Learning Fully-Connected CRFs for Blood Vessel Segmentation in Retinal Images

CONICET

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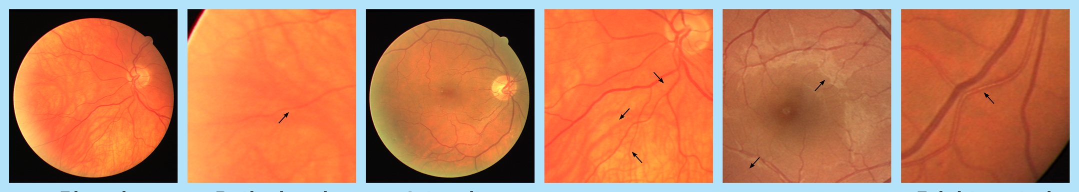
1 INTRODUCTION

motivation

Retinal image analysis is greatly aided by **blood vessel segmentation** as the **vessel structure** may be considered both a **key source of signal**, e.g. in the **diagnosis of diabetic retinopathy**, or a **nuisance**, e.g. in the **analysis of pigment epithelium** or **choroid related abnormalities**.

challenges



Biased background · Retinal and choroidal vessels · Intensity variations · Different widths · Pathologies · Bright central reflex

our contribution

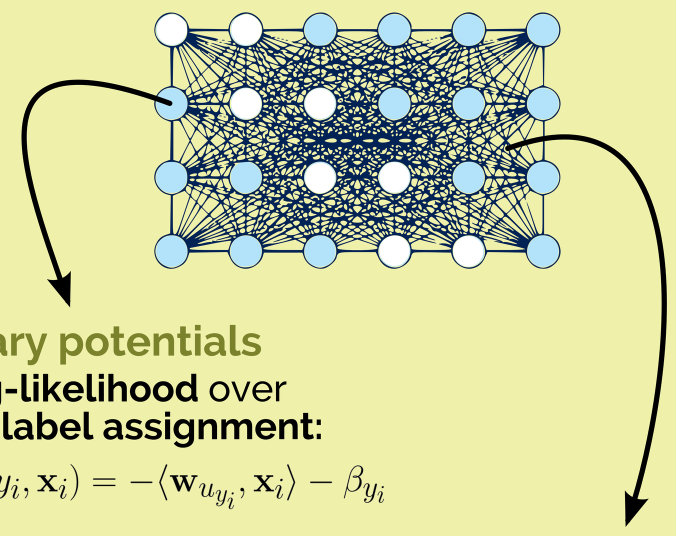
We present a **novel method** for **blood vessel segmentation** in **fundus images** based on a **discriminatively trained, fully connected conditional random field** (CRF) **[1]**.

2 FULLY-CONNECTED CRF SEGMENTATION

energy definition

The **segmentation task** is posed as an **energy minimization problem** in a **fully connected CRF:**

$$E(\mathbf{y}) = \sum_i \psi_u(y_i, \mathbf{x}_i) + \sum_{i<j} \psi_p(y_i, y_j, \mathbf{f}_i, \mathbf{f}_j)$$



unary potentials

Log-likelihood over the **label assignment:**

$$\psi_u(y_i, \mathbf{x}_i) = -\langle \mathbf{w}_{u_{y_i}}, \mathbf{x}_i \rangle - \beta_{y_i}$$

pairwise potentials

Similar distribution but considering only the **interactions between pixels features and their labels**

$$\psi_p(y_i, y_j, \mathbf{f}_i, \mathbf{f}_j) = \mu(y_i, y_j) \sum_{m=1}^{M} w_p^{(m)} k^{(m)} \left(f_i^{(m)}, f_j^{(m)} \right)$$

potts model

$$\mu(y_i, y_j) = [y_i \neq y_j]$$

gaussian pairwise kernel

$$k^{(m)}\left(f_i^{(m)}, f_j^{(m)}\right) = \exp\left(-\frac{|\mathbf{p}_i - \mathbf{p}_j|^2}{2\theta_p^2} - \frac{|f_i^{(m)} - f_j^{(m)}|^2}{2\theta_{(m)}^2} \right)$$

pixel distance · feature simmilarity

estimation of scale values

Scale values of the **pairwise kernels** are **estimated following [2], by taking the median of the distance over random sampled pairs of pixels.**

