

# Optimized Strict Multiscale Frangi Prefiltering for Segmentation

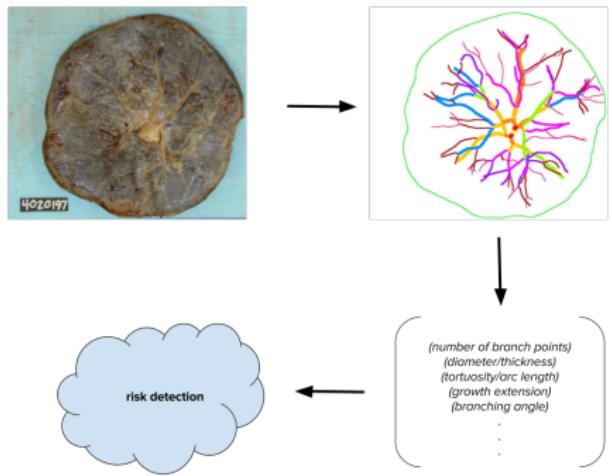
## Towards an automated PCSVN extraction

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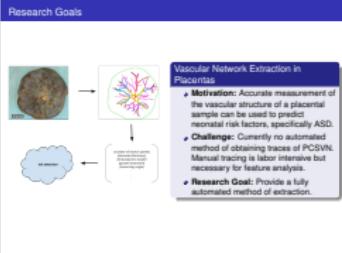
## Vascular Network Extraction in Placentas

- **Motivation:** Accurate measurement of the vascular structure of a placental sample can be used to predict neonatal risk factors, specifically ASD.
- **Challenge:** Currently no automated method of obtaining traces of PCSVN. Manual tracing is labor intensive but necessary for feature analysis.
- **Research Goal:** Provide a fully automated method of extraction.

## Cake Defense

- Introduction

- Research Goals



1. In the figure, a manual trace of the placental chorionic vascular surface network (PCSVN) is performed. This trace is measured in multiple ways. Those measurements are turned into a feature vector, which can be used to predict a risk. Refer to Boruta paper.
2. Manual tracing requires like 5 hours or something and requires training. There is some guesswork that's done in it too and some limitations in the ground truth itself (will cover later)

# The Image Processing Problem

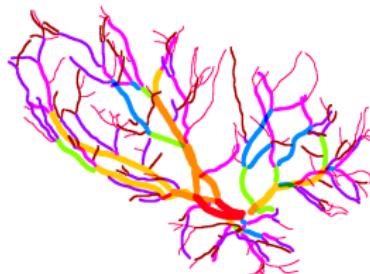
## Our image domain

- The PCSVN is a connected network of veins and arteries on the surface of the placenta
- Ground truth for 201 samples from private NCS dataset
- Placentas have been formalin-fixed, so arteries are more prominent.
- Pictures taken from top down, some glare, some inconsistencies.
- Placental images are comparatively noisy



## Strategy

Given the curvilinear nature of these vessels, we will appeal to differential geometry.



# Cake Defense

- Introduction

- The Image Processing Problem

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- The PCSVN is a connected network of veins and arteries on the surface of the placenta
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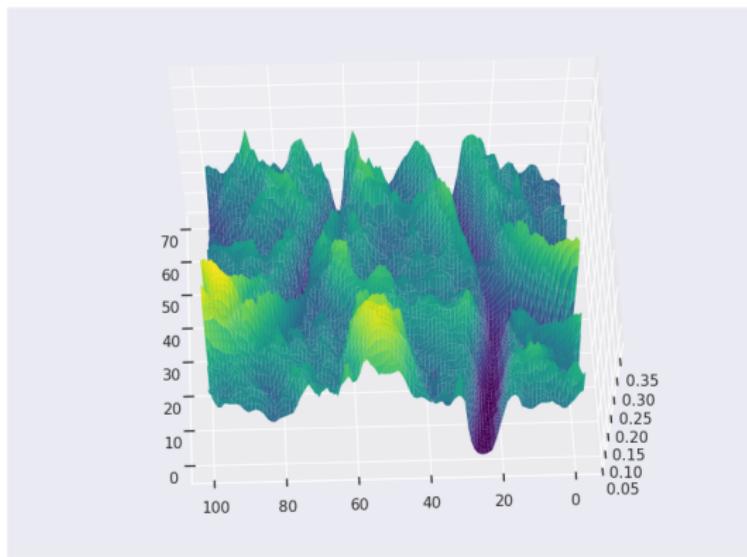
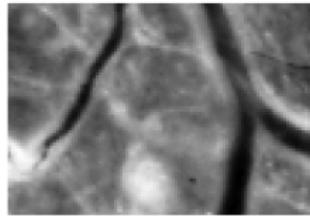
**Strategy**

Given the curvilinear nature of these vessels, we will appeal to differential geometry.

