their intensity are the more appropriate characteristics for the segmentation. They named this feature set as 'Pixel position + intensity'. The noise factors due to the eyelid may affect the posterior circumference identification stage.

Clustering Algorithm: Proenca evaluated the forth coming four unsupervised clustering and classification algorithm; Kohonen's self-organizing maps/topological ordered maps, K-means, Fuzzy K-means, Expectation-maximization.

Zhaofeng He et al., proposed an accurate and fast iris segmentation. Though his approach is not directly dealt with non-cooperation, the methodology which they published in their publication indirectly may suit for the non-cooperative situation. They identified three inherent drawbacks of the existing methods which are not solved yet; the time consumption due to N3 parameter space large search; circular models such as integro-differential operator and circular Hough transform are not efficient for the non-circular iris boundaries; No attention for heterogeneous characteristics such as eyelid localization, reflections, eyelashes and shadows.

A.Abhyankar[6] et al., and E.M.Arvache[7,8] et al., used active contour model to identify the pupillary and iris boundaries. They concluded two primary issues of the iris segmentation to identify the pupillary and iris boundaries accurately; to deal with occlusion by several noise factors. Both the challenges are most possible occurrence in the non-cooperative situation.

The author has addressed these issues with the following sub steps.

Iris Detection and Reflection Removal: The authors utilized Adaboost-cascade detector which was proposed by Viola and Jones [9] in their implementation for the face objects. The method was effective for detecting well-structured objects like faces. The authors also identified that the failure of the method due to specular reflection [10] in iris image. So, they proposed a reflection removal method before applying Adaboost-casecade detector. The reflections were filled with the help of bilinear interpolation method. By adopting the Adaboost-cascade method to train an iris detector, they classified the iris detection into the following two steps; to reduce the unnecessary computation, non-iris regions are eliminated before further processing; and a sample position of the iris center is identified in the iris image.

Pupillary and Iris Boundary Identification: By considering the sample position of the iris center which was outputted from the previous step, the novel iterative Pushing and Pulling (PP) method has been used for the pupillary and limbic boundary localization. This method was derived from the Hook's law which will work as follows. Initially the iris image is transformed into polar coordinates and then vertical edge detection is performed on the transformed image. The resulted edge point and the center point with an imaginary spring-like line in the Cartesian coordinates are joined.

They also addressed the following practical problems of the effective implementation of this method; the rough position of the pupil center; Edge point detection; setting of 'spring' constant; Convergence criteria. We recommend the readers to refer [11] for details of the special considerations.

Edge fitting based on PP method: PP method possess a natural capability of more accurate edge fitting methods (snakes [12]) which can address an inherent problem for all circle-model-based iris localization method when encountering noncircular iris boundary. The required number of edge detections and circle fitting iterations enable PP method to perform well for the edge fitting. The pupillary and limbic boundaries are calculated via the following approximation cubic smoothing spline

$$p\sum_{i=0}^{N-1}[r_{\theta i} - S(\theta_i)]^2 + (1-p)\int |S''(\theta)|^2 d\theta$$

where the distance between the edge data and spline can be measured using the first part of the equation and the roughness of the fitting is being measured using the second part. The authors suggested choosing the p value as 0.85 for pupillary boundary and 0.5 for the limbic/iris boundary.

Eyelid Localization (EL): In order to identify the upper and lower eyelids the authors applied the 1D rank filter and histogram filter. Here the rank filter is used to remove the eyelashes and histogram filter addresses the shape irregularity. The flow of the eyelid localization which was implemented by the author is, the Region of interest (RoI) of the original iris image, on which a horizontal rank filter with L=7 and p=2 is being applied; then it is being applied to the vertical edge detection followed by histogram filtering; finally, the exact shape of the eyelid was obtained by parabolic curve fitting.

Eyelashes and Shadow Detection: It is one of the important origins of occlusion that challenges iris segmentation. Eyelashes and shadows are generally darker than eyelids and iris. Keeping this as a constrained the author has fixed the detection strategy as thresholding. Motivated from the implementation of Daugman's methodology, the author has introduced a new mwthod to achieve a proper threshold by analysing the intensity distributions of different iris regions [13, 14]. Their approach starts with classifying the candidate iris region into two segments: ESfree and EScandidate. Then, the intensity histograms of both segments are calculated.

