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Theoretical-information quality model for image segmentation

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Abstract

A problem of image segmentation quality is considered. The problem is viewed as selecting the best segmentation from a set of images generated by segmentation algorithm at different parameter values. A segmentation quality model for selecting the best segmentation based on information redundancy measure is proposed. The developed technique was applied to SLIC and graph-cut segmentation algorithms. Computing experiment confirmed that the segmented image corresponding to minimum redundancy measure demonstrates suitable dissimilarity when compared with the original image. The segmented image which was selected using the proposed criterion, gives the highest similarity with the ground-truth segmentations.

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Keywords: Image Segmentation; Segmentation Quality Model; Information Redundancy Measure; Variation of Information

1. Introduction

This paper is concerned with the problem for choosing parameters of segmentation algorithm in order to obtain the best segmentation quality. Haralik and Shapiro [1] defined segmentation as a process of partitioning image represented by a region Ω into n non-overlapping subregions Ω_1, Ω_2,..., Ω_n. The pixels in subregions are grouped by some feature and differ from the elements of the adjacent areas. Formal definition of segmentation is given in [2]. Any of the segmentation algorithms has one or more parameters that affect the result. Parameters

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should be set in order to provide the best quality of segmentation. The problem of setting optimal parameter values is rather difficult.

Segmentation process can be represented by a model:

$$V = F(U,t), \tag{1}$$

where U is an input image, V is a segmented image, F is an operator describing segmentation algorithm, t is a parameter.

In this work, we formulate the problem of segmentation quality as follows. Suppose, for a given input image U we obtain a set of Q segmented images $\mathcal{V} = \{V_1, V_2, ..., V_q, ..., V_Q\}$ varying parameter t. It is necessary to choose image V_q providing minimum for a given performance criterion $M(U, V_q)$:

$$q_{\min} = \arg\min_q \left(M(U, V_q) \right), \; q = 1, 2, ..., Q. \tag{2}$$

When solving various tasks of image analysis, an adequate quality criterion should be applied. This may be a visual evaluation of an expert or any quantitative measure. The results of segmentation are usually compared with manually partitioned images [3]. These images are referred as ground truth. The quality can be described by quantities characterizing boundary detection error, region consistency, and segment covering. In papers [4, 3] the authors used precision-recall framework for comparing segment boundaries. In [5] Martin et al. proposed global and local consistency errors as the measures for comparing segments in images generated by segmentation algorithm and ground truth segmentations. Some other measures for evaluating segmentation quality are discussed in works [6, 7, 21].

If the segmentation operation is considered as clustering of pixels, then the set-theoretical, statistical, and theoretical-information measures proposed to compare data clustering results, are used [8]. The most commonly used are: chi-square measure; Rand Index [9] and its variants [10]; Fowlkes-Mallows measure [11]; mutual information and normalized mutual information [12]; variation of information [13]. These measures allow one to compare different versions of partitioning image into non-overlapping regions.

In paper [14], another approach is proposed. Parameter of the graph-cut segmentation algorithm [20] was chosen depending on the result of estimating similarity between segmented and original images. As a measure of similarity, the authors proposed to use weighted uncertainty index computed using the values of the normalized mutual information [12] between the color channels of the original and segmented images. Frosio and Ratner proposed to choose parameter value providing the best segmentation in terms of visual perception. The dependence of the uncertainty index on parameter value (and accordingly, the number of the segments) is approximately monotonous (see [14] and Figure 1). Using expert estimations of partitions at various parameter values, the areas of under-segmentation, over-segmentation, and optimal segmentation were outlined in the space “parameter - uncertainty index”. At the processing phase, an iterative procedure was applied to obtain parameter value providing the best image partition. The drawbacks of this method are related with the necessity of the training procedure. Segmentation algorithm produces acceptable results only for those types of images which were involved in the training process. It is also preferable to have peaked or concave dependency of the used performance index on the parameter value.

If the segmentation method is developed according to the criteria of visual perception, then a model of the human visual system should be used. In work [16], a theoretical-information model of the human visual system is proposed. The model is based on Barlow hypothesis [17] about minimizing data redundancy at the early stages of signal processing in the human visual system.

In this work, two main requirements are taken into account. First, the quality criterion should provide the best segmentation in terms of visual perception. Second, the quality criterion should have an extremum. Basing on principle of minimizing data redundancy [16], we propose to use a measure of information redundancy as a segmentation quality criterion. We show that a particular method of forming theoretical-information criterion provides it with extremum. In order to demonstrate that the segmented images corresponding to the minimum of the