1. The surface of the placenta has a lot of changes in color/topology apart from the PCSVN so a lot of techniques that work elsewhere for vascular segmentation seem to fail here. Thus segmentation is more complicated than say, an eyeball MRI (like original Frangi paper)
2. Mention colors are simply vessel widths (3 to 19 odds) are part of the tracing protocol. that's really outside of the scope of this thesis, but kept anytime we show a ground truth because they're pretty
3. **META:** fix/align/crop the images better

# Appealing to Differential Geometry

Idealize image as a 3D surface (a graph) with  $(x, y)$  spatial coordinates and intensity as the height function.



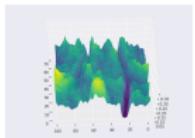
## Cake Defense

## └ Mathematical Methods

## └Appealing to Differential Geometry

## Appealing to Differential Geometry

Idealize image as a 3D surface (a graph) with  $(x, y)$  spatial coordinates and intensity as the height function.



1. Point of this slide is show that finding curvilinear surfaces is reasonable
2. This point is a lot clearer when you show multiple vessel widths.
3. Also way clearer later when you show the surface after Gaussian blur, not sure if I should put that here and “lie”/complicate things early on or not.
4. Crop graph, center, etc
5. **META:** Really need to review this whole section to talk about bright/dark features; make sure it's clear

- (Thm of Meusnier) If you look at a point on the surface and fix a tangent vector, then all surface curves through that point with that velocity will have the same curvature there. So the curvature is intrinsic to the surface, call it normal curvature.
- Varying the tangent vector, we call extremal values of normal curvature the **principal curvatures**. The associated tangent vectors are **principal directions**.
- (Thm. of Olinde Rodrigues) These principal curvatures/directions are the eigenvalues/eigenvectors of a particular map called the **Weingarten map**.

## Cake Defense

## └ Mathematical Methods

## └ Review of Differential Geometry of (Continuous) Surfaces

- » (Thm of Meusnier) If you look at a point on the surface and fix a tangent vector, then all surfaces curves through that point with that velocity will have the same curvature there. So the curvature is intrinsic to the surface, call it normal curvature.
- » Varying the tangent vector, we call extremal values of normal curvature the **principal curvatures**. The associated tangent vectors are **principal directions**.
- » (Thm. of Olvide Rodrigues) These principal curvatures/directions are the eigenvalues/eigenvectors of a particular map called the **Weingarten map**.

1. “Let’s just pretend we’re dealing with this as a continuous surface for now”
2. Weingarten map also called shape operator. Also can just define the second fundamental form and use that matrix (for our purposes)
3. Note that all this is true for *any* kind of surface, but we really just care about graphs.
4. If you want to get into notation, you can do so as far as explicitly showing what the Weingarten map is (requires Gauss map). You probably can avoid showing any setup of Meusnier– defining curves and so on.

## Weingarten Map for Graphs

Given the graph  $f : U \rightarrow \mathbb{R}^3$  where  $(x, y) \mapsto (x, y, h(x, y))$ , the matrix representation of its Weingarten map is given by

$$\widehat{\mathbf{L}} = \text{Hess}(h)\tilde{\mathbf{G}}$$

where  $\tilde{\mathbf{G}} := \frac{1}{(1+h_x^2+h_y^2)^{3/2}} \begin{bmatrix} 1+h_y^2 & -h_x h_y \\ -h_x h_y & 1+h_x^2 \end{bmatrix}$  and  $\text{Hess}(h) = \begin{bmatrix} h_{xx} & h_{xy} \\ h_{yx} & h_{yy} \end{bmatrix}$

## Approximating

- In particular, given a point where  $h_x \approx h_y \approx 0$ , we have  $\tilde{\mathbf{G}} \approx \text{Id}$ , and thus  $\widehat{\mathbf{L}} \approx \text{Hess}(h)$ .
- For ease of use, we can simply find eigenvalues of the Hessian instead.
- This gives rise to a class of filters, the so-called Hessian-based filters.