As a continuous effort of their previous work, Tieniu Tan et at., [15] implemented a coarse localization scheme based on clustering method which localized the approximate position of the iris and identified the non-iris regions. They implemented the efficient and robust segmentation of noise iris images for non-cooperative iris recognition through the following four modules; coarse iris localization; eyelid localization; pupillary and limbic boundary localization; and eyelash / shadow detection.

The authors implemented the eight-neighbour connection based clustering, to cluster the whole iris image into different part according to their structure.

After the successful clustering of the iris image, they used the semantic refinements to further identify these cluster regions as candidate iris region or non-iris regions for the purpose of coarse iris localization. According to the authors perspectives the following semantic priors have been considered.

- Iris region can be localized using the intensity value as the sclera and iris are greatly varied from their intensity value. And its region usually has '-o-'like shape.
- Eyebrow boundary always seems like a dark horizontal stripe.
- A spectacular frame usually has a dark and approximately rectangle like shape.
- In order to make understand to computers about these semantic priors, the authors used Shape, intensity and position of each clustered regions.

After identifying the rough position of iris, in order to identify the pupillary and limbic boundary, the authors modelled the pupillary and limbic boundary as two non-centric circles, and they used Daugman's integro-differential operator. Due to heavy computation and the algorithm affects from local optima they proposed a novel integro-differential constellation to tackle both problems. The authors constructed an integro-differential ring to calculate the search direction.

The basic idea of the integro-differential ring is, initializing the search point at P0; integro-differential operator is being calculated on eight-neighbour points and proceeded further to attain the highest score of integro-differential. This search will be stopped using 'stop at once" strategy, which means integro-differential of neighbouring pixel is larger than the present point then they stop and turn to this point. In order to overcome the local optima of eight-neighbour integro-differential ring, integro-differential constellation has been used. Also, to reduce the computation the authors adopted three integro-differential ring with radius of 1, 3 and 6. In non-cooperative iris segmentation, the resulted output of the previous step is tending to be non-circular. Since Fourier series expansion [16] and cubic smoothing spline [17] usually fail because of the difficulty in detecting sufficient valid edge points and the authors tried to detect and eliminate the localization inaccuracies via intensity statistics.

For eyelid localization, the authors implemented the same as they have implemented in their earlier work. The used the canny edge detector for edge detection and Eyelid curvature model for shape irregularity of eyelids.

Eyelashes and Shadows (ES) are the most important factors which are degrading the performance of the iris segmentation. The authors investigated with the assumption that the threshold vales of the iris and non-iris region will greatly vary as the majority sclera portions contains white pixels.

During 2011, Yingzi Du et al [18]., published their research work on non-cooperative iris segmentation. They performed the segmentation by accepting the input of eye image from the video. Since the input images are taken from the video they paid their initial attention to detect the availability of the iris region in the image. In order to eliminate the poor quality images (images without iris region) they applied a quality filter on the input image. Moreover, they used the existence of the specular reflections [19] as a manifestation of an open eye. All images were down sampled to one twenty-fifth of the original image size. The average pupil radius is ten pixels in the downsampled image. A high-pass filter was designed to detect the specular reflections of the downsampled images.

After eliminating the poor quality images, an orientation invariant cluster-based video image thresholding was applied. Based on the intensity value of the pixel and its eight neighbors, an alternate to a regular thresholding approach, K-Means Clustering algorithm has been applied. The clustering of this proposed method has been carried in two steps as follows.

- In order to identify the clusters a K-means clustering method has been used followed by principle component analysis (PCA) to reduce the clustering center dimension.
- Classification step, where the detected clusters are used to threshold the image.

Instead of applying the edge detection algorithm for the entire image, it was applied only to the region of interest (ROI) [20] for coarse pupil localization and validation. To detect and remove the eyelids and eyelashes the authors proposed the following strategy. Eyelids are the horizontally strongest edges [21]. The authors proposed a window based variance and intensity thresholding to separate the noisy data from the iris region. The edges of the noise data are stronger than edges of the iris pattern, and that the intensity of noise is either higher or lower than the iris pattern.

