Optimized Strict Multiscale Frangi Prefiltering for Segmentation

Towards an automated PCSVN extraction

Luke Wukmer

Advisor: Dr. Jen-Mei Chang
Department of Mathematics and Statistics
California State University, Long Beach
lwukmer@gmail.com

April 9, 2019

Research Goals

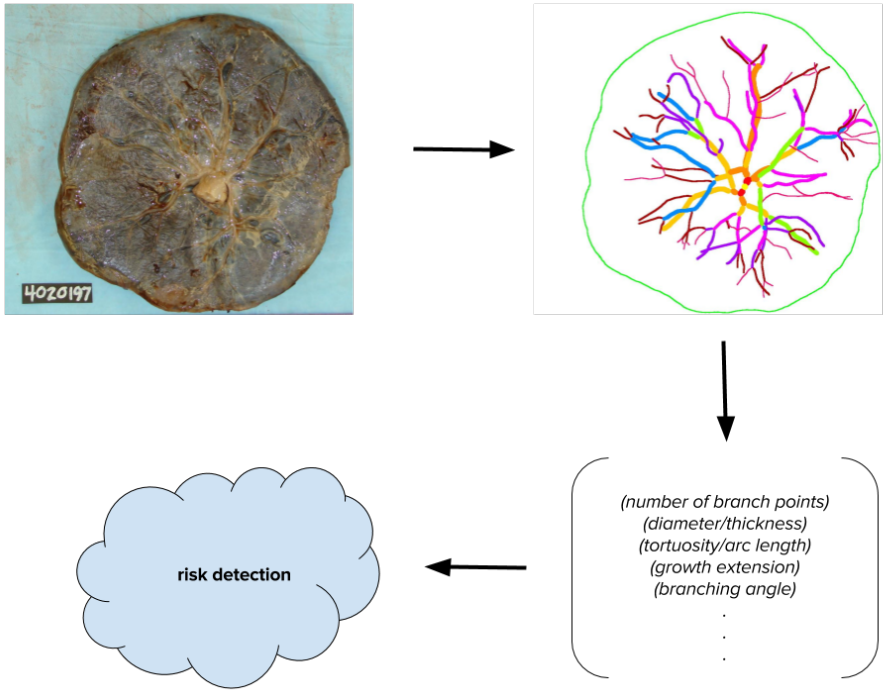


Figure: **(Top)**: A manual trace of the placental chorionic vascular surface network (PCSVN) is performed. This trace is measured, which is turned into a feature vector, which is used as a predictive aid.

Vascular Network Extraction in Placentas

- **Motivation:** An accurate measurement of the vascular structure of a placental sample can be used to predict neonatal risk factors.
- **Challenges:**
  - Placental images are very noisy, so many conventional methods fail.
  - Currently no completely automated method of obtaining traces of vascular network. Manual tracing is labor intensive but necessary for feature analysis.
- **Research Goal:** Provide a fully automated method of extraction.

Previous Research

(a) Nen Huynh used Frangi filtering result (different data set)

(b) Frangi filtering is followed by morphological filtering (using principal-directions). Agreement with ground truth is displayed.

(c) There's a different research group using advanced methods

Differential Geometry in Image Processing

The Frangi Filter

Implementation Detail: Calculating Discrete Hessian

Principal Curvatures and Principal Directions

$$\mathsf{L} \in \mathbb{R}^{m \times n} \iff L \in \mathcal{C}^2\Big([0, m] \times [0, n]\Big)$$

$$\mathsf{H}(x, y) = \begin{bmatrix} L_{xx} & L_{xy} \\ L_{yx} & L_{yy} \end{bmatrix}$$

$$\kappa_i, u_i \quad \text{for } i = 1, 2$$

such that

$$\mathsf{H}u_i = \kappa_i u_i \ , \ |\kappa_1| < |\kappa_2|$$

Frangi Filter Measure

$$F\{\cdot\} = \begin{cases} 0 & \text{if} \kappa_2 < 0, \\ \exp\left(\frac{-A^2}{2\beta^2}\right)\left(1 - \exp\left(\frac{-S^2}{2c^2}\right)\right) & \text{else} \end{cases} \tag{1}$$