# Cake Defense

## └ Mathematical Methods

### └ Relationship Between Hessian and Weingarten Map for Graphs

#### Weingarten Map for Graphs

Given the graph  $f : U \rightarrow \mathbb{R}^2$  where  $(x, y) \mapsto (x, y, h(x, y))$ , the matrix representation of its Weingarten map is given by

$$\tilde{L} = \text{Hess}(h)\tilde{G}$$

$$\text{where } \tilde{G} := \begin{bmatrix} 1 & 0 \\ -1 & 0 \end{bmatrix}, \quad \begin{bmatrix} 1 + h_x^2 & -h_x h_y \\ -h_x h_y & 1 + h_y^2 \end{bmatrix} \text{ and } \text{Hess}(h) = \begin{bmatrix} h_{xx} & h_{xy} \\ h_{yx} & h_{yy} \end{bmatrix}$$

#### Approximating

- In particular, given a point where  $h_x \approx h_y \approx 0$ , we have  $\tilde{G} \approx \text{Id}$ , and thus  $\tilde{L} \approx \text{Hess}(h)$ .
- For ease of use, we can simply find eigenvalues of the Hessian instead.
- This gives rise to a class of filters, the so-called Hessian-based filters.

1. Make sure you have the graph definition clearly here. It's at the top but make it more prominent / earlier slidewise
2. Make point about when we're not at a critical point, we don't guarantee any of this (but it seems to work out okay)
3. "Remember this point right here, we will come back to this."

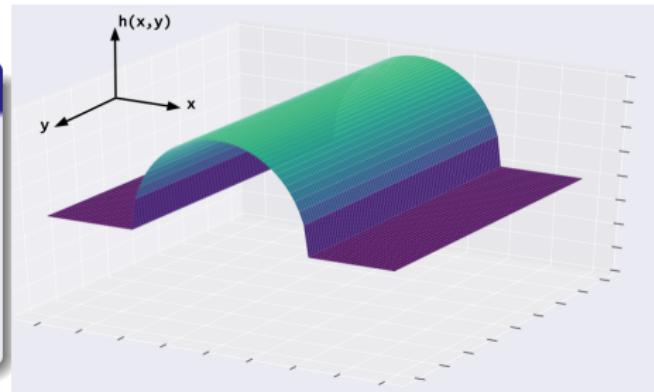
## Example: Finding Weingarten map and Principal Curvatures

### Cylindrical Ridge of radius $r$

Let  $f$  be the graph given by

$f : \mathbb{R}^2 \rightarrow \mathbb{R}^3$  by  $f(x, y) = (x, y, h(x, y))$ ,

with  $h(x, y) = \begin{cases} \sqrt{r^2 - x^2} & -r < x < r \\ 0 & \text{else} \end{cases}$



$$h_x = \frac{-x}{\sqrt{r^2 - x^2}} \quad , \quad h_{xx} = \frac{-r^2}{(r^2 - x^2)^{3/2}}$$
$$h_y = 0 \quad , \quad h_{yy} = 0 \quad , \quad h_{xy} = 0$$

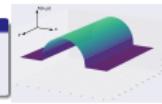
## Cake Defense

## └ Mathematical Methods

## └ Example: Finding Weingarten map and Principal Curvatures

Cylindrical Ridge of radius  $r$ Let  $f$  be the graph given by

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with  $h(x, y) = \begin{cases} \sqrt{r^2 - x^2} & -r < x < r \\ 0 & \text{else} \end{cases}$ 

$$h_0 = \frac{-x}{\sqrt{r^2 - x^2}} \quad , \quad h_{00} = \frac{-x^2}{(r^2 - x^2)^{3/2}}$$

$$h_0 = 0 \quad , \quad h_{00} = 0 \quad , \quad h_{0y} = 0$$

1. Show the example here. Your example calculates from a different definition, like with Gauss map etc. so maybe rework or decide what you want here.
2. "Calculate boring partial derivatives"
3. Note: the formula for weinmat is on the next slide

