An Automatic Framework for the Graph-based Representation of Coronary Arteries

A. Reyes-Figueroa, J.A. Camacho-Gutiérrez, F. Cervantes-Sánchez
Centro de Investigación en Matemáticas (CIMAT)

Sebastián Salazar-Cortés,
Facultad de Informática, Universidad Autónoma de Querétaro

Ivan Cruz-Aceves,
CONACYT, Centro de Investigación en Matemáticas (CIMAT)

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Contents

Introduction

We present an automatic framework for the segmentation and graph-based representation of coronary arteries in X-ray angiograms.

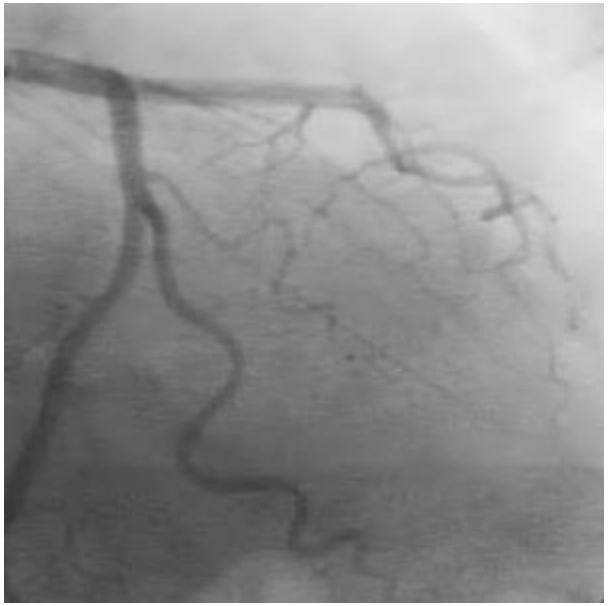
The first stage of vessel segmentation is carried out by using Gaussian matched filters trained by the Univariate Marginal Distribution Algorithm.
In the second step, the line simplification algorithm of Ramer-Douglas-Peucker is used to represent the coronary artery skeleton as a graph, where the nodes are the dominant pixels for shape preservation.

Introduction

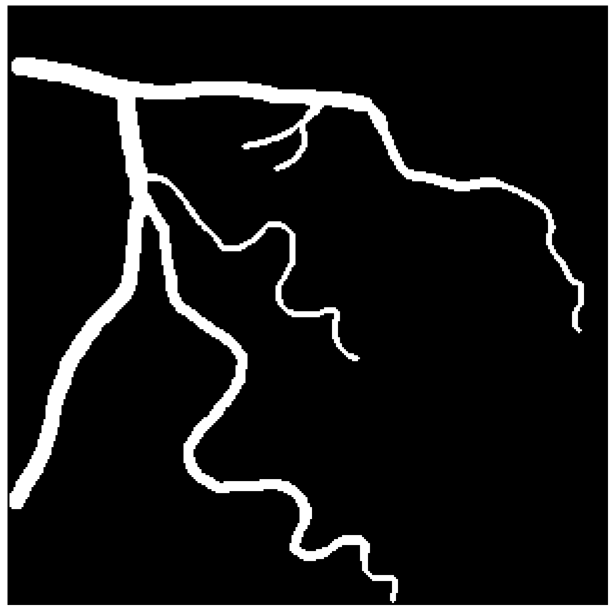
- In clinical practice, the coronary angiography represents current gold standard for detecting and monitoring vessel abnormalities.

- Disadvantages with X-ray angiograms: non-uniform illumination and low contrast between vessel-like structures and background.

- In literature, these two drawbacks have been addressed in two different steps; enhancement and binary classification.



Input image

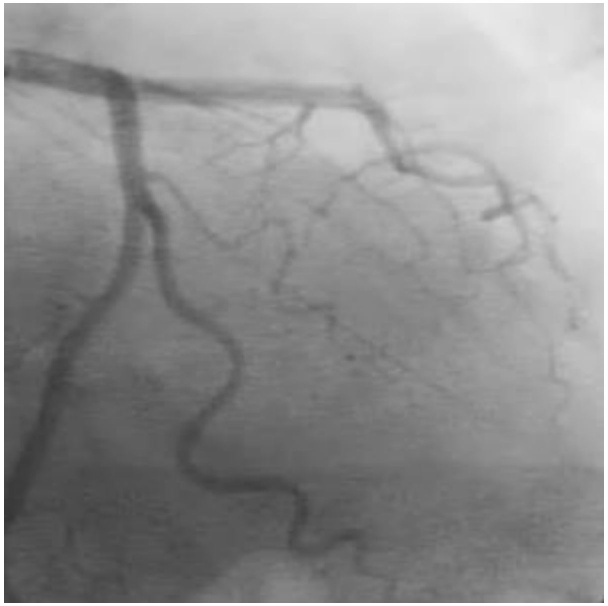


Segmented image

Introduction

The second main problem focuses on simplify the vessel-like structures.

- **Try to reduce the number of points, needed to resume the arterial information.**
- **Main purposes:**
  - **Compressing data,**
  - **Reconstruction of structures,**
  - **3D image registration / rendering,**
  - **Simulate motion and blood flow on arteries,**
  - **Reduce complexity.**
- **Suitable for computer-aided diagnosis.**



