Mosaicking Retinal Images: **Segmentation**

Viet Than

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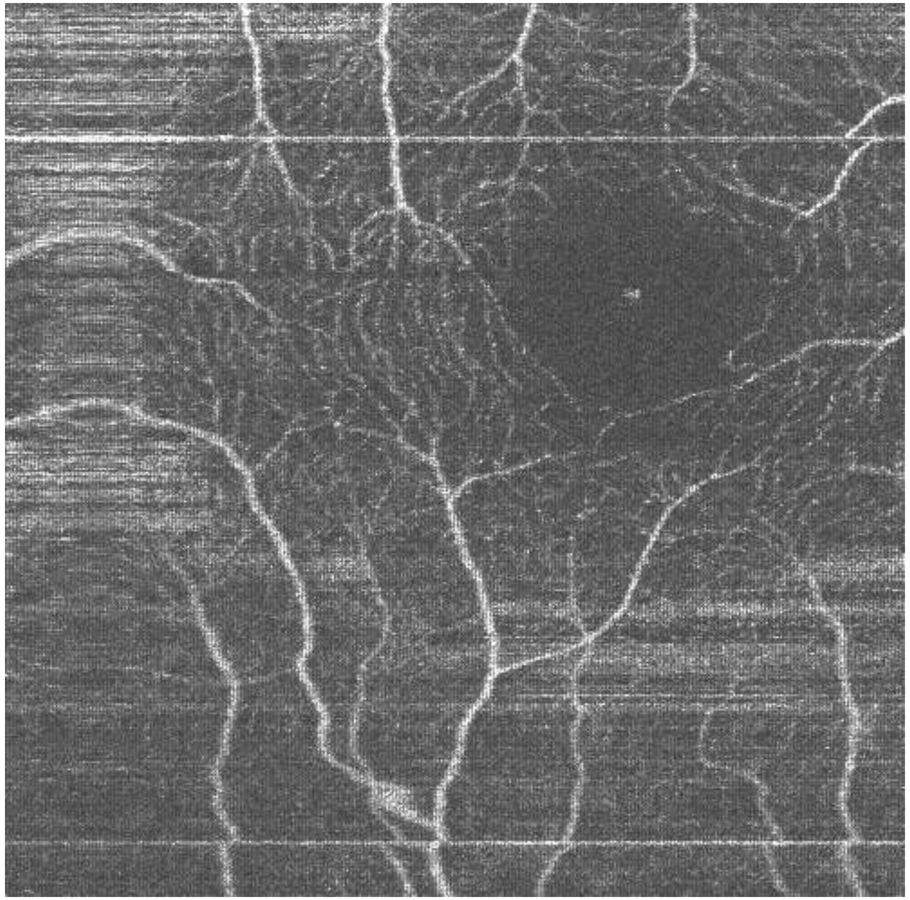
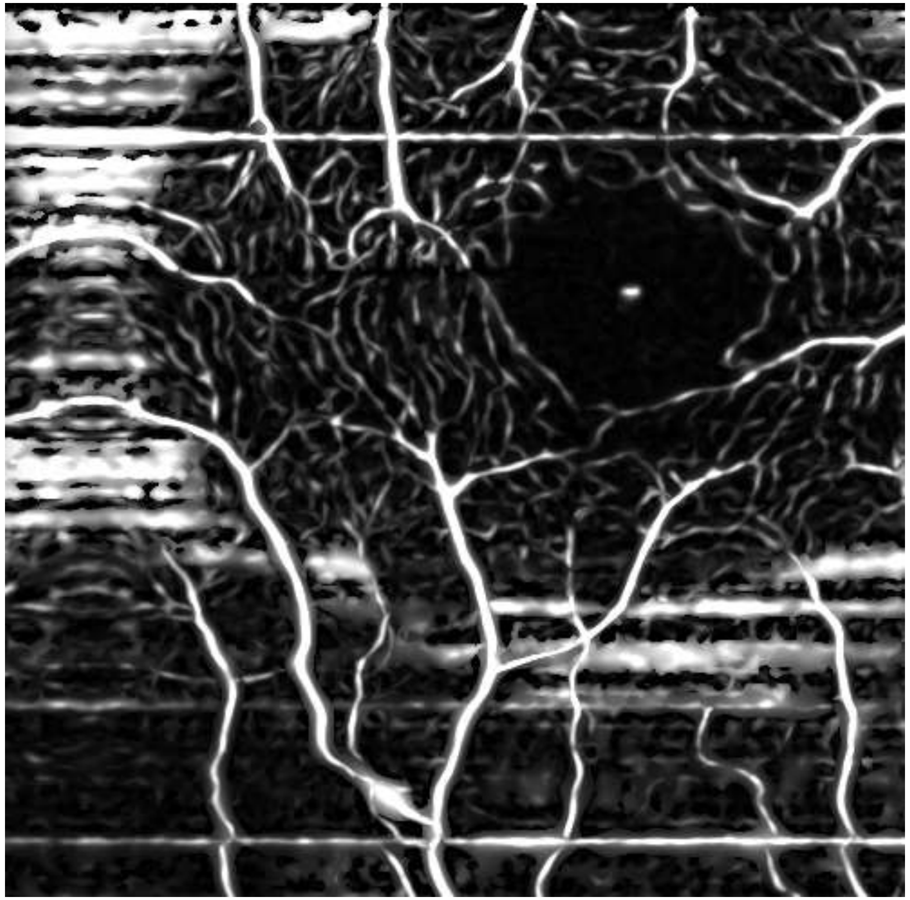
In collaboration with Joe Malone and Professor Kenny Tao, Diagnostic Imaging and Image-Guided Interventions Lab