## Example: Finding Weingarten map and Principal Curvatures

### Weingarten matrix representation (for graphs)

$$\widehat{\mathbf{L}} = \text{Hess}(h)\tilde{\mathbf{G}}, \quad \text{where} \quad \tilde{\mathbf{G}} := \frac{1}{(1 + h_x^2 + h_y^2)^{3/2}} \begin{bmatrix} 1 + h_y^2 & -h_x h_y \\ -h_x h_y & 1 + h_x^2 \end{bmatrix}$$

$$\text{Hess}(h) = \begin{bmatrix} h_{xx} & h_{xy} \\ h_{xy} & h_{yy} \end{bmatrix} = \begin{bmatrix} \frac{-r^2}{(r^2-x^2)^{3/2}} & 0 \\ 0 & 0 \end{bmatrix} \quad \tilde{\mathbf{G}} = \frac{1}{\left(1 + \frac{x^2}{r^2-x^2}\right)^{3/2}} \begin{bmatrix} 1 & 0 \\ 0 & 1 + \frac{x^2}{r^2-x^2} \end{bmatrix}$$

$$\begin{aligned} \widehat{\mathbf{L}} &= \text{Hess}(h)\tilde{\mathbf{G}} = \frac{1}{\left(1 + \frac{x^2}{r^2-x^2}\right)^{3/2}} \begin{bmatrix} \frac{r^2}{(r^2-x^2)^{3/2}} & 0 \\ 0 & 0 \end{bmatrix} \\ &= \dots = \begin{bmatrix} \frac{-1}{r} & 0 \\ 0 & 0 \end{bmatrix} \end{aligned}$$

## Cake Defense

## └ Mathematical Methods

## └ Example: Finding Weingarten map and Principal Curvatures

## Weingarten matrix representation (for graphs)

$$\tilde{L} = \text{Hess}(h)\tilde{G}, \quad \text{where } \tilde{G} = \frac{1}{(1 + R_x^2 + R_y^2)^{3/2}} \begin{bmatrix} 1 + R_y^2 & -R_x R_y \\ -R_x R_y & 1 + R_x^2 \end{bmatrix}$$

$$\text{Hess}(h) = \begin{bmatrix} h_{xx} & h_{xy} \\ h_{yx} & h_{yy} \end{bmatrix} = \begin{bmatrix} \frac{x^2}{(r^2-x^2)^{3/2}} & 0 \\ 0 & 0 \end{bmatrix} \quad G = \frac{1}{(1 + \frac{x^2}{r^2-x^2})^{3/2}} \begin{bmatrix} 1 & 0 \\ 0 & 1 + \frac{x^2}{r^2-x^2} \end{bmatrix}$$

$$\tilde{L} = \text{Hess}(h)\tilde{G} = \frac{1}{(1 + \frac{x^2}{r^2-x^2})^{3/2}} \begin{bmatrix} \frac{x^2}{(r^2-x^2)^{3/2}} & 0 \\ 0 & 0 \end{bmatrix}$$

$$= \dots = \begin{bmatrix} \frac{1}{r} & 0 \\ 0 & 0 \end{bmatrix}$$

Here's the steps without dots just in case you need to add it back in:

$$\begin{aligned} \tilde{L} &= \text{Hess}(h)\tilde{G} = \frac{1}{\left(1 + \frac{x^2}{r^2-x^2}\right)^{3/2}} \begin{bmatrix} \frac{r^2}{(r^2-x^2)^{3/2}} & 0 \\ 0 & 0 \end{bmatrix} \\ &= \frac{1}{\left(\frac{r^2}{r^2-x^2}\right)^{3/2}} \begin{bmatrix} \frac{r^2}{(r^2-x^2)^{3/2}} & 0 \\ 0 & 0 \end{bmatrix} = \frac{(r^2-x^2)^{3/2}}{r^3} \begin{bmatrix} \frac{-r^2}{(r^2-x^2)^{3/2}} & 0 \\ 0 & 0 \end{bmatrix} = \begin{bmatrix} \frac{-1}{r} & 0 \\ 0 & 0 \end{bmatrix} \end{aligned}$$

1. This is just some matrix multiplication, exponent rules, and finding common denominators. This would be a good challenge problem for Math 112A minus the matrix.
2. Mostly, just point out it's  $\begin{bmatrix} a & 0 \\ 0 & 0 \end{bmatrix}$  times  $\begin{bmatrix} b & 0 \\ 0 & c \end{bmatrix}$