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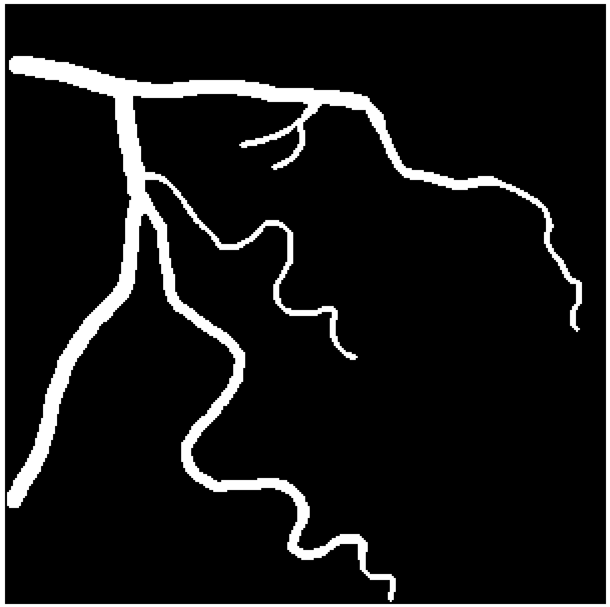
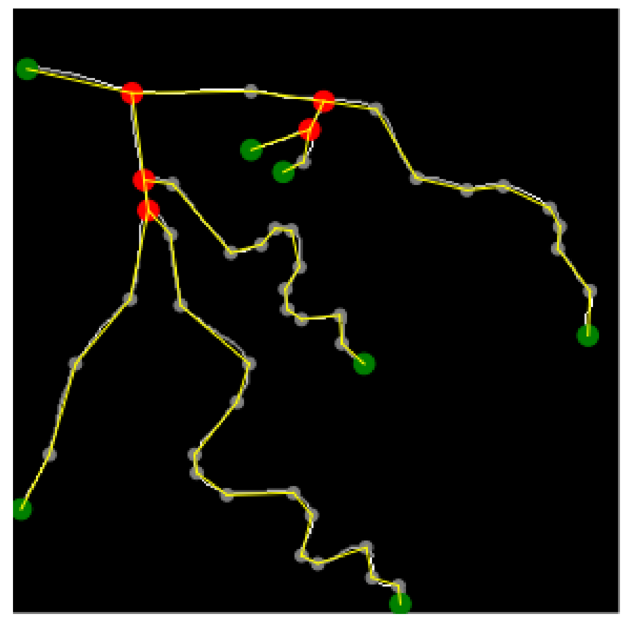


Segmented image



Simplified structure

Vessel segmentation

Vessel segmentation

In the enhancement step, different techniques have been proposed:

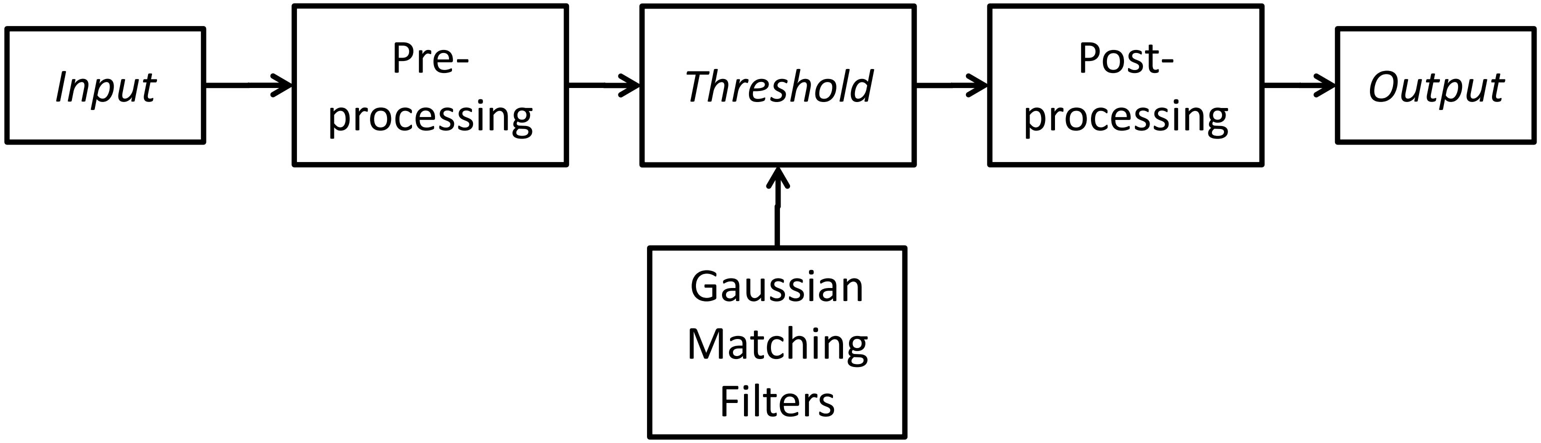
- mathematical morphology, Gaussian filters,
- linear operators, and so on …

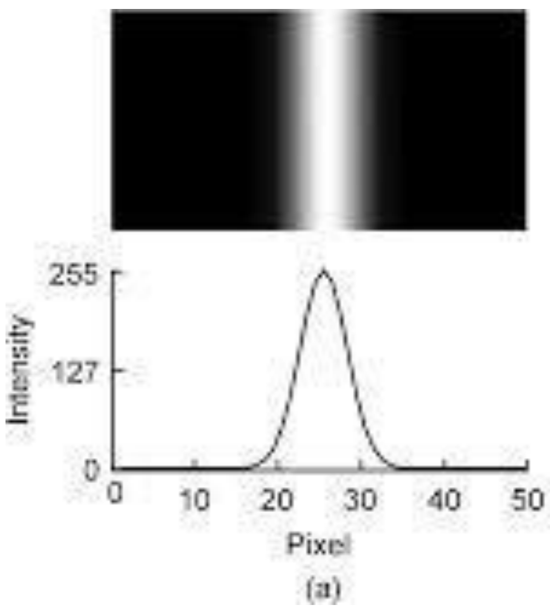
The Gaussian matched filters (GMF) were originally proposed by Chaudhuri et al. [1].

The GMF method represents an spatial template image strategy.

<u>The Idea</u>: the shape of the blood vessels can be approximated by a Gaussian profile at different orientations!