$$S = \sqrt{\kappa_1^2 + \kappa_2^2} \quad \text{(structureness)} \tag{2}$$

$$A = \left|\frac{\kappa_1}{\kappa_2}\right| \quad \text{(anisotropy)} \tag{3}$$

with β, c, parameters

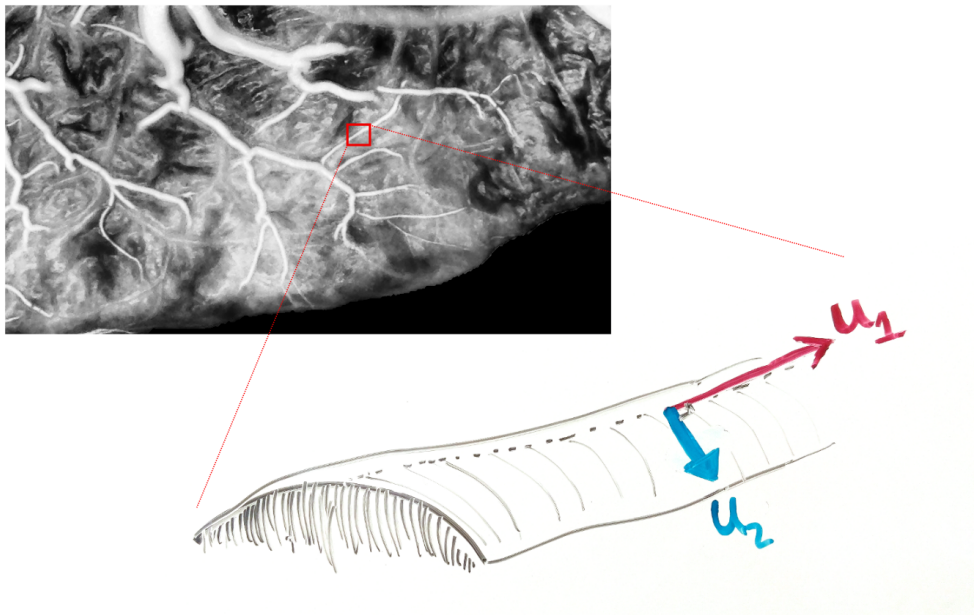
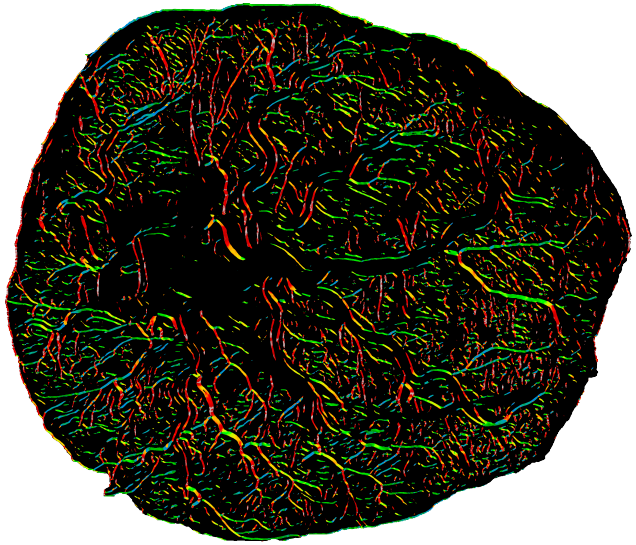


