

Determination and Comparison of Fabric Pills Distribution Using Image Processing and Spatial Data Analysis Tools

Lenka Techniková, Maroš Tunák, Jiří Janáček

Abstract—This work deals with the determination and comparison of pill patterns in 2 sets of fabric samples which differ in way of pill creation. The first set contains fabric samples with the pills created by simulation on a Martindale abrasion machine, while pills in the second set originated during normal wearing and maintenance. The goal of the study is to determine whether the pattern of the fabric pills created by simulation is the same as the pattern of naturally occurring pills. The system of determination and comparison of the pills is based on image processing and spatial data analysis tools. Firstly, 3D reconstruction of the fabric surfaces with the pills is realized with using a gradient fields method. The gradient fields method creates a 3D fabric surface from a set of 4 images. Thereafter, the pills are detected in 3D fabric surfaces using image-processing tools in the MATLAB software. Determination and comparison of the pills patterns of two sets of fabric samples is based on spatial data analysis using tools in R software.

Keywords—3D reconstruction of the surface, image analysis tools, distribution of the pills, spatial data analysis tools.

I. INTRODUCTION

PILLS are small balls of entangled fibers which protrude from the fabric surface and are created by friction on the textile surface during normal wearing and maintenance of clothes. Pilling resistance of fabric is obviously an important characteristic of its quality and durability, thus the objective characterization of the pills by estimating their prevalence, size distribution and spatial homogeneity during the process of wearing is of interest.

As the natural process of pill creation during wearing of clothes takes a relatively long time this process can be accelerated by simulation on various instruments used in the textile industry. A pilling resistance test of textile materials is carried out by several instruments, especially by a Martindale abrasion machine. The principle behind simulation of pill creation is based on the friction arising from rubbing one sample surface against itself or another standardized material.

The two heads of the Martindale machine are placed against each other where the lower head is stationary and the upper head is moveable. The upper head is moved in the form of a

Lissajous figure. A Lissajous figure is a geometric figure starting as a straight line, continuing over a widening ellipse up to a narrow ellipse and the process ends as straight line again. Therefore, it is assumed that the pills should have homogenous distribution.

Objective methods for detection of pills and pilling evaluation are often based on image analysis methods. Several studies proposed to segment the pills from their fabric structure in different ways. Study [1] showed a method for the measurement of fuzz fibers (which are able to create pills) based on image analysis techniques applying on projection images of fabric. Other study [2] used corner detectors for finding crossing points of yarns and detecting of pills in grayscale images of fabric. Method based on 2D discrete Fourier transforms dividing of the fabric image on periodic and non-periodic part for the purpose of recognition of pills is presented in work [3]. Performance of edge flow method for extraction of pills from RGB images characteristic is shown in article [4]. Other researchers used a wavelet reconstruction scheme with undecimated discrete wavelet transforms. Thereafter, pills can be extracted from decomposed image where periodic fabric pattern is suppressed [5]-[7]. A further system for reconstructing 3D fabric surfaces by using two side-by-side images of a pilling fabric captured on a pair of regular digital cameras without special lighting was introduced in study [8].

The main aim of this study is to improve the image analysis method for pill detection and characterization and to find out whether the fabric pills created by simulation on the Martindale machine have the same pattern as the pills created by normal wearing and washing. Our approach is based on a 3D reconstruction of the fabric surfaces in which: 3D reconstruction is carried out by gradient fields' method; pill detection is achieved by image analysis tools in MATLAB software; and evaluation of the pills pattern is achieved using spatial statistics. The spatial patterns of simulated and naturally created pills are characterized using such spatial data analysis tools as point density, K - function and other explorative characteristics in R software. The explorative characteristics of the spatial pill patterns are also compared with the characteristics of fitted model of point processes. Such a comparison can provide hints as to the mechanism of pill formation.

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II. REPRESENTATIVE SETS OF FABRIC SAMPLES

For the experiment 100 fabric samples with various weaves, colors, patterns and pills on the fabric surfaces were used. The samples were divided into two sets. The first set contained 60 samples with pills on their surfaces created using the Martindale machine. The second set has 40 samples with pills created during normal wearing and washing of the clothes.