Vessel segmentation

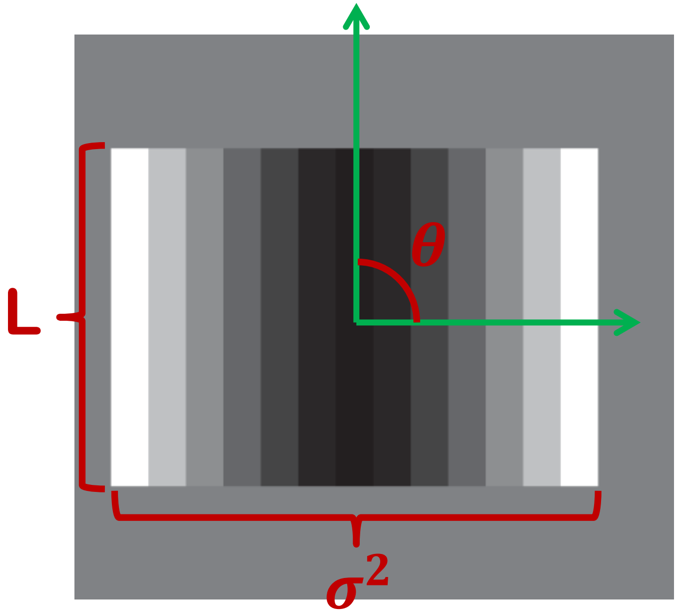




$$G(x,y) = -\exp\left(\frac{x^2+y^2}{2\sigma^2}\right), |y| \leq \frac{L}{2}$$

Gaussian template

Vessel segmentation



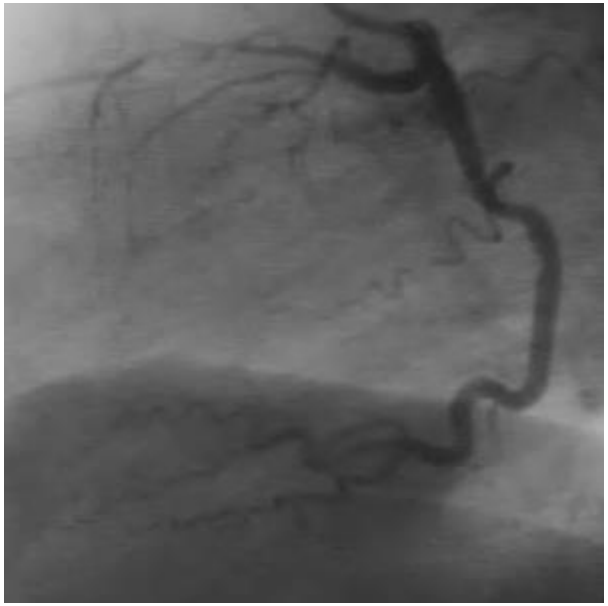
<u>Parameters</u>:

- **Length (L)**
- **Width of vessel (σ^2)**
- **Orientation (angle θ)**

usually one set the number of oriented filters k at orientations

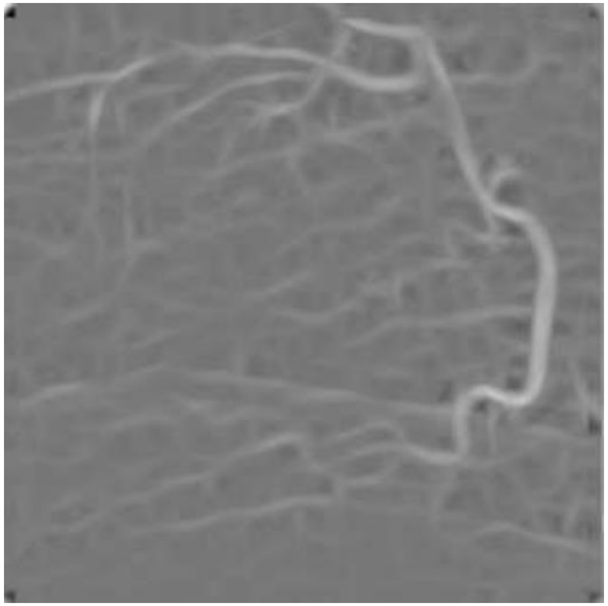
$$\theta = \frac{\pi j}{k}, j = 1,2, \dots, k$$

Vessel segmentation



Input image

GMF →



Filtered image

Vessel segmentation

Many researchers have suggested strategies, applications or empirically values for the GMF parameters, in order to improve its performance in vessel detection.