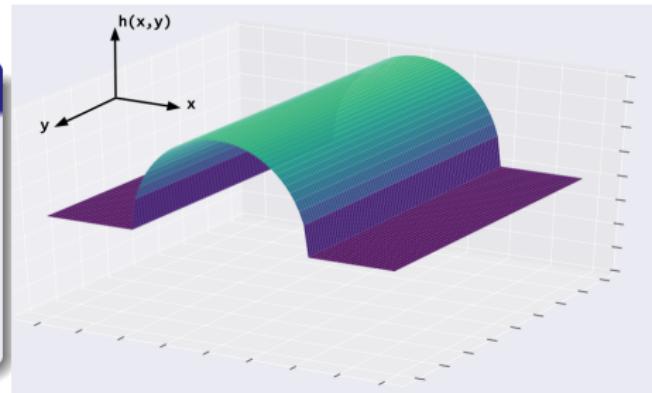
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$f : \mathbb{R}^2 \rightarrow \mathbb{R}^3$  by  $f(x, y) = (x, y, h(x, y))$ ,

with  $h(x, y) = \begin{cases} \sqrt{r^2 - x^2} & -r < x < r \\ 0 & \text{else} \end{cases}$



$$\hat{L} = \begin{bmatrix} -\frac{1}{r} & 0 \\ 0 & 0 \end{bmatrix} \quad \text{Matrix of Weingarten map}$$

$u_2 = (1, 0)$ ,  $u_1 = (0, 1)$  principal directions (eigenvectors of  $\hat{L}$ )

$\lambda_2 = -\frac{1}{r}$ ,  $\lambda_1 = 0$  principal curvatures (eigenvalues of  $\hat{L}$ )

## Cake Defense

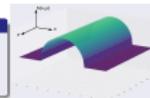
## └ Mathematical Methods

## └ Example: Finding Weingarten Map and Principal Curvatures

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with  $h(x, y) = \begin{cases} \sqrt{r^2 - x^2}, & -r < x < r \\ 0, & \text{else} \end{cases}$



$$\hat{L} = \begin{bmatrix} -\frac{1}{r} & 0 \\ 0 & 0 \end{bmatrix} \quad \text{Matrix of Weingarten map}$$

 $\lambda_0 = (1, 0)$ ,  $\mathbf{u}_0 = (0, 1)$  principal directions (eigenvectors of  $\hat{L}$ ) $\lambda_0 = -\frac{1}{r}$ ,  $\lambda_1 = 0$  principal curvatures (eigenvalues of  $\hat{L}$ )

- META:** need to show what hessian eigs/eigvecs are and emphasize that at the ridge point it's identical
- META:** also can explain (here or later) if there's a stronger signal at the ridge point or if it's literally anywhere on the ridge
- This is what to stick in somewhere:

$$\text{Hess}(h) = \begin{bmatrix} h_{xx} & h_{xy} \\ h_{xy} & h_{yy} \end{bmatrix} = \begin{bmatrix} -\frac{r^2}{(r^2-x^2)^{3/2}} & 0 \\ 0 & 0 \end{bmatrix} \quad (1)$$

Note that eigenvalues are still 0 and the top left element (now a function of  $x$ ), eigenvectors are (can be chosen to be) the same throughout, and if  $x = 0$  (at the crest) then  $\hat{L} = \text{Hess}$  exactly, as expected.

## The (Uniscale) Frangi Filter

$$\mathcal{V}(x, y) = \begin{cases} 0 & \text{if } \lambda_2 > 0 \\ \exp\left(-\frac{A^2}{2\beta^2}\right) \left(1 - \exp\left(-\frac{S^2}{2c^2}\right)\right) & \text{otherwise} \end{cases}$$

where

$$A := |\lambda_1 / \lambda_2| \quad (\text{Anisotropy Measure})$$

$$\text{and } S := \sqrt{\lambda_1^2 + \lambda_2^2} \quad (\text{Structureness Measure})$$

for eigenvalues  $\lambda_1, \lambda_2$  of the Hessian (at point  $(x,y)$ ),  $|\lambda_1| \leq |\lambda_2|$   
and  $\beta$  and  $c$  are parameters

## Cake Defense

### The Frangi filter

#### The (Uniscale) Frangi Filter

$$V(x, y) = \begin{cases} 0 & \text{if } \lambda_2 > 0 \\ \exp\left(-\frac{\lambda_1}{2B^2}\right) \left(1 - \exp\left(-\frac{\lambda_1}{2A^2}\right)\right) & \text{otherwise} \end{cases}$$