Two representative sets of samples A and B were selected in this study. Set of samples A contained 2 samples: A1 (plain weave) and A2 (twill weave) with pills created by simulation on the Martindale machine. Set of samples B contained 2 samples too: B1 and B2 (knitted fabrics) with the pills created during normal wearing and washing. The samples have various numbers of pills on the surfaces from 30 to 137 (samples were created in all of grades of pilling). Fig. 1 shows 2 representative sets of samples A and B. The weave, the number of pills, the pilling grade and the method of pill creation of the set samples A and B are presented in Table I. Usually in the textile industry, evaluation of the pilling grade of samples is based on image standards with 5 grades of pilling (1 – 5) consequently: from slight surface fuzzing (grade of pilling 1) up to severe pilling (grade of pilling 5).

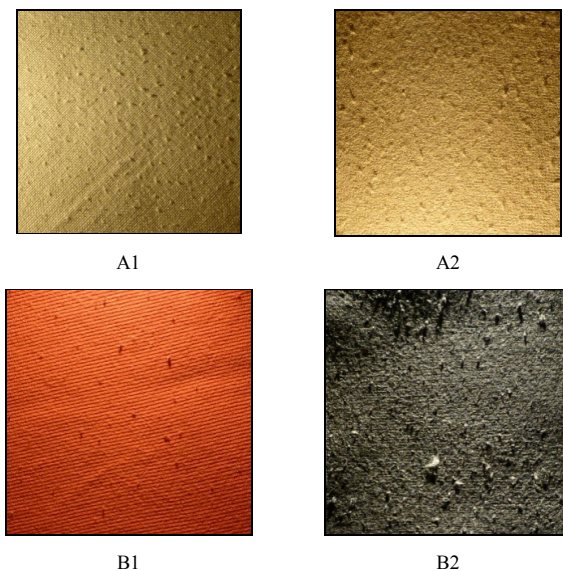


Fig. 1 Original images of two representative sets of samples A, B

TABLE I
BASIC DESCRIPTION OF THE FABRIC SAMPLES

Sample	Weave	Number of pill	Grade of pilling	Method of pill creation
A1	Plain	137	1	Simulation
A2	Twill	86	2	Simulation
B1	Knit	30	3	Wearing
B2	Knit	102	2	Wearing

III. 3D RECONSTRUCTION OF FABRIC SURFACES AND DETECTION OF PILLS

First of all, image capturing of the samples was needed for realization of 3D reconstruction of the fabric surface based on

gradient field method. The samples were laterally illuminated evenly from 4 sides: from the top, bottom, right and left sides. For each of the samples the set of 4 images was captured by Canon EOS 400D camera. The fabric surface was reconstructed in 3D by using a gradient fields method from the set of 4 images. The basic elements for the reconstruction are shadows of the pills created by lateral illumination of the samples during image capturing. The principal aim of the method is to make a gradient field of the image integrable (possible to be mathematically intergrated). If the gradient field is integrable, it is possible to reconstruct the surface by using the Poisson Solver Equation in MATLAB implementing Neumann boundary conditions [9]-[11]. The algorithm used for 3D reconstruction of the fabric surfaces is described in study [10]. 3D reconstructed surfaces of the samples created by the gradient fields method are showed in Fig. 2.

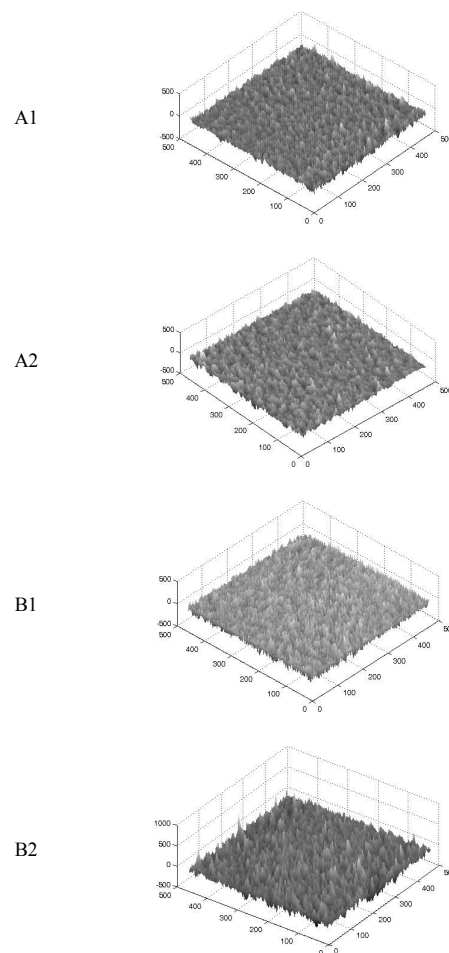


Fig. 2 3D reconstructed fabric surfaces of samples A1, A2, B1 and B2

Consequently, detection of pills is possible. Detection of the pills is based on image-processing tools in MATLAB [12]. It involves, for example, these operations:

