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Multi-class learning for vessel characterisation in intravascular ultrasound

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1 Abstract

In this thesis we tackle the problem of automatic characterization of human coronary vessels in Intravascular Ultrasound (IVUS) image modality. The basis for the whole characterization process is machine learning applied to multi-class problems, where the Error-Correcting Output Codes (ECOC) framework is used as central element for the design of multi-class classifiers. Two main contributions are presented in this thesis. First, a novel method for the design of potential function for Discriminative Random Fields is presented, namely ECOC-DRF. The method is successfully applied to problems of object classification and segmentation in synthetic and natural images. Furthermore, ECOC-DRF is applied to obtain a robust classification of the main morphological areas of coronary vessels in IVUS sequences. Based on ECOC-DRF, the main regions of the coronary artery are robustly segmented by means of a novel *holistic* approach, namely HoliMAb, representing the second contribution of this thesis. The HoliMAb framework is applied to problems of lumen border and media-adventitia border detection, achieving an error comparable with inter-observer variability and with state-of-the-art methods.

2 ECOC-DRF

ECOC-DRF [1] is a framework where potential functions for Discriminative Random Fields are formulated as an ensemble of classifiers. We introduce the *label trick*, a technique to express transitions in the pairwise potential as meta-classes. This allows to independently learn any possible transition between labels without assuming any pre-defined model. The Error Correcting Output Codes matrix is used as ensemble framework for the combination of margin classifiers. Given a set of data observation $\mathbf{X} = (\mathbf{x}_1, \ldots, \mathbf{x}_L)$ which is associated a set of labels $Y = (y_1, \ldots, y_L)$, ECOC-DRF model is formulated as:

$$P(Y|\mathbf{X}) = \frac{1}{Z(\mathbf{X})} \prod_{i=1}^{L} e^{\alpha_N \vec{\delta}_{N_i}} \prod_{j \in \mathcal{N}_i} e^{\vec{\alpha}_E^T \vec{\delta}_{E_{ij}}}, \tag{1}$$

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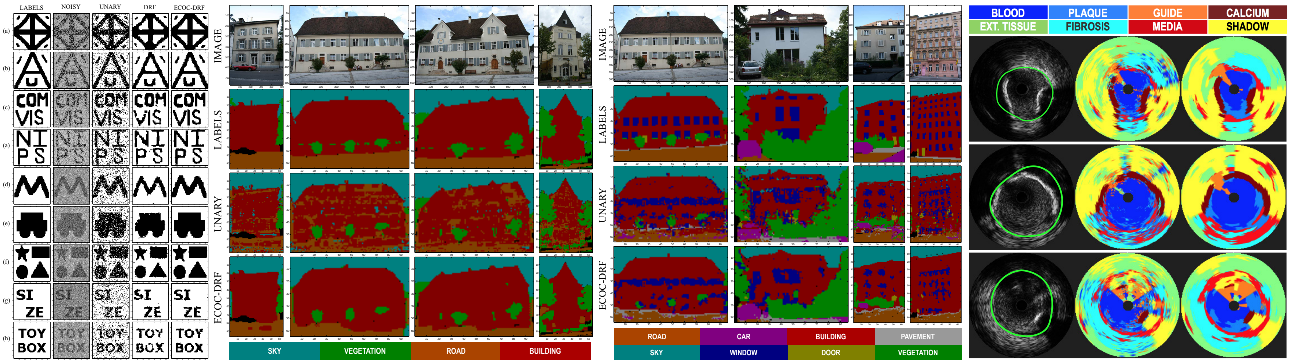

(a) (b) (c) (d)

Figure 1: Examples of image denoising (a) and pixel-wise classification in natural images (b,c) for the ETRIMS dataset, when four classes (b) and eight classes (c) are considered. In (d) the vessel characterization and automatic media-adventitia border detection in Intravascular Ultrasound images are depicted.

where $\vec{\delta}_{N_i}$ and $\vec{\delta}_{E_{ij}}$ are the distance measures for the unary potential and the pairwise potential, respectively, $\alpha_N < 0$ is a coefficient that governs the behavior of the unary potential and $\vec{\alpha}_E$ is a vector of coefficients regulating the behavior of the pairwise potential. In a multi-class problem with K classes, we assume the existence of a distance vector $\vec{\delta}(\mathbf{x}) \in R^{1\times K}$, related to $m(\mathbf{x})$ where each k^{th} value is as smaller as the sample $\mathbf{x}$ is more likely to belong to the k^{th} class. We applied ECOC-DRF to a large set of classification problems, covering both synthetic and real images for binary and multi-class cases, outperforming state-of-the art in almost all the experiments. In Figure 1, examples of image denoising and of image classification using ECOC-DRF are depicted.

3 Borders detection in intravascular ultrasound

A framework for the automatic segmentation of vessel borders in Intravascular Ultrasound is presented [2], consisting of two main parts: first, a multi-class classification method that exploits pixel-wise and contextual information to identify the main tissues in the IVUS image is applied; successively, based on the classification output, the definition of the border is achieved by taking advantage of the relationship between tissues with respect to the border itself. The vessel characterization task is performed using ECOC-DRF [1]. Examples of multi-class classification in IVUS images are depicted in Figure 1(d). On top of the classification output, the vessel borders are obtained by exploiting relationships between tissues and the curve itself. For this purpose, a functional Φ is defined, based on a given a curve X, to express the amount of classified tissues that are either correctly placed $(t+)$ or wrongly place $(t-)$, with respect to the considered curve: $\Phi(X) = \sum_{i=1}^{m} w_i^+ t_i(X)^+ + \sum_{j=1}^{n} -w_j^- t_j(X)^- = \mathbf{w} \cdot \mathbf{t}^T$. The vector of weights $\mathbf{w}$ governs the importance of each tissue in the definition of the curve and is learned during the training process. In order to provide an analytical model of the curve (lumen or media-adventitia border), we take advantage of its periodicity: for this reason, its formulation through the Fourier series is used. Examples of detected media-adventitia are depicted in Figure 1(d).

References

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