3 LEARNING FULLY CONNECTED CRF'S PARAMETERS USING SOSVM

structured output svm

We optimize this expression using [3].

$$\min_{\mathbf{w}, \xi \geq 0} \frac{1}{2}\|\mathbf{w}\|^2 + C\xi$$
$$\text{s.t.} \quad \forall \left(\bar{y}^{(1)}, ..., \bar{y}^{(n)}\right) : \sum_{i=1}^{n} \langle \mathbf{w}, \varphi(s^{(i)}, y^{(i)}) - \varphi(s^{(i)}, \bar{y}^{(i)}) \rangle \geq \sum_{i=1}^{n} \Delta(y^{(i)}, \bar{y}^{(i)}) - \xi$$

training set

Weights are **learned** from the **training set:** $S = \{ \left(s^{(1)}, y^{(1)}\right), ..., \left(s^{(n)}, y^{(n)}\right) \}$

unary feature vector, bias constant and pairwise feature vector $s^{(i)} = \{x^{(i)}, B, f^{(i)}\}$

$y^{(i)} \in \mathcal{L} = \{-1, +1\}$ **manual annotation**

feature map

$$\varphi(s, y) = \left(\sum_k \varphi_u(\mathbf{x}_k, y_k), \sum_k \varphi_\beta(B, y_k), \sum_k \sum_{j<k} \varphi_p\left(y_k, y_j, \mathbf{f}_k, \mathbf{f}_j\right) \right)$$

unary term $\varphi_u(\mathbf{x}_k, y_k) = \mathbf{x}_k \otimes \varphi_y(y_k)$

bias term $\varphi_\beta(B, y_i) = B\varphi_y(y_i)$

pairwise term $\forall m : \left[\varphi_p\left(y_k, y_j, \mathbf{f}_k, \mathbf{f}_j\right)\right]_m = \mu(y_i, y_j) k^{(m)}(f_i^{(m)}, f_j^{(m)})$

$$\varphi_y(y_i) \begin{cases} (1,0) & \text{if } y_i = -1 \\ (0,1) & \text{if } y_i = 1 \end{cases}$$

loss function

Hamming loss

$$\Delta(y, \bar{y}) = \sum_i [y_i \neq \bar{y}_i]$$

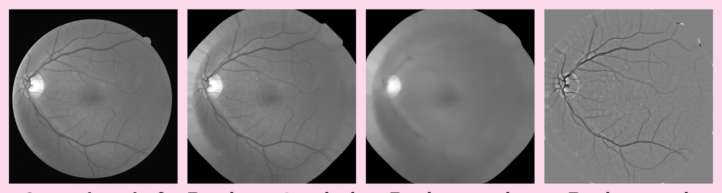
weight vector

$\mathbf{w} = (\mathbf{w}_u, \mathbf{w}_\beta, \mathbf{w}_p)$ **weights for unary, bias and pairwise terms, respectively**

4 FEATURES

preprocessing

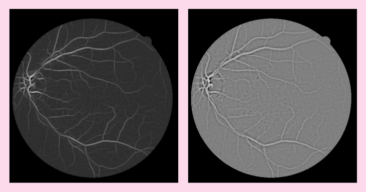
Images are **preprocessed** to **avoid false detections** in the **border of the FOV** and **to reduce** the **effect** of **biased illumination**.