- application of a Gaussian filter to remove the noise in the 3D images of the samples

- morphological operation *open* for grayscale image
- segmentation of the pills with the help of global thresholding (the threshold was experimentally set up around 0.2)
- morphological operations *open* for binary images
- removal of smaller objects than 7 pixels and objects connected to the boundary of the binary image
- using the *regionprops.m* function to acquire pill characteristics such as the number of the pills and so on

Fig. 3 shows the original images of the representative sets of samples A and B and the binary images of the samples where the white objects represent detected pills.

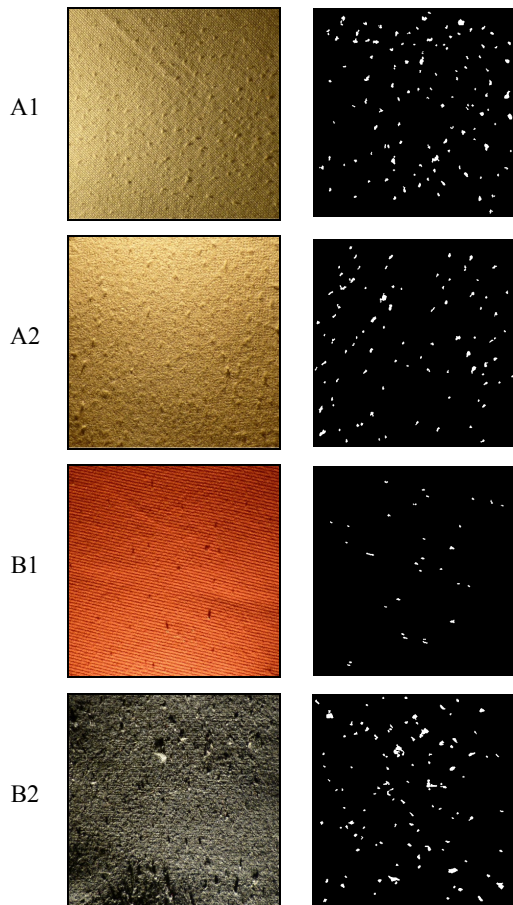


Fig. 3 Origin images of samples A1, A2, B1 and B2 in first column and corresponding binary images with detected pills as the white objects in second column

IV. DETERMINATION OF PILL DISTRIBUTION– SPATIAL DATA ANALYSIS TOOLS

After detection of the pills, qualitative evaluation of the pilling is possible. Qualitative evaluation of pilling means determination and evaluation of the pills distribution in a sample space. Generally, point patterns can be homogenous or inhomogeneous [13]-[15]. Spatial data analysis tools such as the density of the points, *K*-function and other explorative characteristics are used to determine pill distribution in the

representative sample sets. Acquisition of point patterns of the pills is required. A point pattern of the sample means to display the points system where the points represent the centroids of the pills.

Fig. 4 shows the variety of point distribution for homogeneous point patterns, a) random, b) regular and c) clustering.

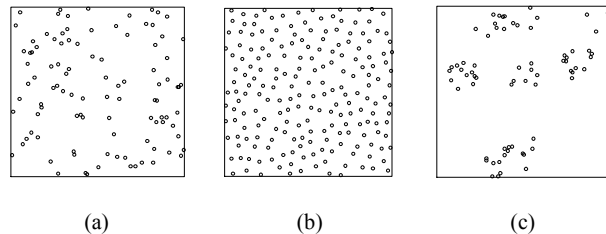


Fig. 4 Illustration of the variety of point distribution for homogeneous point patterns a) completely random, b) regular and c) clustering [13]

A. Density of the Points

The density of the points acted as a visual evaluation of the homogeneity of the points in the point pattern. The density of the points is defined as the expected number of points per unit area.