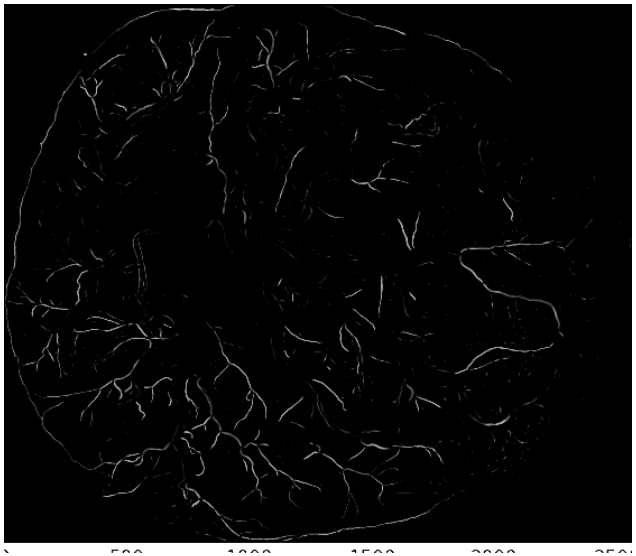
Figure: The principal curvatures (eigenvectors of the Hessian matrix) point in the direction of greatest and least curvature at each pixel

The Frangi filter [2] finds tubular structures on the surface. Corresponds to areas where κ_2 is large and κ_1 is small.

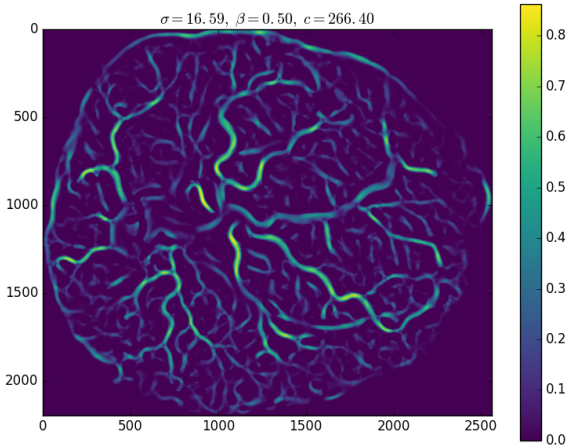
Improved Parameters for Frangi Filter



(a) Placental sample (bad parameters)

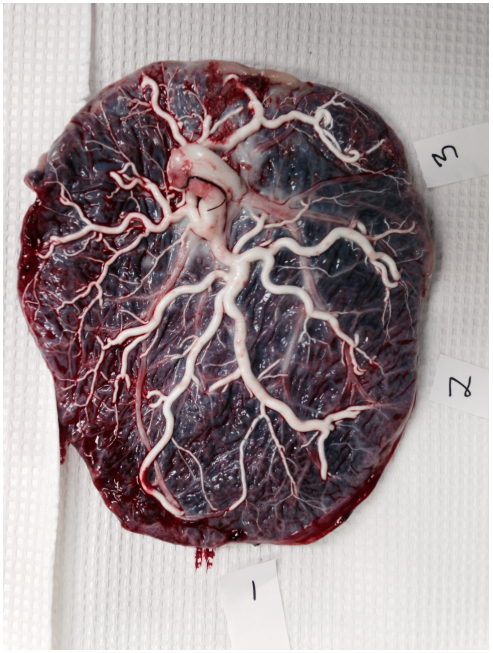


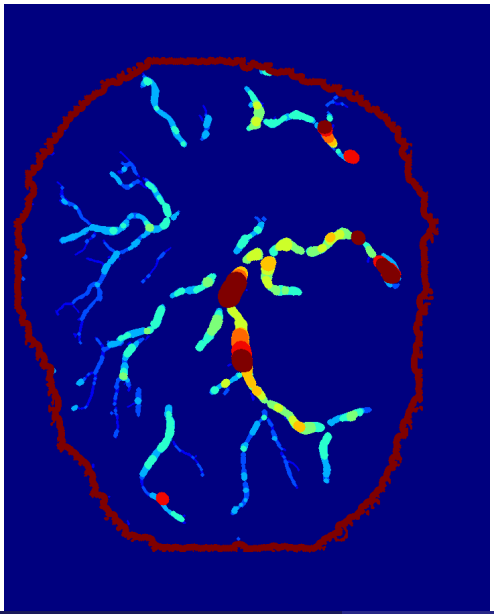
(b) improved parameters



(c) improved parameters (larger scale space)