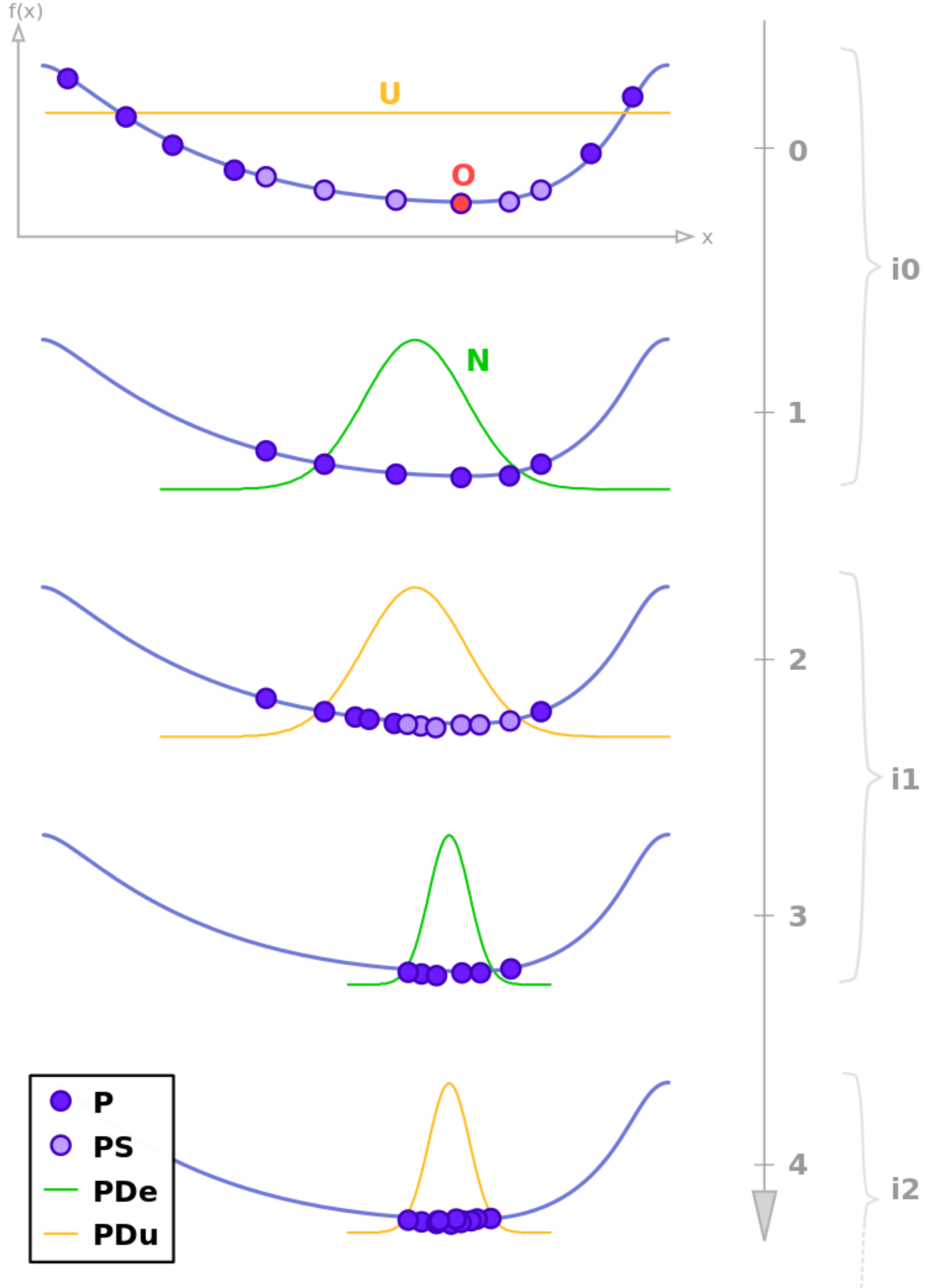
- **Kang et al. [2], [3] proposes new values for σ^2, while reducing the number k.**
- **Chanwimaluang et al. [4] used the original method in retinal registration.**
- **Cinsdikici and Aydin [5] proposed a new number of oriented filters k for retinal vessel segmentation.**
- **Al-Rawi et al. [6], [7] proposed a new search space and optimization strategies to find the optimal set of parameters.**

Vessel segmentation

Cruz et al. [8], [9] proposed the use of population-based methods (evolutive heuristics) for the parameter optimization in a new search space focused on coronary arteries.

This strategy has been adopted
in the present work. As optimization strategy we use Univariate Marginal Distribution Algorithm (UMDA) [10], since it works suitable for linear problems [11], [12], [13].

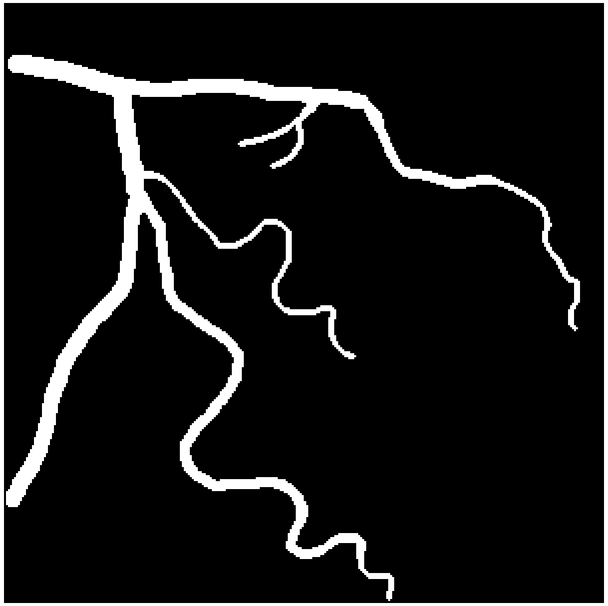
UMDA scheme



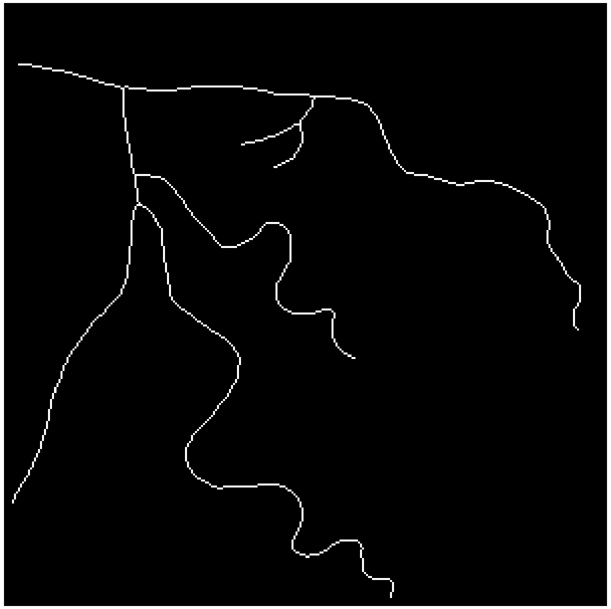
Simplification method

Graph-based representation

<u>Second stage:</u> Graph-based representation of the segmented coronary artery tree. In this step, the Ramer-Douglas-Peucker method (RDP) is used to reduce the number of pixels of the blood vessel skeleton.