MedICL



Input

Projection of OCT Volume
Fovea Angiography



Output

Projection of input volume
after Hessian/Frangi filter

Initial Problem:

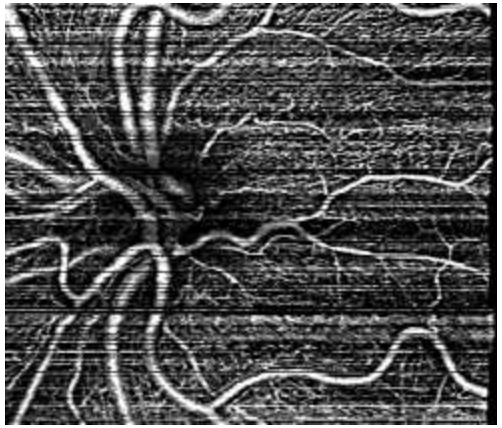
OCT Angiography is a non-invasive tool to examine retina for early-stage diseases based on microvasculature.
However, there is a fundamental tradeoff between vascular resolution and image field of view (tldr: the higher the resolution, the smaller the "scope" of the image)

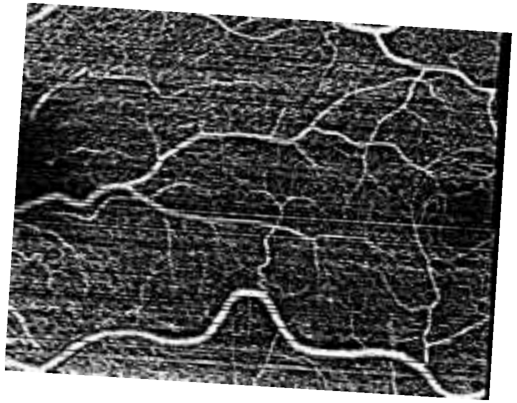
Proposed solution:

1. Enhance the blood vessels (**Segmentation**)
2. Merge and combine into one (Registration)

THE GOAL:

Merge the two below pictures





Vocabulary

Optical coherence tomography (OCT): Uses lightwaves to obtain 2D/3D scans at micrometer resolution for biological tissue

Angiography: Visualizing/graphing of blood vessels

Retina: The membrane covering the back of the eyeball responsible for collecting the light coming into your eye

Introduction to Image Processing

Doing a convolution between a kernel and an image

"Convolution is the process of adding each element of the image to its local neighbors, weighted by the kernel" – *Kernel (Image Processing),* Wikipedia

We are making a kernel that will allow us to pick out vesselness features

Sharpen	$\begin{bmatrix} 0 & -1 & 0 \\ -1 & 5 & -1 \\ 0 & -1 & 0 \end{bmatrix}$	
Box blur (normalized)	$\frac{1}{9}\begin{bmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{bmatrix}$	
Gaussian blur 3 × 3 (approximation)	$\frac{1}{16}\begin{bmatrix} 1 & 2 & 1 \\ 2 & 4 & 2 \\ 1 & 2 & 1 \end{bmatrix}$	

