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A fuzzy morphological hit-or-miss transform for grey-level images: A new approach

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Abstract

The translation of the hit-or-miss transform (HMT) for grey-level images from the HMT for binary images is not simple. Initially established as a powerful tool for morphological binary image processing, some generalizations for grey-level images have been proposed in the literature. The difficulty lies in the definition of the complement of a given grey-level image. In this paper, after performing a detailed review of the different approaches proposed in the literature, including those based on fuzzy logic, we propose the definition of the hit-or-miss transform for grey-level images in the framework of the fuzzy mathematical morphology based on fuzzy conjunctions and implications under the duality with respect to a fuzzy negation approach. Some theoretical properties of this operator are studied when a general fuzzy conjunction is considered. In particular, we prove that this fuzzy morphological HMT reduces to the binary one when it is applied to binary images. After that, we focus on the fuzzy morphological HMT derived from t-norms and we introduce the concept of "part of an image" which will guide the study of the desirable properties of our operator and the interpretability of the obtained results. Some preliminary experimental results provide evidence of the potential of this tool to be feasible in design algorithms for detecting patterns. Moreover, some comparisons with other hit-or-miss transforms proposed in the literature are performed.
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1. Introduction

Mathematical Morphology (MM) was introduced in the early sixties by Matheron [36] and Serra [56]. Originally developed for binary images, it provides an extremely useful set of tools for the analysis and shape recognition in this class of images. Soon thereafter, it was extended to grey-level images (GL) according to different approaches (see [22,35,56,59,61,66]). Fuzzy mathematical morphology (FMM) is a generalization of the binary morphology using concepts and techniques from the fuzzy set theory [8,41]. This theory allows a better treatment and a represen-

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tation with greater flexibility of the uncertainty and ambiguity present in any level of an image. In our concern, an up-to-date book about the methods and techniques of mathematical morphology, from the crisp to fuzzy case, passing through segmentation, evaluation and decision, filtering and connectivity, color and multivariate images, applications to medical image analysis, satellite imagery and document analysis, among others, can be found in [46].

Among the tools provided by the MM, there is the hit-or-miss transform (HMT) [22,56], which is capable of identifying in a binary image groups of pixels satisfying certain geometric restrictions or forming a specific configuration. The HMT is well defined and widely used [56,59] in binary image processing and it involves the search and location of a predefined shape, represented by a composite structuring element (SE) which is composed of two other ones, in the image and its complement. The SEs are designed to match the geometry of objects of interest in the foreground and background of the image. Despite this, there have been few authors who have considered its possible extension to grey-level images. The main difficulty, as we shall see, resides in that this operator uses in its definition the image and its complement, and this last concept in grey-level mathematical morphology is not easy to model.

In an effort to extend its use, several researchers have proposed definitions and methods to extend the HMT to grey-level images. Khosravi and Schafer [27] developed the concept of "template matching" based on a generalization of the HMT in grey-level images with noise. Schaefer and Casasent [55] presented a version of HMT applied to object detection. Ronse, in a theoretical paper [54] generalized the HMT to complete lattices. Raducanu and Grana [53] proposed a greyscale HMT based on level sets (LSHMT). Soille [59] introduced two extensions for hit-or-miss, the so called unconstrained HMT and the constrained HMT and he applied them to the analysis of topographic maps. A detailed account of these extensions can be found in [44,49]. In particular, in [44] a unified framework to compute a grey-level HMT (GLHMT) was presented (see [38] for a new conceptual view of the HMT). Also, recent extensions of HMT to multivariate images have been proposed [2,62,64]. A recent review on multivariate of HMT can be found in [31].

The hit-or-miss transform is often used to detect specific configurations of pixels and it has interesting applications. We can find applications in document analysis [9] where openings are developed by replacing erosions with hit-or-miss transforms (see [54] for a similar development in digital contour extraction). These generalizations are applied to binary text images. Moreover, a blur hit-or-miss transform is defined in order to improve the robustness of the HMT. Also, there are applications in template and pattern matching [4,27,54], and boundary and edge extraction [24,33]. In [24] an edge detector is defined based on the binary HMT modifying the structuring element. Moreover, it is useful in face detection and localization [15,52]. In [15], a face feature detection algorithm based on a fuzzy hit-or-miss transform (FHMT) for color images is presented, and in [52] a method which gives the image coordinates of the face in grey-level images is proposed. This procedure is defined on the morphological multiscale fingerprint image (MMF). The face location is estimated as the maximum likehood image window matching both erosive and dilative MMF models of the object. More applications can be found in medical image analysis [10,45], where in [10], a method for 3D segmentation of coronaries using a grey level HMT is proposed. Another considered application is building and vehicle detection [26,32,60], where in [26], a morphological shared-weight neural network (MSNN) is used to classify image pixels from roads into targets and non-targets. The MSNN extracts features using an HMT. In [32], a new method for building extraction in Very High Resolution (VHR) remotely sensed images based on binary mathematical morphology operators is proposed. In particular, there is an adaptive HMT with varying sizes and shapes of the structuring elements. In [60], a method for building detection in VHR multispectral images is presented. This method is based on spectral information of the image and the HMT. The HMT is used to assign pixels to buildings. The HMT is also studied in satellite and astronomical image analysis [1,25,49]. In [1], a method to filter noise based on HMT is proposed for digital images. It is applied to the detection of solar features in H-alpha solar images. In [25], a method for partition a satellite image into homogeneous regions based on HMT is proposed. In [49], a new formulation for a robust HMT to deal with very noisy images is proposed. The method is applied to astronomical images in order to detect very faint objects In analysis of geographic and topographic data [59,63], we can also find some applications of the HMT. In [59], a method to detect linear and non-linear features in spatial databases is introduced. This method consists of two steps. The morphological operators like HMT are used in the first step to find the most suitable re-segmenting scale in the geographic data.

The great number of different applications induces the existence of many different methodologies to apply the HMT. In some of these applications the hit-or-miss transform is used after the image is preprocessed and binarized. However, the main drawback of some of the previous papers is that they do not contain any theoretical analysis of the proposed transformations. In particular, they only include some empirical analysis of the behavior of their operators.

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