where

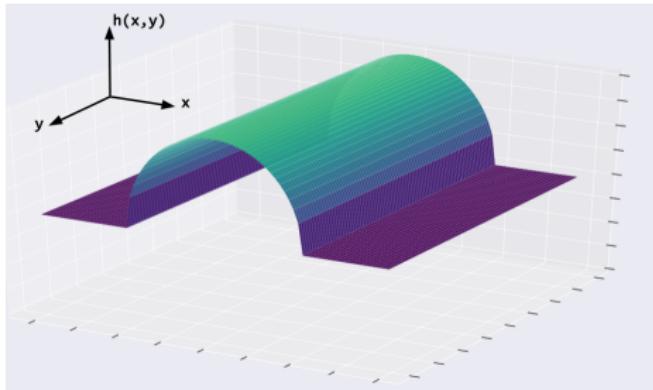
 $A := |\lambda_1/\lambda_2|$  (Anisotropy Measure)and  $B := \sqrt{\lambda_1^2 + \lambda_2^2}$  (Structurlessness Measure)for eigenvalues  $\lambda_1, \lambda_2$  of the Hessian (at point  $(x, y)$ ).  $|\lambda_1| \leq |\lambda_2|$  and  $\beta$  and  $c$  are parameters.

1. Mostly point out how it all fits together. Two simple functions of the principal curvatures, put into exponential forms, with a parameter to control each.
2. “We’ll go through this step by step and look at each part more closely”
3. Mention that if you wanted to use the “real” principal curvatures here you’re more than welcome to
4. Don’t need to spend too much time on this slide, we’ll put it back again

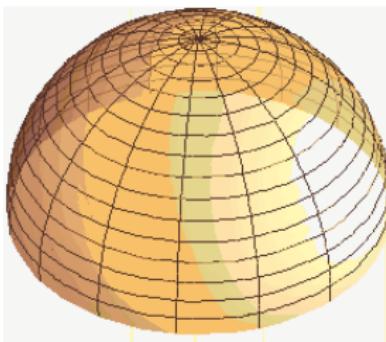
## Anisotropy Factor

$$\exp\left(-\frac{A^2}{2\beta^2}\right) \quad , \quad A := \left| \frac{\lambda_1}{\lambda_2} \right| \quad (2)$$

- For selecting anisotropic content (lines not blobs)
- When  $A$  is very close to 0,  $|\lambda_2| \gg |\lambda_1|$ , and the factor is  $\approx 1$ .
- Choosing parameter: Frangi suggested  $\beta = \frac{1}{2}$  as a reasonable default.



(a) Anisotropic



(b) Isotropic

## Structureness Factor

$$\left(1 - \exp\left(-\frac{S^2}{2c^2}\right)\right) \quad , \quad S := \sqrt{\lambda_1^2 + \lambda_2^2} \quad (3)$$

- This selects content with significant curvature.
- Purpose is to filter out numerically small values, we only want significant curvilinear content ( $S$  large).
- Important to pick a reasonable value for the image at hand / image domain.
- Frangi suggested “half the maximum value of the Hessian norm”. We will define the parameter  $\gamma$  and define  $c(\gamma) = \gamma S_{\max}$ , since  $S_{\max}$  is the Frobenius norm of the Hessian.

## Cake Defense

### The Frangi filter

#### Structureness Factor

##### Frangi filter anatomy

###### Structureness Factor

$$\left(1 - \exp\left(-\frac{S^2}{2\sigma^2}\right)\right) , \quad S := \sqrt{\lambda_1^2 + \lambda_2^2}$$

(3)

- This selects content with significant curvature.
- Purpose is to filter out numerically small values, we only want significant curvilinear content ( $S$  large).
- Important to pick a reasonable value for the image at hand / image domain.
- Frangi suggested "half the maximum value of the Hessian norm". We will define the parameter  $c$  and define  $c(\cdot) = \gamma S_{\text{max}}$ , since  $S_{\text{max}}$  is the Frobenius norm of the Hessian.

1. For example, we don't want our filter to report a point as curvilinear structure if  $\lambda_1/\lambda_2$  is large, but we can't differentiate between  $\lambda_2 = 100$ ,  $\lambda_1 = .01$  and  $\lambda_2 = .001$ ,  $\lambda_1 = .000001$
2. This is actually critically important to define, entire filter will be extremely noisy otherwise. Less important in MRI images, but more important for our context where there is significant noise. Talk about the standard implementation where  $c=15$  is the default for seemingly no reason.
3. I'm not sure when/how to introduce  $\gamma$  instead but it should be prominent enough that I don't have to worry about using it exclusively in later slides