Taken from: *Kernel (Image Processing),* Wikipedia

Monochromatic Gaussian blur

100	100	100	100	100
100	0	0	0	100
100	0	0	0	100
100	0	0	0	100
100	100	100	100	100

1/16	2/16	1/16
2/16	4/16	2/16
1/16	2/16	1/16

94	81	75	81	94
81	44	25	44	81
75	25	0	25	75
81	44	25	44	81
94	81	75	81	94

Taken from: Applications of Convolution in Image Processing Dhruv https://www.youtube.com/watch?v=BQyMZ0caFbg

The Frangi Filter

Paper: "Multiscale vessel enhancement filtering"

A.F. Frangi, W.J. Niessen, K.L. Vincken, and M.A. Viergever. In Medical Image Computing and Computer-Assisted Intervention, pages 130–137, 1998.

"A common approach to analyze the local behavior of an image, L, is to consider its Taylor expansion in the neighborhood of point Xo"

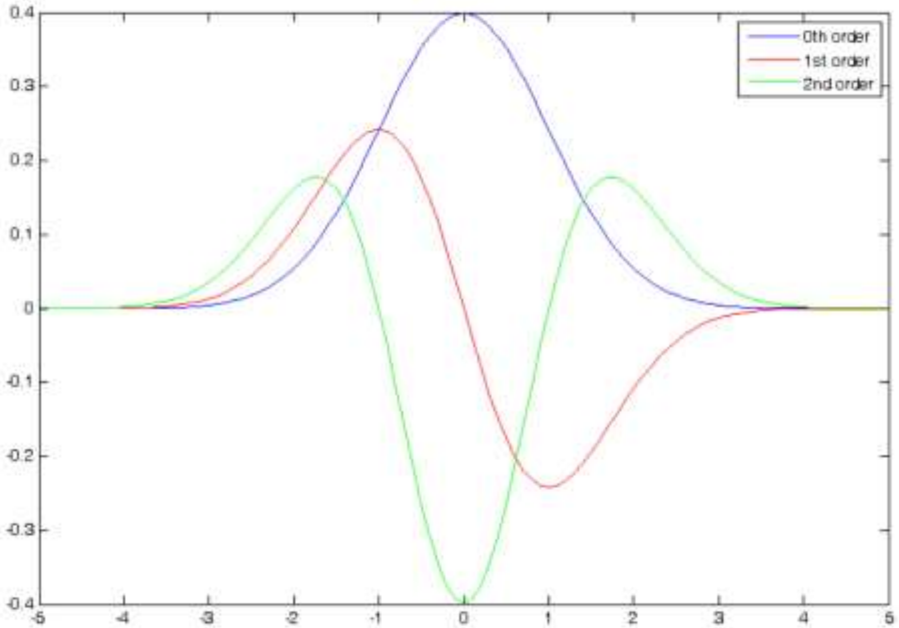
$$L(\mathbf{x}_o + \delta\mathbf{x}_o, s) \approx L(\mathbf{x}_o, s) + \delta\mathbf{x}_o^T \nabla_{o,s} + \delta\mathbf{x}_o^T \boxed{\mathcal{H}_{o,s}} \delta\mathbf{x}_o$$

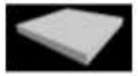
We are only looking at the Hessian matrix, a square matrix of the second order partial derivative.

$$\mathbf{H}f = \begin{bmatrix} \frac{\partial^2 f}{\partial x^2} & \frac{\partial^2 f}{\partial x \partial y} & \frac{\partial^2 f}{\partial x \partial z} & \cdots \\ \frac{\partial^2 f}{\partial y \partial x} & \frac{\partial^2 f}{\partial y^2} & \frac{\partial^2 f}{\partial y \partial z} & \cdots \\ \frac{\partial^2 f}{\partial z \partial x} & \frac{\partial^2 f}{\partial z \partial y} & \frac{\partial^2 f}{\partial z^2} & \cdots \\ \vdots & \vdots & \vdots & \ddots \end{bmatrix}$$

$$\frac{\partial}{\partial x}L(\mathbf{x},s) = s^{\gamma}L(\mathbf{x}) * \frac{\partial}{\partial x}G(\mathbf{x},s)$$

Scale Image Convolution Gaussian (derivative)



3D			
Structure	λ_1	λ_2	λ_3
	L	L	H-
	L	L	H+
	L	H-	H-
	L	H+	H+
	H-	H-	H-
	H+	H+	H+

Eigenvalues

Every square matrix can decompose into "characteristic values" called eigenvalues and eigenvectors.