R.Chen et al [22]., investigated the iris segmentation into two aspects. Circular based model and Non-circular based model. They proposed a segmentation algorithm based on adaptive mean shit and merged active contour model which produced better result for the non-cooperative situation. They tested their methods with the images which are taken under the near infra-red condition.

The author has differentiated their approach from integrated active contour model (IAC) which was proposed by Sagiv et al., [23] in two main aspects. In addition to the boundary & region details, local statistical prior for the texture are also integrated in their constructed model; A new mathematical model expression has been formulated by the author [24] in order to evaluate the energy function.

The entire segmentation strategy adopted a coarse-to-fine method. This Adaptive Mean Shift algorithm is proposed to make sure that the sample position of the iris can be accurately identified the degraded image by fully utilizing iris structure information. Merged active contour (MAC) Model – the initial contour is successfully driven to iris boundary.

They developed a segmentation model by adopting two stages in their methodology. The first stage deals with the coarse localization which was embedded with the Adaptive mean shift; iris region representation and coarse localization. The second stage is fine segmentation based on merged contour model.

After localizing the coarse pupil, a fine segmentation has been performed by the authors based on the MAC. Based on the MAC model proposed by [25] iris segmentation consists of the following 4 main steps.

a) Initial curve = A circle with right geometric parameters

b) This boundary is detected by minimizing the energy function

c) A new circle is placed in the proximity of the inner iris boundary. Using the minimized energy function this circle will be expanded until the outer iris boundary.

As the size of the circle is subject to vary by distance, the segmented iris is further normalized into a rectangular block with a fixed change.

4. RESULTS

In order to reduce the search time over the circle Radman et al., [26] used the circular Gabor filter to determine the approximate position of the pupil center. They adopted an improved Integro-differential operator (IDO) to segment the iris [27]. To stay away from the false segmentation [28] that may arise due to the non-cooperative situations such as occlusion of the eyelids, the path of the contour integration is delineated by the ranges –π/4:π/4 and 3π/4:5π/4 rad. The adopted IDO operator defined by the author is given below.

$$\max_{(x_0,y_0,r)}\left|G_\sigma(r) * \left[\frac{\partial}{\partial r}\left(\int_{-(\pi/4)}^{(\pi/4)}\frac{I(x',y')}{\pi r/2}ds + \int_{(3\pi/4)}^{(5\pi/4)}\frac{I(x',y')}{\pi r/2}ds + \right)\right]\right|$$

After the eyelid and pupil detection the eyelid has been detected using live-wire method.

A K-mean clustering algorithm has been applied to find the expected region of the iris segmentation by sahmoud and Abuhaiba [29] with the motivation of reducing the search region of the edges followed by a circular Hough transform to fine the localize the iris center.

In our earlier work [30] we proposed the non-cooperative iris segmentation in three phases. The pupil and eyelashes are removed using the threshold values followed by canny edge detection has applied. Finally, Cartesian to polar conversion has been applied to extract the segmented iris image.

In order to save the computation time, Wan et al. [31] used a Laplace pyramid which was implemented for the circular based iris segmentation. Zuo and Schmid [32] implemented ellipse fitting with threshold to localize the Pupil and Integro-differential operator for limbic boundary.

Active Contour Model: Providing a high contrast good quality iris image as an input, Daugman proposed an active contour method to identify the pupil and limbic boundary. Vasta [33] proposed a two stage iris segmentation algorithms whereas the first stage used the elliptical model to estimate the pupil and limbic boundary of the iris and the next stage they applied the modified Mumford-shah functional on the estimated boundaries of the first stage to identify the exact pupil and limbic boundary. Shah and Rose [34] investigated with Geodesic active contour.

By initializing the mask value manually to the active contour [35, 36] Talebi et al. [37] suggested a Ballon active contour to identify the pupil and limbic boundary. Koh et al. [38] and Hilal et al. [39] used circular Hough transform to initialize the active contour. Frucci et al. [40] implemented a watershed transformation and circle fitting for iris segmentation for outer boundary which was considered as Non-circular method where as they implemented circular method for the pupil.

The major drawback identified in all these methods is the complexity in initializing the active contour. Gradient Vector Force (GVF) active contour [41] has proposed to overcome the drawback of the traditional active contour model [42]. The proposed method of is again affected due to the noisy factor.