Future Work

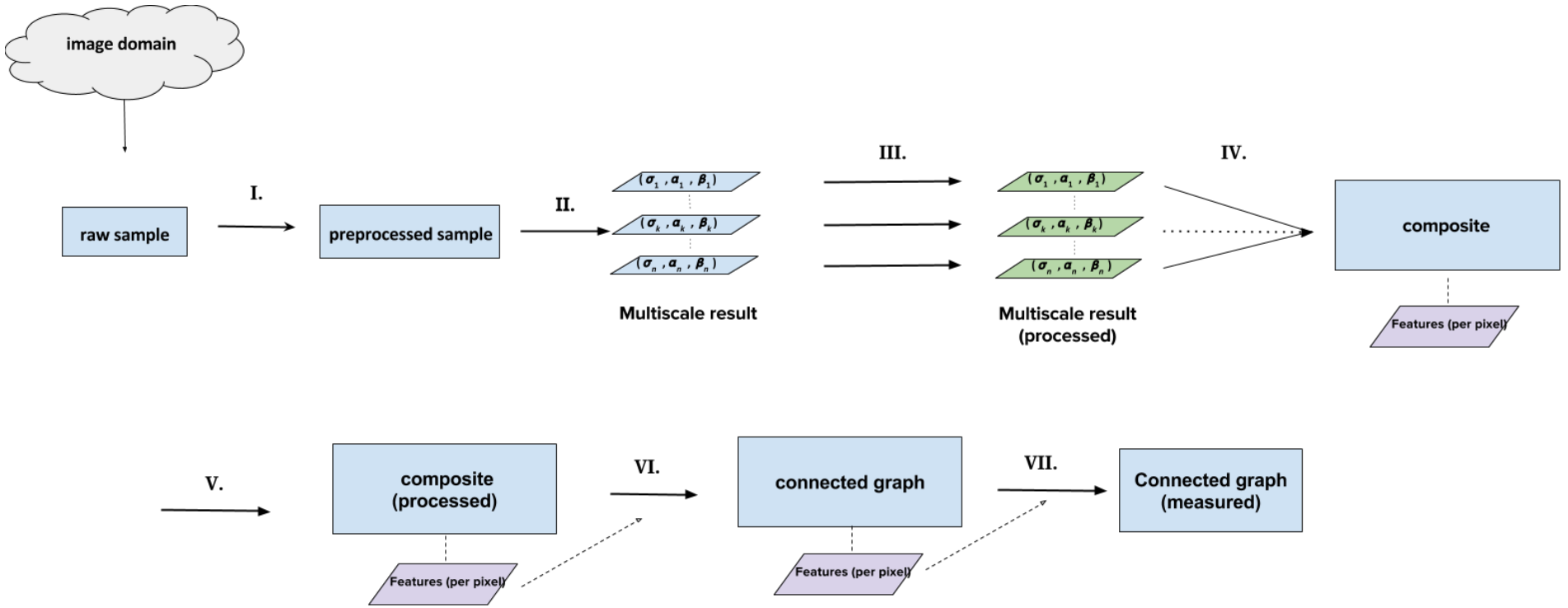




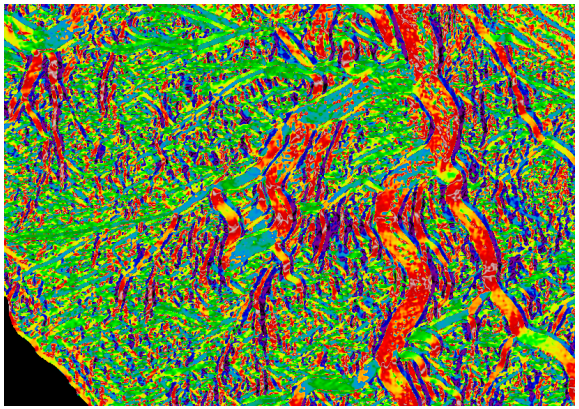
Additional Work Required

- Extend to other samples and image domains.
  - new barium samples
  - other placental samples (NCS, EARLI)
  - STARE, DRIVE retinal database
  - other curvilinear image sets?
- Adapt previous morphological filtering to improved frangi targets
- Speedups with FFT (completed!)
- Find good way to quantify results
- Graph connection problem, etc.