To display the local point's density it is necessary to define the value of standard deviation of the Gaussian smoothing kernel. The size of standard deviation was set on 60 pixels in this study (the image size 500 x 500 pixels). The density of the pills of the sample sets indicates that the point pattern is inhomogeneous. Fig. 5 illustrates the point patterns of the samples where the points represent the centroids of the pills and the density of the representative sets of the samples.

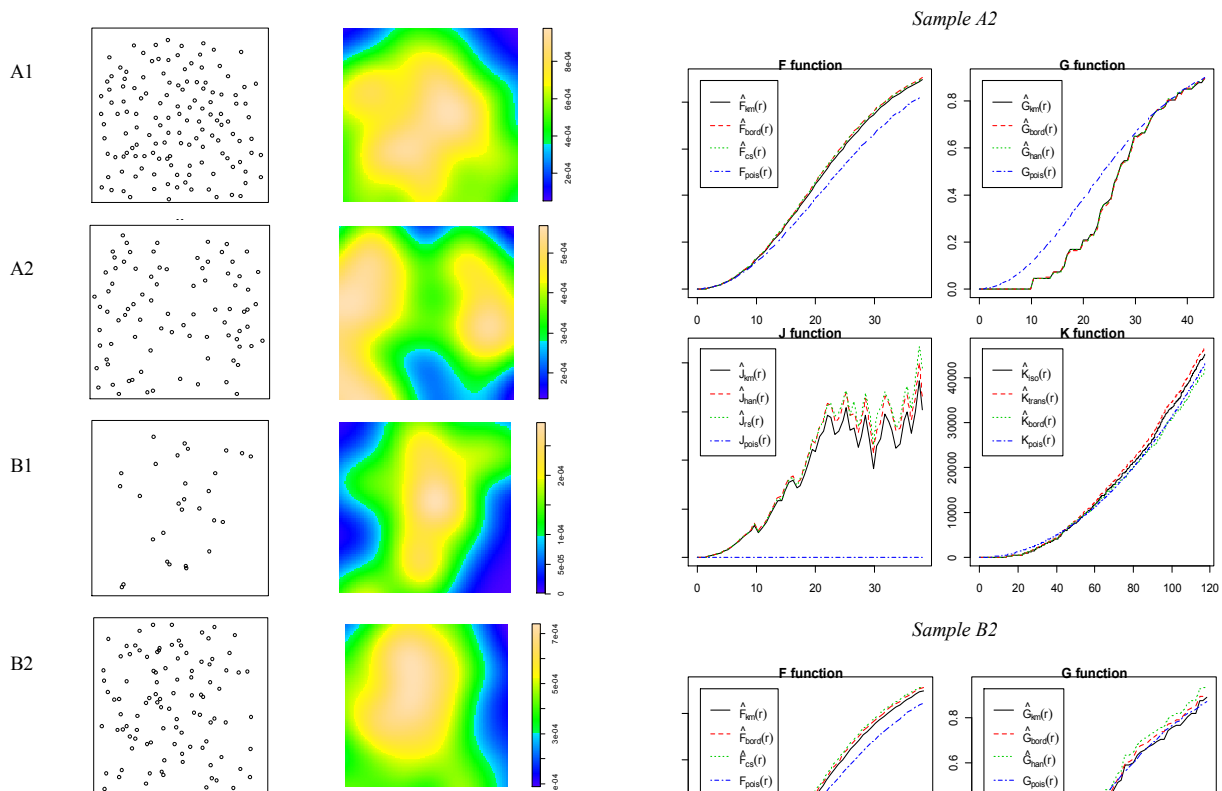


Fig. 5 Point patterns (first column) and local density of the representative sets of the samples (second column)

B. Explorative Characteristics

Explorative characteristics such as F , G , K and J – functions were used to determine and evaluate the pill distribution of the sample sets. The main aim was to find out whether the pills have homogenous or inhomogeneous, random or nonrandom distribution in their point pattern compared with the theoretical Poisson model. The functions are defined as [14]:

- K -function for stationary point pattern is the mean number of points in a defined circle with radius r .
- F -function is a cumulative distributive function for the distances between the reference points and their nearest neighbors.
- G -function is a distributive function for the distances of the points from their nearest neighbors in the point pattern.
- J -function is a combination of functions G and F $J(r) = 1 - G(r) / 1 - F(r)$. $J=1$ identifies the Poisson pattern, $J < 1$ identifies clusters, $J > 1$ defines regularity.