Segmented image



Skeletonization

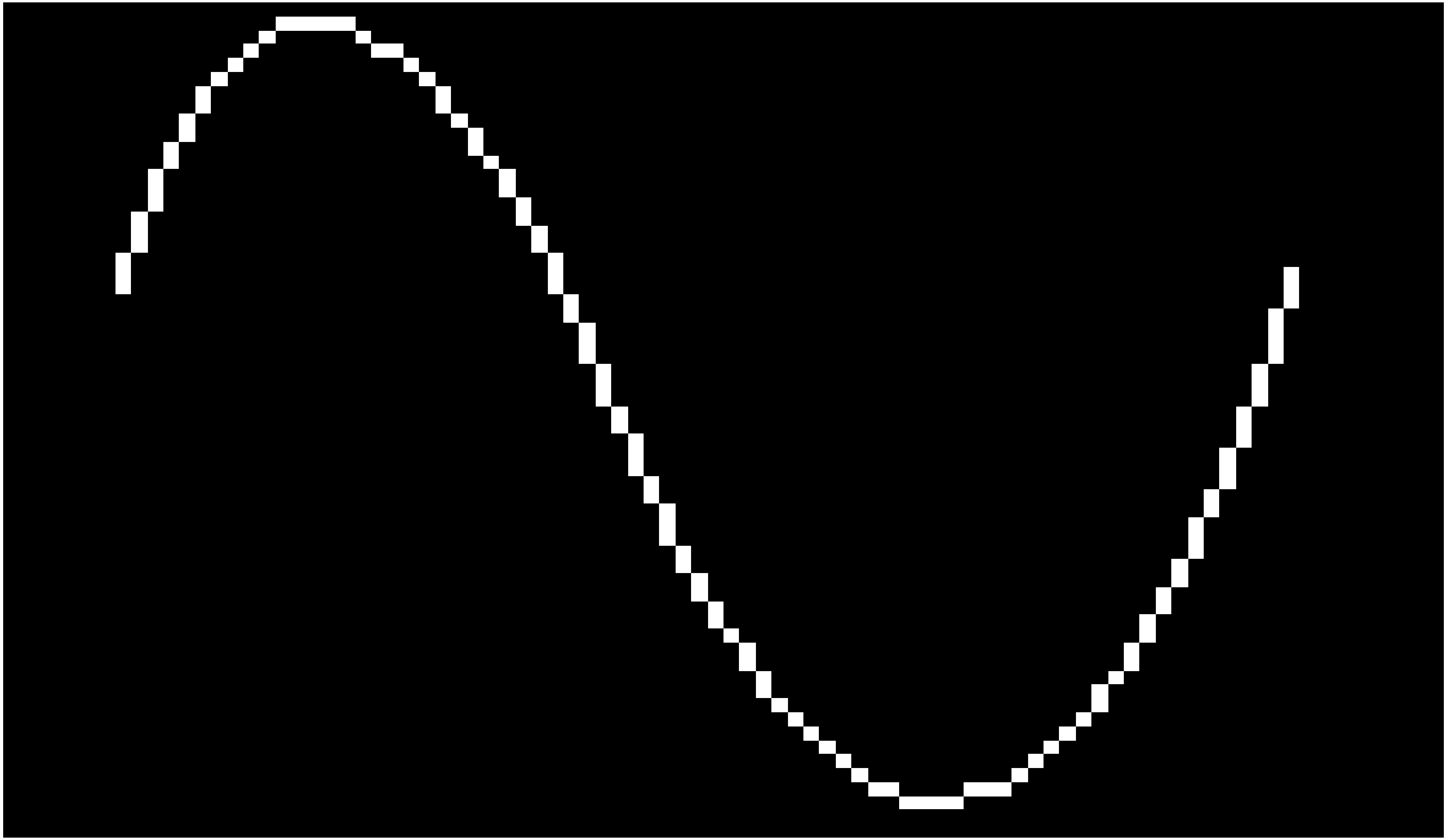
Graph-based representation

RDP algorithm reduces the number of existent points in a line, based on divide and conquer approach [$O(n \log n)$ average, $O(n^2)$ worst].

It is widely used in applications such as:
- traffic signs detection,
- compressing GPS trajectory data,
- reconstruction of building ground plans,
- robotics

Idea: reduce the complexity of lines which expressed trajectories or vectors.

Ramer-Douglas-Peucker



RDP iterations

Graph-based representation

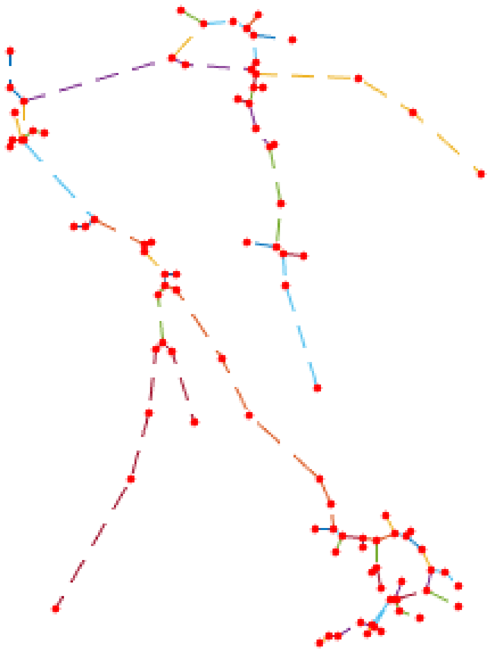
Several approaches to construct the graph:

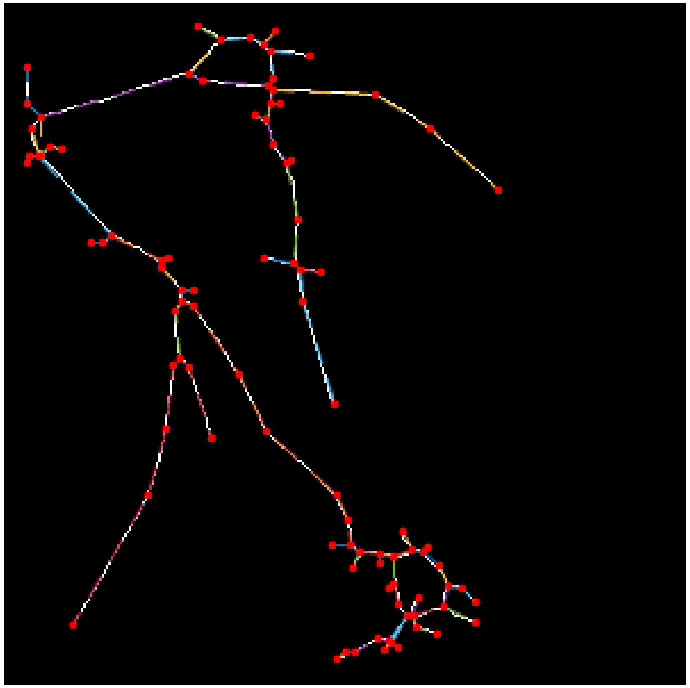
- Detect branch points

- Then:
  - PFS or BFS over the associated graph, by using simplified skeleton as base, or
  - Split connected components (after remove branch points) and construct incidence relations.