Appendix: Main Extraction Process

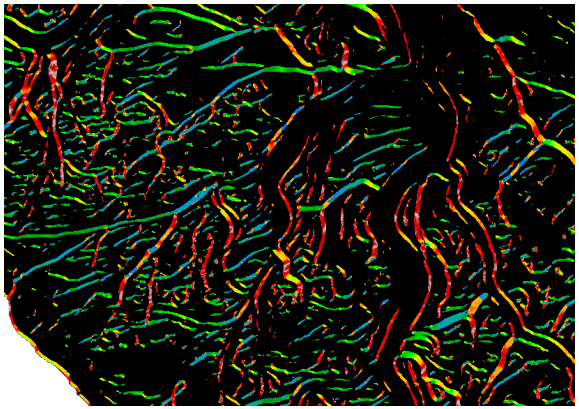


Principal Directions with Frangi Filter (Example with $\sigma = 2$)



(a) all $\theta(u_2, e_1)$

(b) Frangi targets



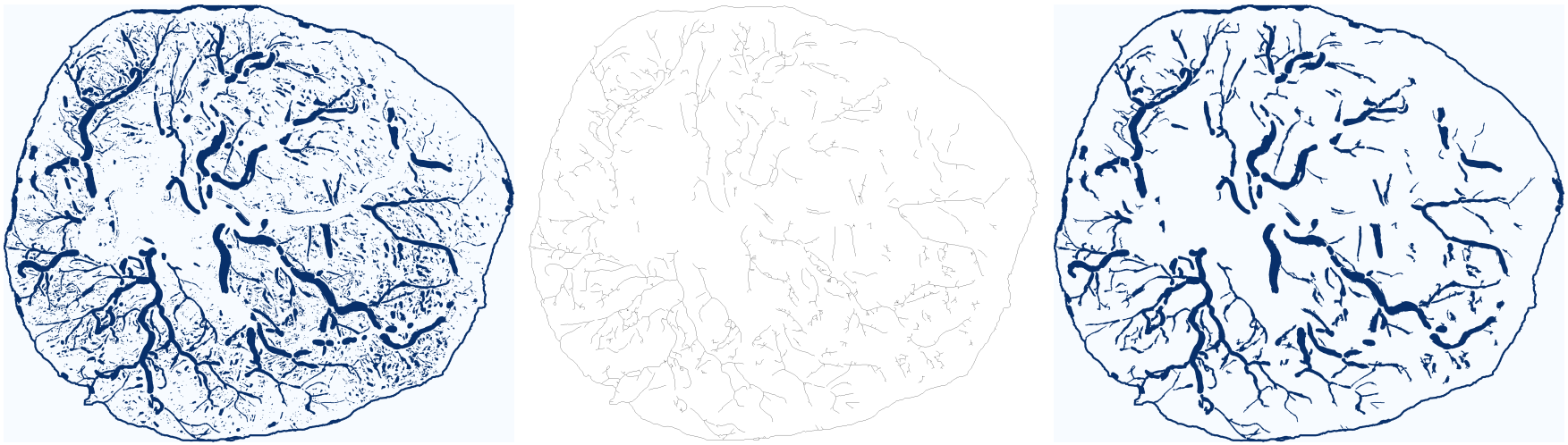
(c) frangi targets with θ

Morphological Filter

- Rectangular filter rotated by $\theta(u_1, e_1)$
- Rectangle size dependent on σ (scale size)
- Binary closing $\rightarrow$ binary opening with disk

Morphological Filtering Algorithm

a. Join all scales.
b. Skeletonize.
c. Iterate over each scale extraction and keep content only if it is connected to the skeleton.



(a) Union of all scales (b) Skeletonization of (a) (c) Sieving (a) through (b)

Figure: Morphological Filtering (smaller scales only)