It was necessary to calculate edge effect corrections for each of these characteristics. Several edge correction methods are available, for example: Meier, Chiu – Stoyan, Hanisch, Ripley edge corrections. They usually are weighted versions of a cumulative distributive function [13]. Examples of explorative characteristics with edge effect corrections (F , G , K and J – function) calculated for sample A2 and B2 are shown in Fig. 6.

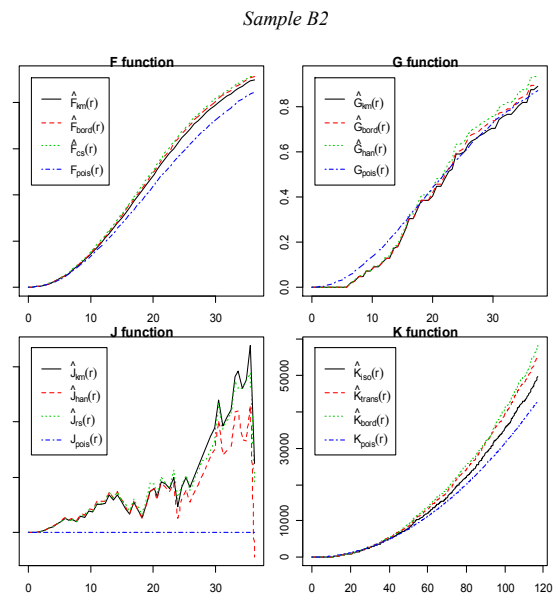


Fig. 6 Explorative characteristics as F , G , K and J – functions calculated for samples A2 and B2 with various methods for edge effect correction

C. K – Function

K -function was chosen as the most important tool for evaluating pill distribution in the sample space. The density of the points indicated that the point pattern of the pills of sample sets is inhomogeneous. It was important information for estimating the model which describes the system of pill distribution. The point pattern of the pills was fitted using the Strauss model (the samples do not have the same intensity of points over the whole space) displayed with the help of the K -function for inhomogeneous point patterns. The Strauss model fitted the point pattern of the pills very well because the pills repulsed each other over short distances and over longer distances the point's distribution is inhomogeneous. Firstly,

the parameters of Strauss model must be defined such as the radius of interaction and the degree of the polynomial. The radius of interaction of the Strauss model was set at value 25, which means that the points have a minimum distance of 25 pixels between them. A third degree polynomial was chosen as the parameter of the density of the Strauss model.

The upper and lower envelopes of the simulated K -functions were calculated for comparison of the simulations with the original pattern using the envelope test. The upper and lower envelopes represent the maximum and minimum intervals of K -functions for several simulations of the Strauss model. If the observed K -function lies inside the envelopes and approaches the theoretical K -function, then the fitted model is correct. For example, fitting of the point pattern of the pills using another model is illustrated here – Poisson model for inhomogeneous distribution of the points. The observed K -functions of the point patterns of the samples lie outside of the envelopes or do not approach the theoretical Poisson K -functions (red line) for small values of r . The Poisson model for random distribution of the points is thus unsuitable to describe the point pattern of the pills. Comparison of the K – functions for inhomogeneous Poisson model and inhomogeneous Strauss model are presented in Fig. 7.