Graph-based representation

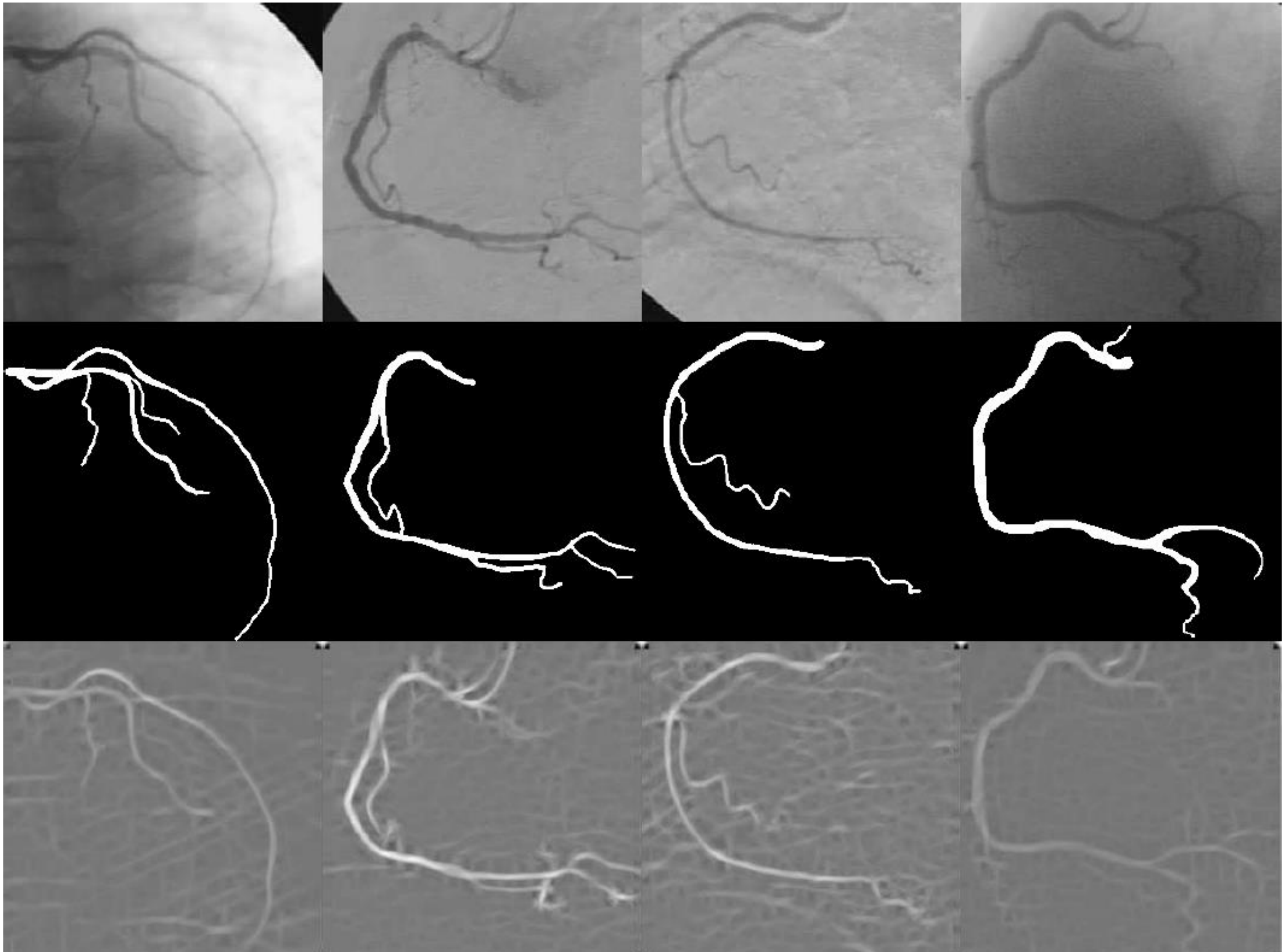
RDP algorithm depends on an ε parameter.