Due to the occlusion by eyelids and eyelashes it is difficult to identify the iris and limbic boundary in non-cooperative situation. The traditional snake active contour may not be suitable for the heterogeneous images captured under the non-cooperative situation. Mohammed A. M. Abdullah et al. suggested adding an additional force with the GVF active contour model. The absence of this additional force may lead the curve to shrink and vanish even though the perfect edge detection is being applied. The GVF snake [43] can be rewritten with the proposed model as,

$$\alpha v_{ss} - \beta v_{ssss} - V + K\bar{n}_s = 0$$

Where,n(s) is the unit vector normal to the contour at point v(s) and K is the amplitude of the additional force.

When the sign of the above equation is getting changed it can be applicable for the shrinking active contour model as given below,

$$\alpha v_{ss} - \beta v_{ssss} - V - K\bar{n}_s = 0$$

A unit normal vector of a curve is,

$$\bar{n}_s = \frac{T'(s)}{||T'(s)||}$$

Where, T(s) is the unit tangent vector, T'(s) is its derivative and ||. || defines the Euclidean norm.

Mohammed A. M. Abdullah et al., investigated that the pupil boundary is a non-circular though the image is captured with the cooperation of the individual. Similarly, the limbic boundary is also a non-circular, and the captured image will always be occluded by the eyelashes, reflections, obstructions and eyelids. The authors have divided their segmentation model into two sections as pupil and iris segmentation.

Pupil Segmentation: The iris image capturing system can be divided into two methods based on the lighting conditions of the environmental surface; Images captured under Near-Infrared (NIR) light & Images captured under wavelength light. The authors conducted the experiment on both the possibilities of the iris image capturing methods.

Iris image captured under NIR light:

The thresholding methods are the most appropriate to identify the pupil boundary as they are darker than the other portion of the iris image. Also the dissimilarity between the pupil and iris area is high.

CASIA V4.0 and MMU2 database image are used by the authors. The author suggested using their proposed active contour method which identifies exact pupil boundary whereas initial boundary of the pupil has determined using morphological operations by clustering the iris image using mean shift method. It can be achieved by the following four sub steps.

1. Reflection Removal

The greater variations of pixel value in the local neighbourhood intensity value have been used to identify the light reflection spots in the pupil region.

2. Mean Shift

Mean shift [44] is a nonparametric iterative algorithm used for clustering based segmentation which seeks a mode or local maxima of density of a given distribution. This method is also used for object tracking. The author suggested using this concept for clustering the image with a uniform kernel [45].

3. Identifying the coarse parameter of the pupil

Later, the adoptive thresholding method proposed by Otsu [46] has been used to isolate the pupil region from the eye image. The identification of pupil coarse parameter may be affected by the eyelashes. In order to overcome these effects, morphological operation is imposed on the binary image. After this circular Hough transform is being applied. Since the vertical edges of the pupil is the input to the circular Hough transform, a canny edge detector is being applied to the binary image whereas the search region is applicable only to the pupil region instead of the whole image. Since the unwanted edges are being removed here, this will lead to reduce the processing time and reduce the error rate of the false circle detection by circular Hough transform.

4. Pupil segmentation with active contours

The output of the circular Hough transform followed by canny edge detection is used as an initial mask of the pupil which lies inside the pupillary region. Then the proposed active contour method will expand this initial mask to achieve the exact pupil segmentation.

Iris images captured under visible light

Unlike images captured under the NIR light [47] these images will have the low contrast between the iris and pupil. Due to this thresholding methods are not suitable method for the pupil boundary identification. Differentiating the pupil with the help of threshold value will probably fail in this case. The heterogeneous images like UBIRIS V1 and UBIRIS V2 database are used. It can be achieved by the following four sub steps.

1. Closed eye detection

Sclera isolation is achieved using HSI (Hue, Saturation, and Intensity) color model. Moreover, the availability of the white pixel is identified using the saturation(S) component. This may help us to identify the availability of the sclera. Based on the Otsu’s thresholding methodology the author concluded that the eye image can be discarded if minimum 1000 white pixels are not available

2. Skin detection

The occurrence of the pupil will be available only in the non-skin region. In order to reduce computational time, the authors suggested using skin colour model which can discriminate the skin and non-skin pixel. Then skin likelihood of each pixel of the trained data is calculated using Baye’ classifier.