## Frangi filter anatomy: Putting it together

### Frangi filter

$$\mathcal{V}_\sigma(x_0, y_0) = \begin{cases} 0 & \text{if } \lambda_2 > 0 \\ \exp\left(-\frac{A^2}{2\beta^2}\right) \left(1 - \exp\left(-\frac{s^2}{2(\gamma S_{\max})^2}\right)\right) & \text{otherwise} \end{cases} \quad (4)$$

$$\text{where } A := |\lambda_1/\lambda_2| \quad \text{and} \quad S := \sqrt{\lambda_1^2 + \lambda_2^2}, \quad |\lambda_2| \geq |\lambda_1| \quad (5)$$

- $\lambda_2 > 0$  means the point would be a local minimum (at a critical point). We are looking for a local maximum by looking for bright curvilinear objects. You can switch this ( $\lambda_2 < 0$  as the case) if you are looking for dark curvilinear.
- Point of  $\exp(\dots)$  and  $1 - \exp(\dots)$  structure is that the filter decays rapidly as anisotropy or structureness decrease.

# Cake Defense

## The Frangi filter

### Frangi filter anatomy: Putting it together

#### Frangi filter

$$V_\sigma(x_0, y_0) = \begin{cases} 0 & \text{if } \lambda_2 > 0 \\ \exp\left(-\frac{\rho^2}{B^2}\right) \left(1 - \exp\left(-\frac{\rho^2}{B^2 + S^2}\right)\right) & \text{otherwise} \end{cases} \quad (4)$$

where  $A := |\lambda_1/\lambda_2|$  and  $B := \sqrt{A_1^2 + A_2^2}$ ,  $|\lambda_0| \geq |\lambda_1|$

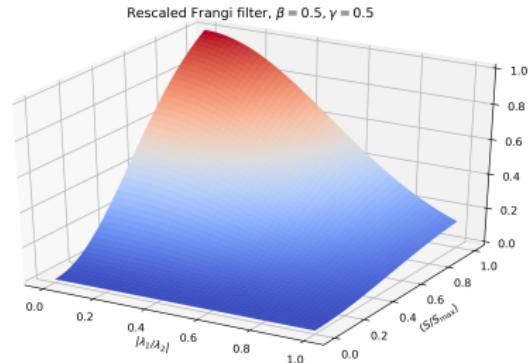
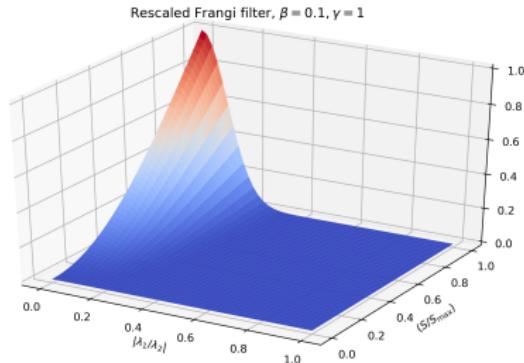
- $\lambda_2 > 0$  means the point would be a local minimum (at a critical point). We are looking for a local maximum by looking for bright curvilinear objects. You can switch this ( $\lambda_2 < 0$ ) in the case if you are looking for dark curvilinear.
- Point of  $\exp(-\cdot)$  and  $1 - \exp(-\cdot)$  structure is that the filter decays rapidly as anisotropy or structures decrease.

1. **META:** Really look into the bright/dark curvilinear subject and try to explain better.
2. **META:** Significance of sign of principal curvature (real one from Weingarten map)?
3. **META:** Get rid of the sigma until after scale space theory?
4. If it's too long to get to this point, maybe start showing samples already

# Frangi filter anatomy: Choosing Parameters

$$\mathcal{V}_\sigma(x_0, y_0) = \begin{cases} 0 & \text{if } \lambda_2 > 0 \\ \exp\left(-\frac{A^2}{2\beta^2}\right) \left(1 - \exp\left(-\frac{s^2}{2(\gamma S_{\max})^2}\right)\right) & \text{otherwise} \end{cases} \quad (6)$$

$$\text{where } A := |\lambda_1/\lambda_2| \quad \text{and} \quad S := \sqrt{\lambda_1^2 + \lambda_2^2}, |\lambda_2| \geq |\lambda_1| \quad (7)$$



- We will show a lot of data with different choices of parameters later.