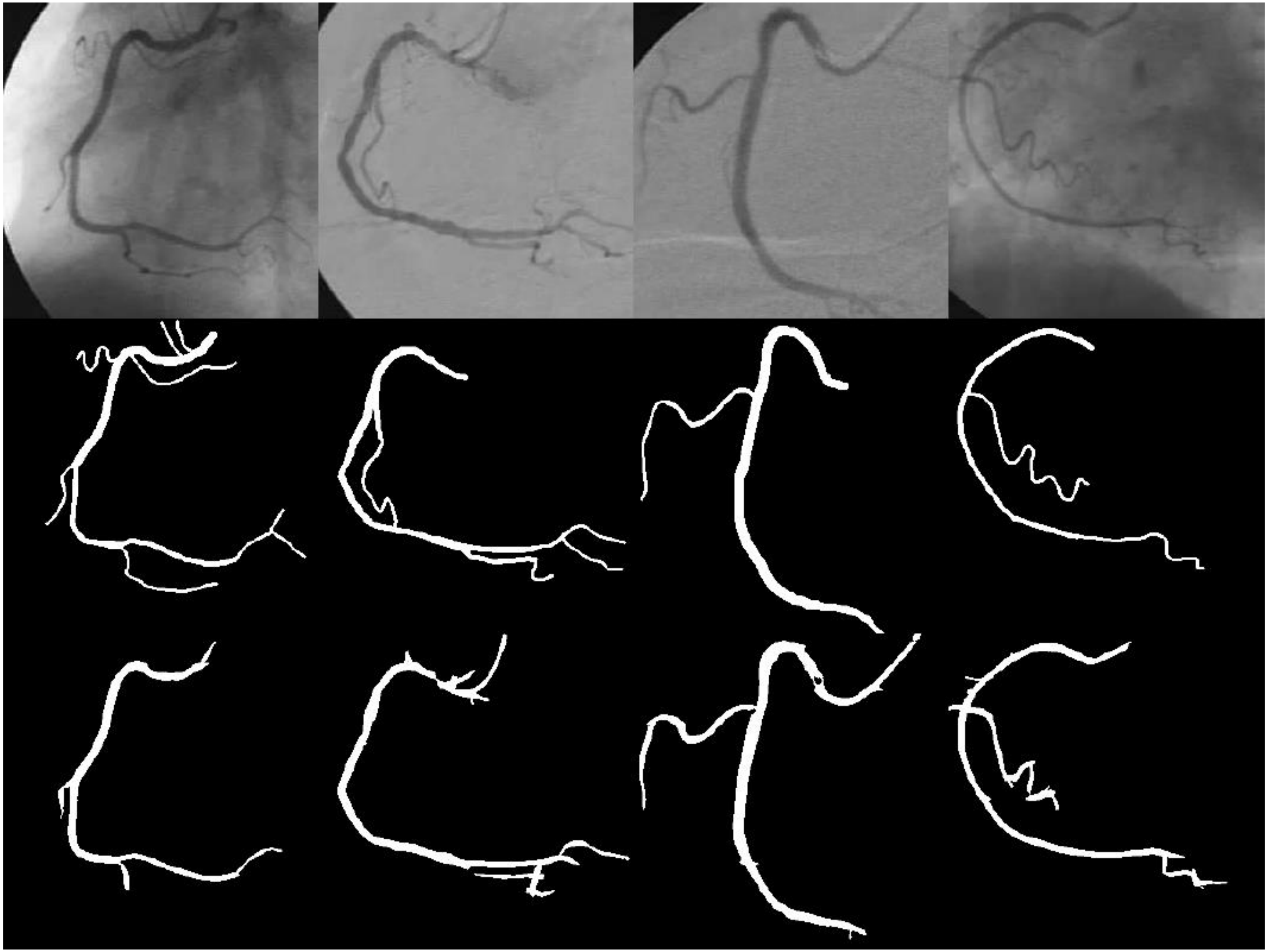
Results

Results



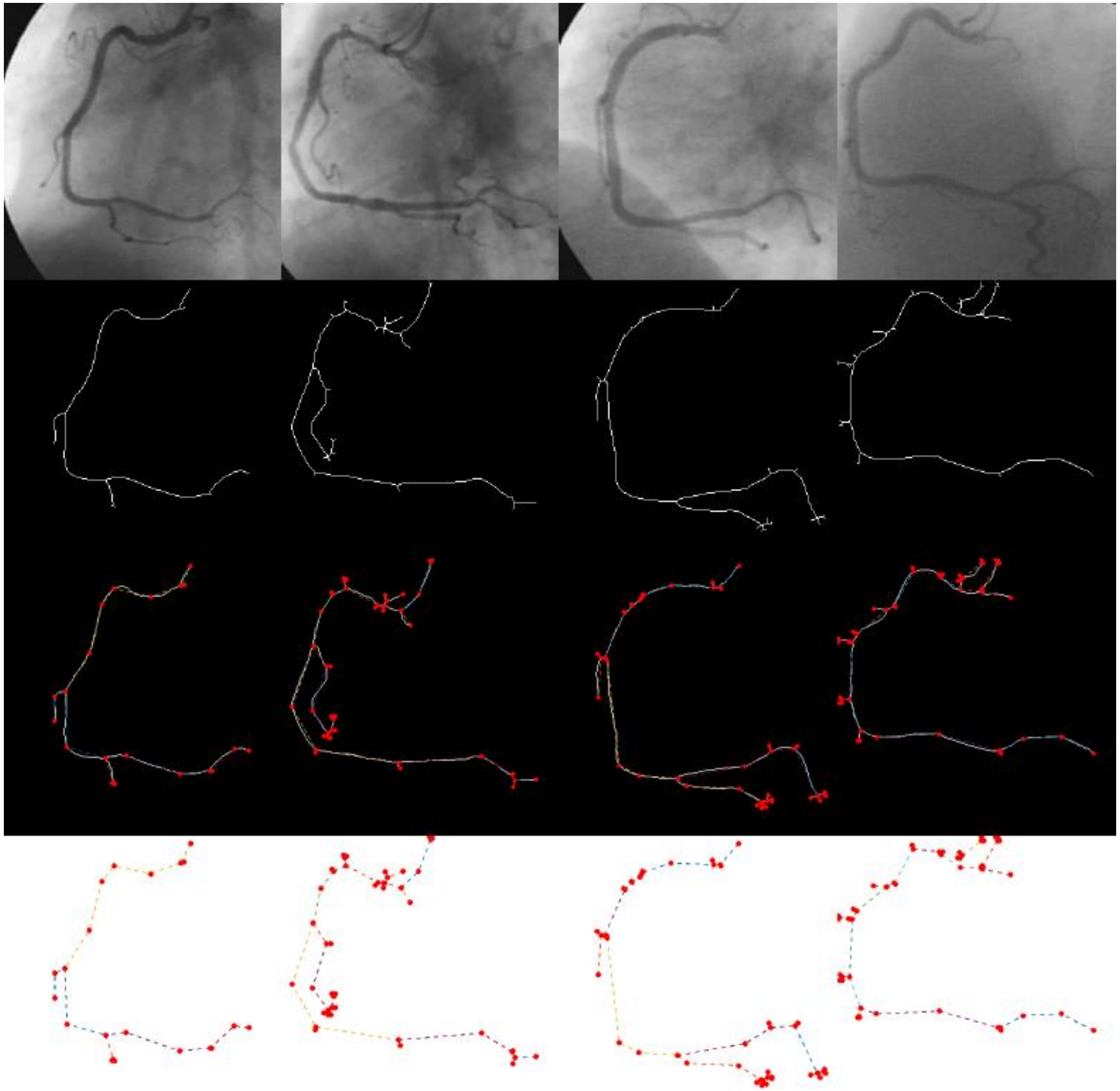
Gaussian response from images using the proposed strategy.