3. Identifying the coarse parameters of the pupil

The authors used YCbCr color space [48] and histogram equalization to identify the coarse parameter of the pupil from the images captured under the wavelength light. Then canny vertical edge detector followed by circular Hough transform has been applied to identify the coarse parameter of the pupil.

4. Accurate pupil segmentation with active contour

The output of the circular Hough transform followed by canny edge detection is used as an initial mask of the pupil which lies inside the pupillary region. Then the proposed active contour method will expand this initial mask to achieve the exact pupil segmentation

IRIS Segmentation: According to the proposed active contour model of iris segmentation algorithm, it consists of the following steps.

1. Eyelashes Removal - 2D order-statistic filtering is applied on the iris images
2. Active Contour Initialization
3. Utilizing the Eyelid Position
4. Eyelids Removal

The overview of the non-cooperative iris segmentation methods is presented and the major studies are elucidated in Table1.

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Table 1. Summary of the Non-Cooperative Iris Segmentation Methods

Author	Method Proposed / Used	Remarks
Cooperative Methods		
Daugman [2]	Integro-Differential Operator	First commercialized method for iris segmentation
Wildes [3]	Circular Hough Transform followed by Edge detection algorithm	Circular based model
Non-Cooperative Methods		
Proenca [4]	Feature Extraction and Fuzzy K-Means clustering algorithm	Initial method of non-cooperative iris segmentation
Zhaofeng He[11] et al.,	Iris detection: Adaboost cascade detector with reflection removal Boundary Identification: Pushing and Pulling method (Edge fitting) Eyelid localization: 1D rank filter and Histogram Eyelashes and shadow detection: Intensity distribution of different iris region	Indirectly suit for the non-cooperative situation
Tieniu Tan et at., [15]	Coarse localization scheme based on clustering method Eight-neighbor connection based clustering	Localized the approximate position of the iris and identified the non-iris region
Daugman [16]	Active contour Model	High contrast good quality image is required
Yingzi Du et al., [18]	Input image from the video Quality filter with specular reflections Downsampled with high pass filter K-Means clustering	Edge detection applied only to the Region of Interest
Fitzgibbon et al., [20]	Direct Least square fitting	Mathematically model the pupil boundary
Sagiv et al., [23]	Integrated Active contour Model	Formulated the new mathematical expression for the energy function
R.Chen et al [25]	Adaptive mean shift Merged active contour model	Both circular based and Non-circular based model
Radman et al., [26]	Circular Gabor filter Improved integro-differential operator Live-wire method	Approximate position of the pupil center determined
sahmoud and Abuhaiba [29]	K-Means clustering followed by circular Hough transform	motivation of reducing the search region of the edges
Wan et al., [31]	Laplace pyramid	Reduced computation time for circular based iris segmentation
Vasta [33]	Pupil: elliptical model Iris: modified Mumford-shah functional	Two stage iris segmentation
Talebi et al [37]	Ballon active contour	initial mask manually set to the active contour
Frucci et al., [40]	watershed transformation and circle fitting	Non-circular method
Mohammed A. M. Abdullah et al., [41]	Gradient Vector Force (GVF) active contour Reflection Removal: local neighborhood intensity value, Mean shift, adoptive thresholding method, circular Hough transform followed by canny edge detection, Proposed active contour method	Overcome the complexity in the initializing the active contour Images captured Under both NIR and Visible light are considered separately

5. CONCLUSION

The authors of the various research papers of our survey have considered both circular and non-circular models. In the case of non-cooperation, the authors considered the images captured under visible and NIR light. The notable methodologies used for non-cooperative iris recognition from our survey are fuzzy-based clustering algorithm, Fourier active contour approach, Adaboost-cascade iris detector, direct least square fitting, pushing and pulling

Method, Adaptive mean shift, merged active contour, improved integro-differential operator, Geodesic Active contour and Gradient vector flow. It is expected that the methods presented in this survey would motivate the young researchers to think of further developments in various aspects and invention of new methods in the interesting area of human identification.

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