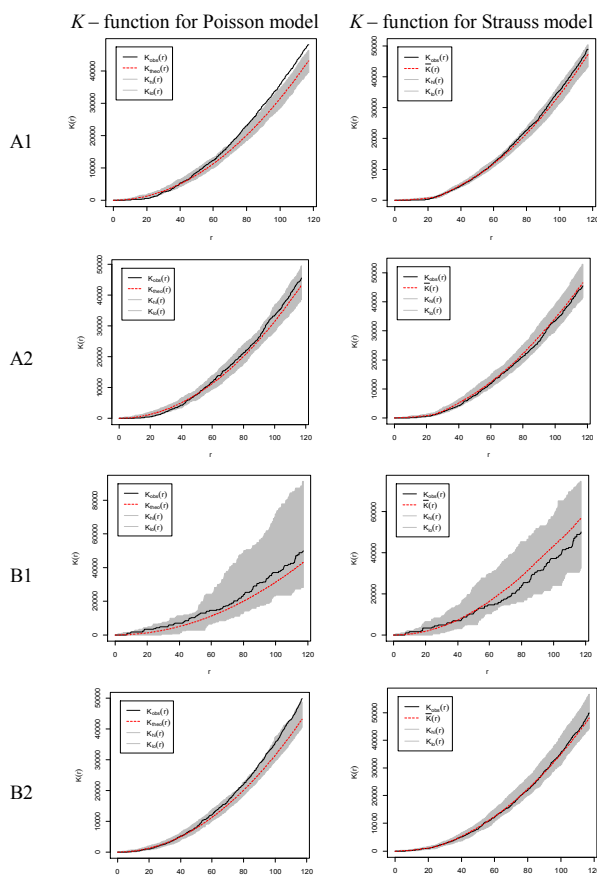


Fig. 7 Comparison of K – functions of the representative sets of samples for inhomogeneous Poisson and Strauss model

V. RESULTS AND DISCUSSION

The density of the points, the explorative characteristics and especially the K -function were used as spatial data analysis tools to determine pill distribution and to compare sample sets. The points in the point patterns of the samples represented the centroids of the pills.

The density results of the pills showed that the point pattern of sample sets is inhomogeneous. K -function for determinate of number of points in a defined circle with radius r in the point patterns was chosen as a reference characteristic used for decisions about pill distribution. The Strauss model appeared to be a suitable model to describe the point pattern of the pills. The observed K -functions for the sample sets lie inside the envelopes of the Strauss model, which suggests that the pills repulsed each other to a distance of 25 pixels and at longer distances distribution of the points is inhomogeneous.

A comparison of 2 models for fitting the inhomogeneous point pattern of pills is presented here. The Poisson model for a random inhomogeneous point pattern was used as the first model. This model was found to be inappropriate for fitting the point pattern of the pills because the observed K -functions lay outside of the envelopes or did not approach the theoretical K -function for the Poisson pattern (red line). The Strauss model appropriately fitted the point pattern of the pills of the sample sets.

The inhomogeneous Strauss model as a model for the spatial pattern of the pills captures well both the repulsion of the pills at short range and inhomogeneous distribution at longer ranges. It gives better results than the inhomogeneous Poisson model or the homogeneous Poisson or Strauss model (data not shown).

VI. CONCLUSION

The main goal of this study was to determine the difference between pill distribution of 2 representative sets of samples using image-processing tools and spatial data analysis tools. This means whether a Martindale machine created pills with the same distribution as the distribution of pills formed by normal wearing and washing. The first set of samples contained samples with the pills created by simulation on a Martindale machine. The second set of samples contained samples with the pills created during normal wearing and washing.

Firstly, a 3D reconstruction of the fabric surface was created using a gradient fields method. The gradient fields method reconstructed the fabric surface from a set of just 4 images. The method proved to be an effective and fast tool for the 3D reconstruction of fabric surfaces with pills. Image-processing tools included in MATLAB software were applied to detect the pills in 3D images of the samples. Detection of the pills using image analysis tools seemed to be relatively accurate.

When the pills were detected, it was then possible to obtain point patterns of the pills and to determine pill distribution of the samples. Points in the point patterns of the samples represented centroids of the pills. Spatial data analysis tools were used to determine and evaluate pill distribution.

The density of the points acted as a visual evaluation of whether the points were distributed homogeneously or inhomogeneously in the sample space. The density of the points of 2 sets of the samples indicated inhomogeneous distribution of the pills. Consequently, the model for fitting the point pattern of the pills was chosen. The Strauss model for inhomogeneous K -functions was chosen as the best fit of the point pattern of the pills. According to the results of the spatial data analysis tools it is possible to state that the pills of both representative sets of the fabric samples have inhomogeneous distribution and their point pattern can be fitted using the Strauss model with the help of the K -function. This means that the pills repulse each other to a short fixed distance and over longer distances the points are inhomogeneous. Distribution of the simulated pills created by a Martindale machine corresponded with the distribution of naturally formed pills.

The observed repulsion of the pills is due to the fact that a pill is formed by gathering fibers from its neighborhood and neighboring pills are effectively competing for the fibers.

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