These values can be used to determine "shape" as eigenvectors always point toward the extrema

$$\mathcal{V}_o(s) = \begin{cases} 0 & \text{if } \lambda_2 > 0 \text{ or } \lambda_3 > 0, \\ \left(1 - \exp\left(-\frac{\mathcal{R}_A{}^2}{2\alpha^2}\right)\right) \exp\left(-\frac{\mathcal{R}_B{}^2}{2\beta^2}\right)\left(1 - \exp\left(-\frac{S^2}{2c^2}\right)\right) & \end{cases}$$

Method with Eigenvectors

Yipu "Barrett" Gao

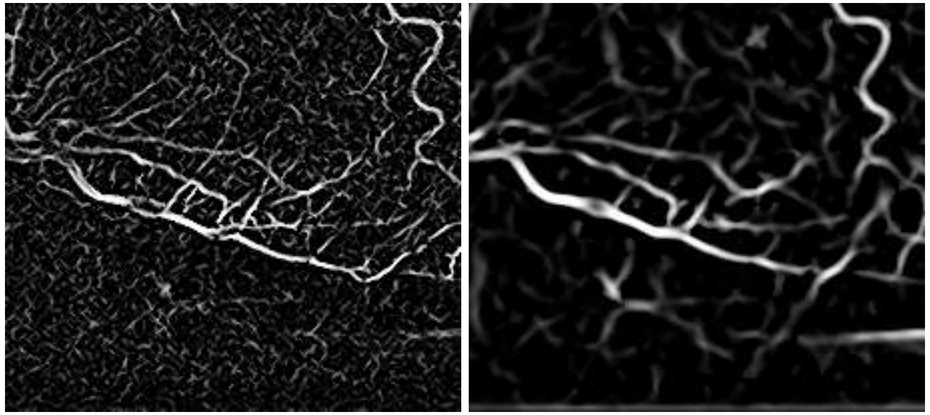
September 4th

Correct For Scale

$$\frac{\partial}{\partial x}L(\mathbf{x}, s) = s^{\gamma}L(\mathbf{x}) * \frac{\partial}{\partial x}G(\mathbf{x}, s)$$

Scale

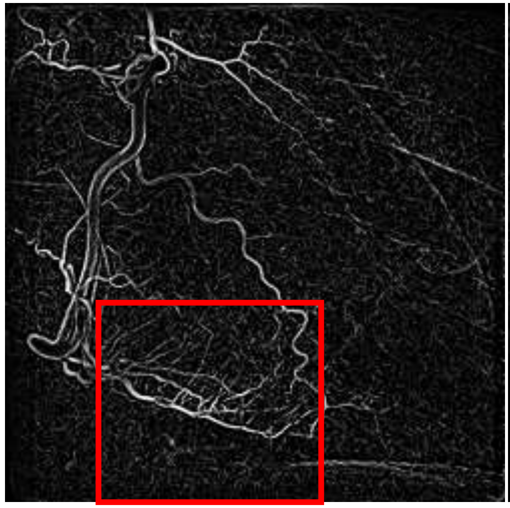
Input



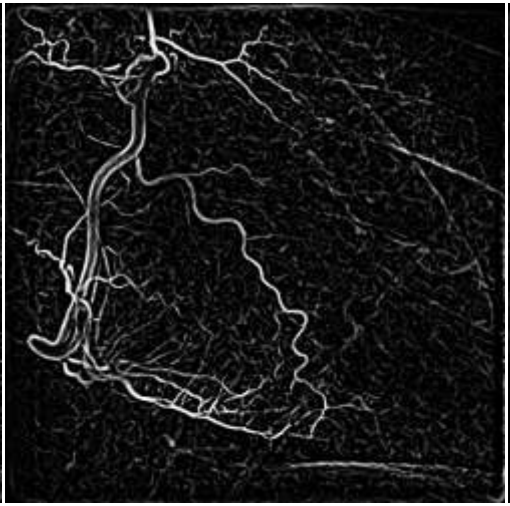
Closeups at scale 0.5 (left), and 2.5 (right)