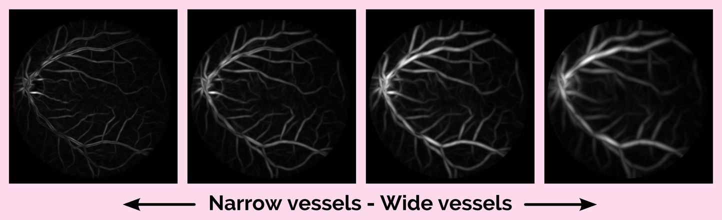
Green band of the original color image · Border extended image based on [5] · Background estimated with a median filter · Background subtracted image

unary features

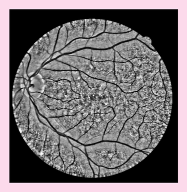
line detectors [4]



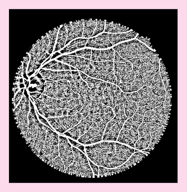
2d multiscale gabor wavelets [5]



vesselness enhancement inspired on [6]



pairwise feature



vessel enhancement inspired on [7]

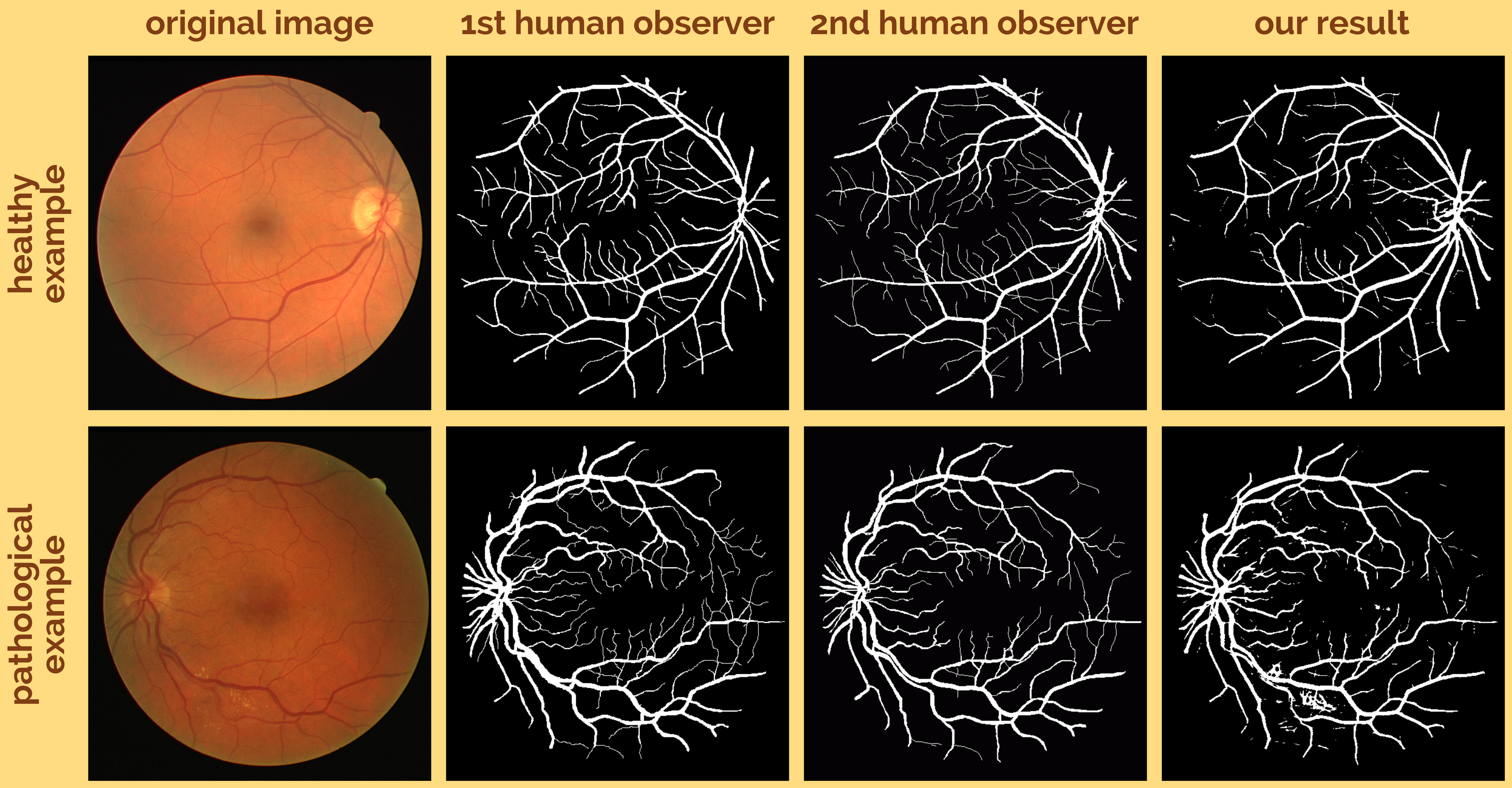
feature selection

Best configuration of features is found by **minimizing** the **distance to a second human observer performance,** using a **validation set.**

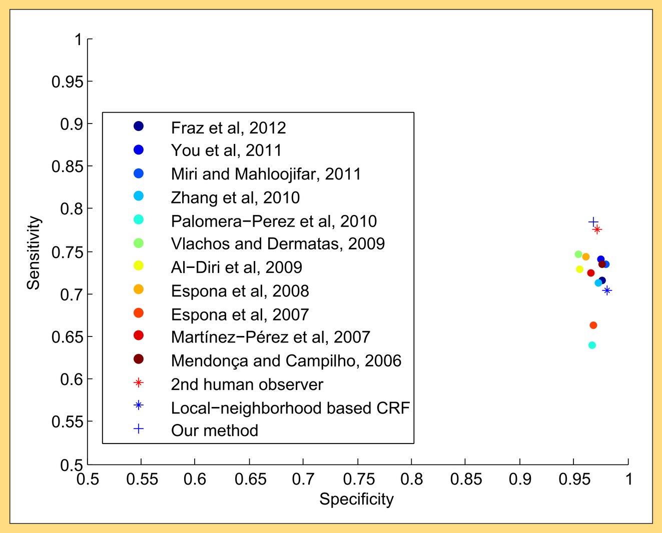
5 VALIDATION AND RESULTS

qualitative evaluation

Experiments and evaluation are performed on DRIVE dataset



quantitative evaluation



evaluation metrics

Our results are compared with the state-of-the-art in terms of sensitivity and specificity

$$Se = \frac{TP}{TP + FN}$$

$$Sp = \frac{TN}{TN + FP}$$

Our method is **statistically tied** with the **performance of a second expert annotator,** and **achieves** a **much higher sensitivity** than **all other current segmentation systems.**

6 REFERENCES

[1] **Krähenbühl, P., Koltun, V.:** Efficient inference in fully connected CRFs with Gaussian edge potentials. **In: NIPS. (2012)**

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[3] **Joachims, T., Finley, T., Yu, C.N.J.:** Cutting-plane training of structural SVMs. **Machine Learning 77(1) (2009) 27–59**

[4] **Ricci, E., Perfetti, R.:** Retinal blood vessel segmentation using line operators and support vector classification. **IEEE T-MI 26(10) (2007) 1357–1365**

[5] **Soares, J.V., et al.:** Retinal vessel segmentation using the 2-d Gabor wavelet and supervised classification. **IEEE T-MI 25(9) (2006)**

[6] **Sinthanayothin, C., et al.:** Automated localisation of the optic disc, fovea, and retinal blood vessels from digital colour fundus images. **British Journal of Ophthalmology 83(8) (1999) 902–910**

[7] **Saleh, M.D., Eswaran, C.:** An efficient algorithm for retinal blood vessel segmentation using h-maxima transform and multilevel thresholding. **Computer Methods in Biomechanics and Biomedical Engineering 15(5) (2012) 517–525**

For any further information and implementation details:
Project webpage: http://pages.saclay.inria.fr/matthew.blaschko/projects/retina/
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