Results



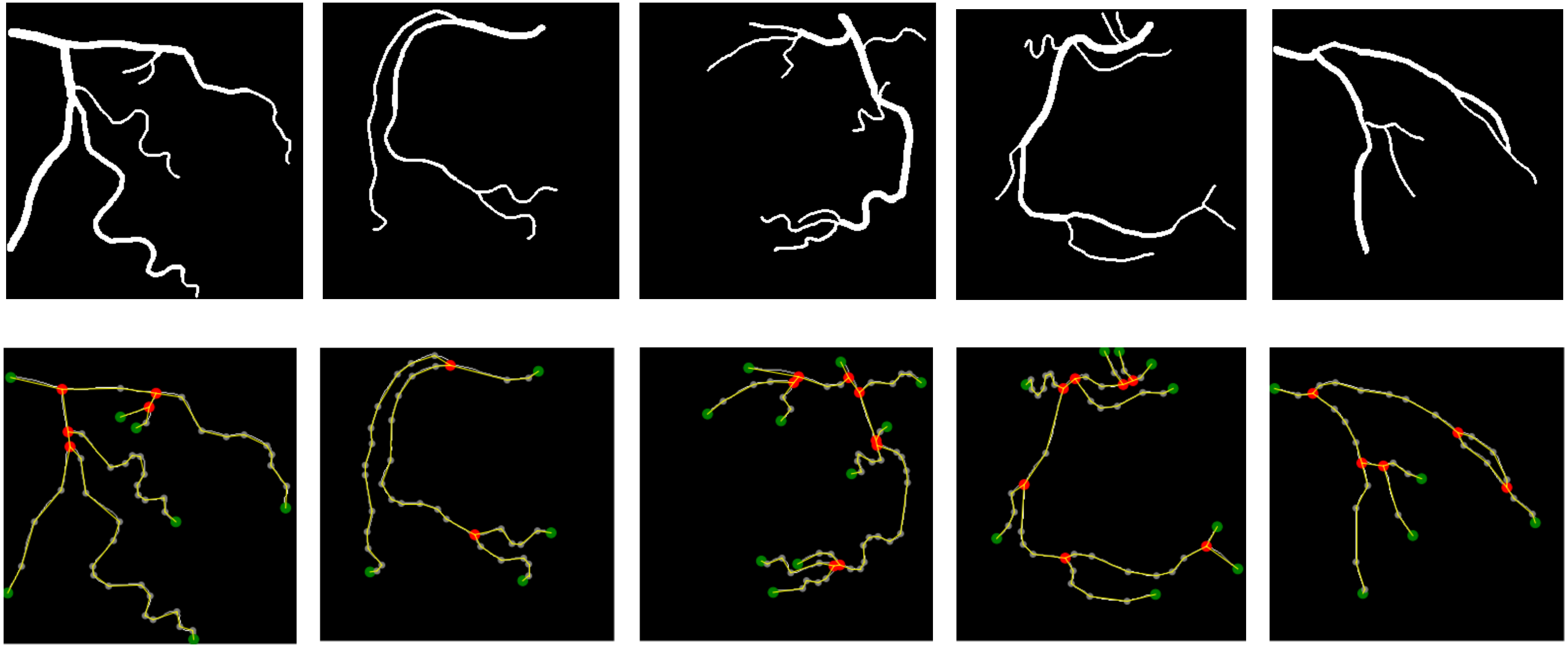
Automatic blood vessel segmentation of angiograms using the proposed method.

Results



Graph-based approach of angiograms using the proposed framework.

Results



Graph-based approach of angiograms using the proposed framework.

Results

TABLE I

PERFORMANCE ANALYSIS BETWEEN DIFFERENT GMF-BASED TECHNIQUES AND THE PROPOSED METHOD.

Method	A_z value
Proposed method	**0.9135**
Chaudhuri et al.	0.8954
Kang et al.	0.8723

<u>Metric used</u>: ROC curve.

All methods were tested over a 30 coronary angiogram image database, (300x300 pixels).

Results

In the binary classification step, to classify the Gaussian response, five thresholding methods of the state-of-the-art have been selected:

- **Methods based on entropy measure [15,16],**
- **Mean value [17],**
- **Histogram concavity [18],**
- **Inter-class variance [19] were tested.**

<u>Metric used</u>: accuracy.

Results

TABLE II
PERFORMANCE ANALYSIS OF DIFFERENT THRESHOLDING METHODS USING THE GAUSSIAN RESPONSE IMAGE ON THE TEST SET.

Method	Accuracy
Otsu [19]	**0.9215**
Pal and Pal [16]	0.9202
Ridler and Calvard [17]	0.9185
Rosenfeld and De la Torre [18]	0.9102
Kapur et al. [15]	0.8941

Results

The simplification step is assessed in terms of the data compression ratio (CR) as follows:

$$CR = 1 - \frac{compressed\ data}{uncompressed\ data}$$

Where

- **compressed data is the number of nodes obtained from the parametric line simplification method**
- **and uncompressed data represents the number of pixels of the automatic segmented coronary artery skeleton.**

Results

TABLE III

PERFORMANCE ANALYSIS FOR DIFFERENT VALUES OF THE RDP METHOD USING THE SEGMENTED ANGIOGRAMS.

Epsilon value	CR	time (in seconds)
$\epsilon = 5$	0.9370	0.0069
$\epsilon = 4$	95.7328	0.0245
$\epsilon = 3$	95.1763	0.0300
$\epsilon = 2$	94.0631	0.0316
$\epsilon = 1$	91.2801	0.0247

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