Result: The maximum intensity at each location

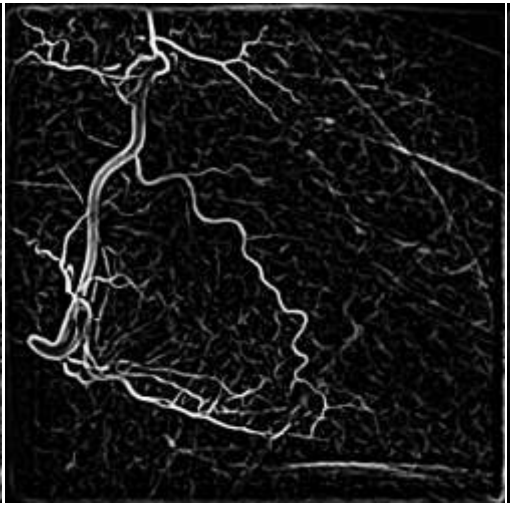
Output



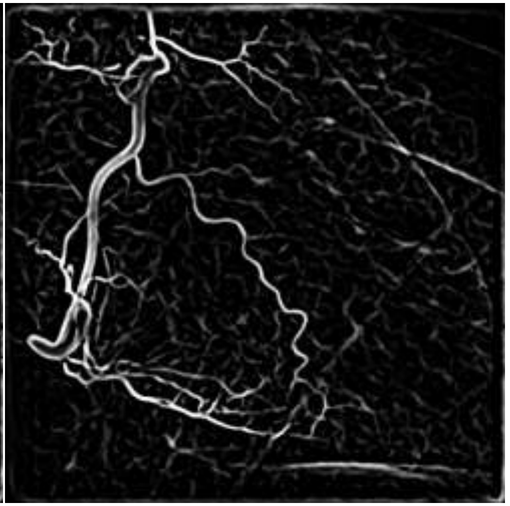
Scale = 0.5



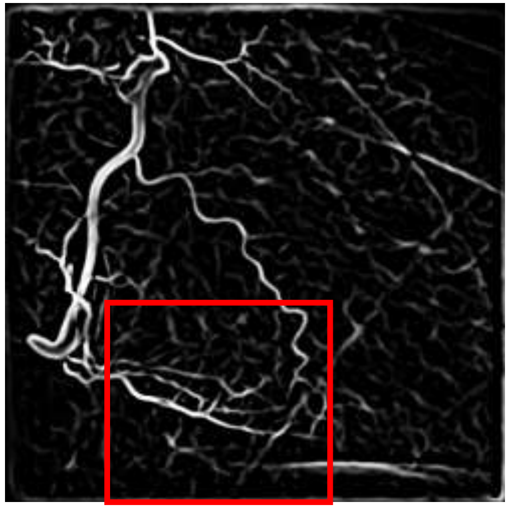
1.0



1.5



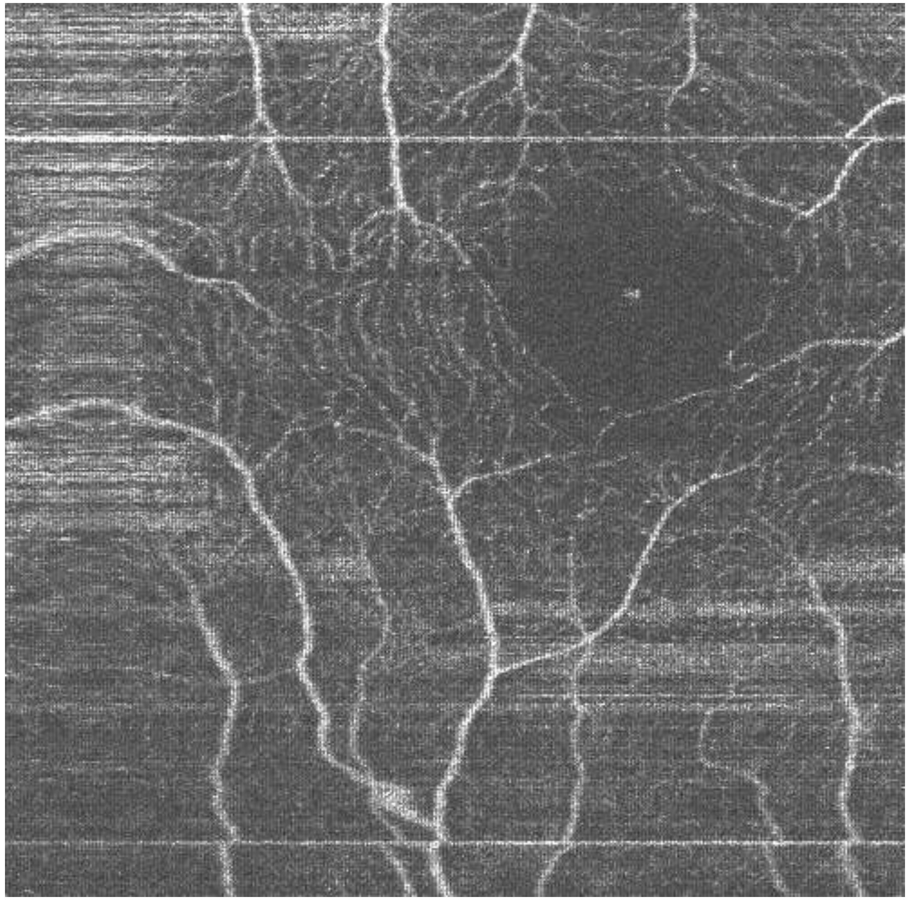
2.0



2.5

ITK: Insight Segmentation and Registration Toolkit

- C++ library
  - More efficient memory usage than MATLAB
  - Open-source
- Readily available on ACCRE
- Hessian filter already written
- Host of functions for other processing capabilities



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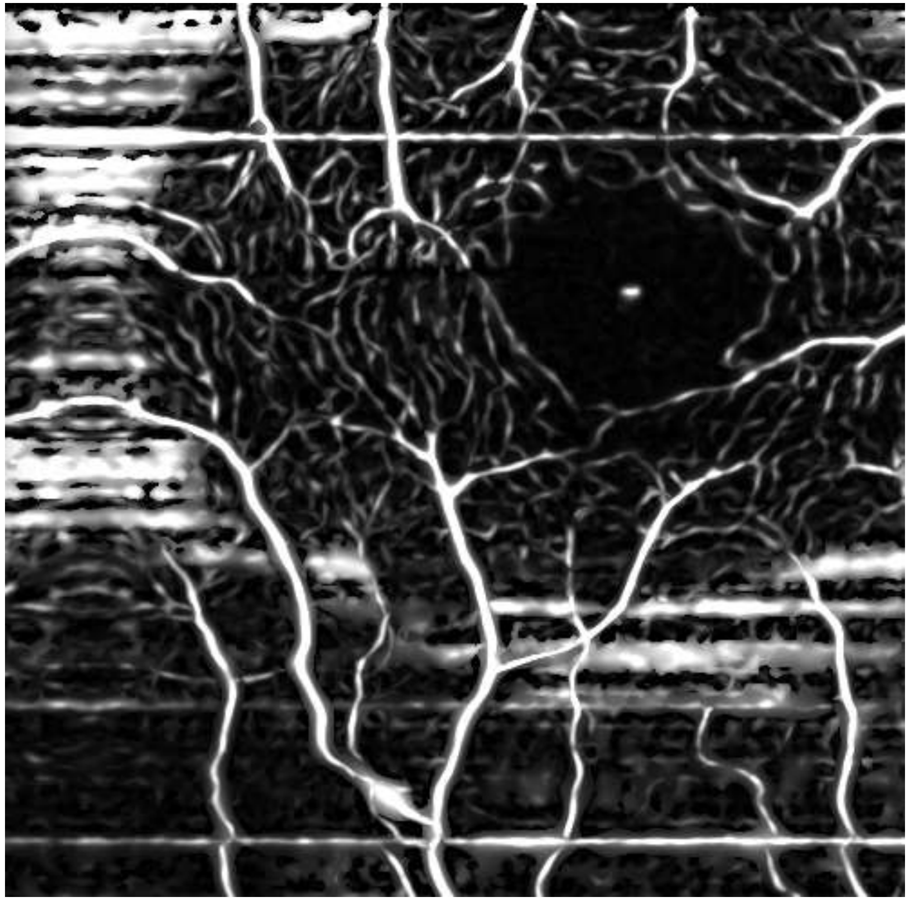

Output

Projection of input volume after
Hessian/Frangi filter

New goals?

- Providing a pipeline for cleaning and processing of handheld OCT
- Evaluate usage for quantitative vasculature assessment

Future direction

- Other Hessian-based vessel enhancing filters?
- Enhance post-processing (thresholding, reduce artifacts etc.)
- Combine/enhance for diffusion tensor imaging
- Recreate/Repair “damaged” regions within OCT using a stochastic/random process

Acknowledgements

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- Diagnostic Imaging and Image-Guided Interventions Lab and Joe Malone and Professor Tao

And thank you, the audience.