- Obviously the image is not actually a continuous surface. It is a particular sampling of a surface.
- We want to embed the image this image with a “resolution” parameter.
- Motivate and say some basic axioms.
- Convolution by Gaussian solves these problems, discrete derivatives are fine too

## Axioms

- Linear shift and rotational invariance
- Semigroup property
- Continuity of scale parameter
- Causality condition

## Cake Defense

### The Frangi filter

#### └ Scale Space Theory

- ▶ Obviously the image is not actually a continuous surface. It is a particular sampling of a surface.
- ▶ We want to embed the image this image with a "resolution" parameter.
- ▶ Motivate and say some basic axioms.
- ▶ Convolution by Gaussian solves these problems, discrete derivatives are fine too

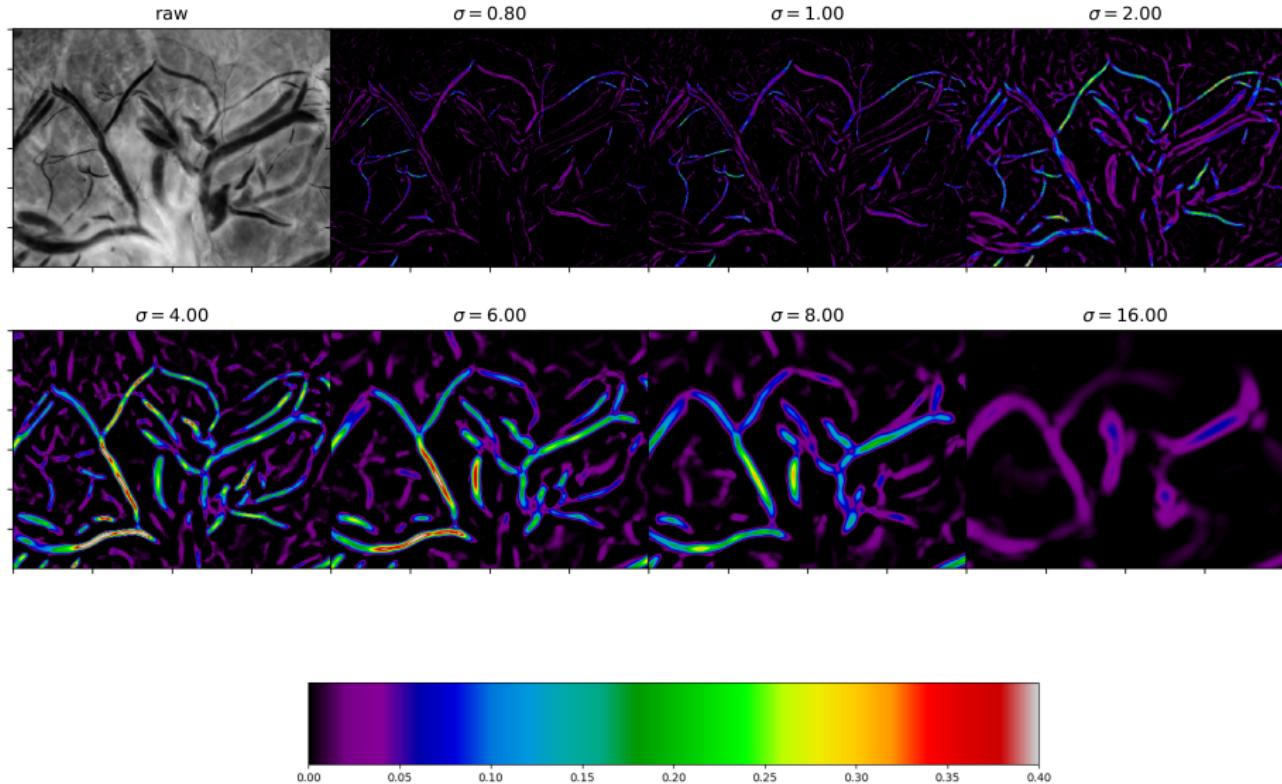
#### Axioms

- ▶ Linear shift and rotational invariance
- ▶ Semigroup property
- ▶ Continuity of scale parameter
- ▶ Causality condition

1. Maybe spend an extra slide on causality condition. Basically, as resolution decreases (scale increases) then local minima do not decrease, and local maxima do not increase.
2. Prepare a couple more details to get into here.

- Convolution by gaussian matrix is slow.
- Calculate in frequency space as a multiplication
- Much much much faster
- Show the speed graph, explain MSE findings

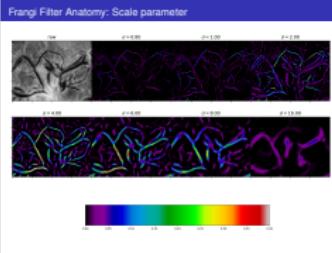
# Frangi Filter Anatomy: Scale parameter



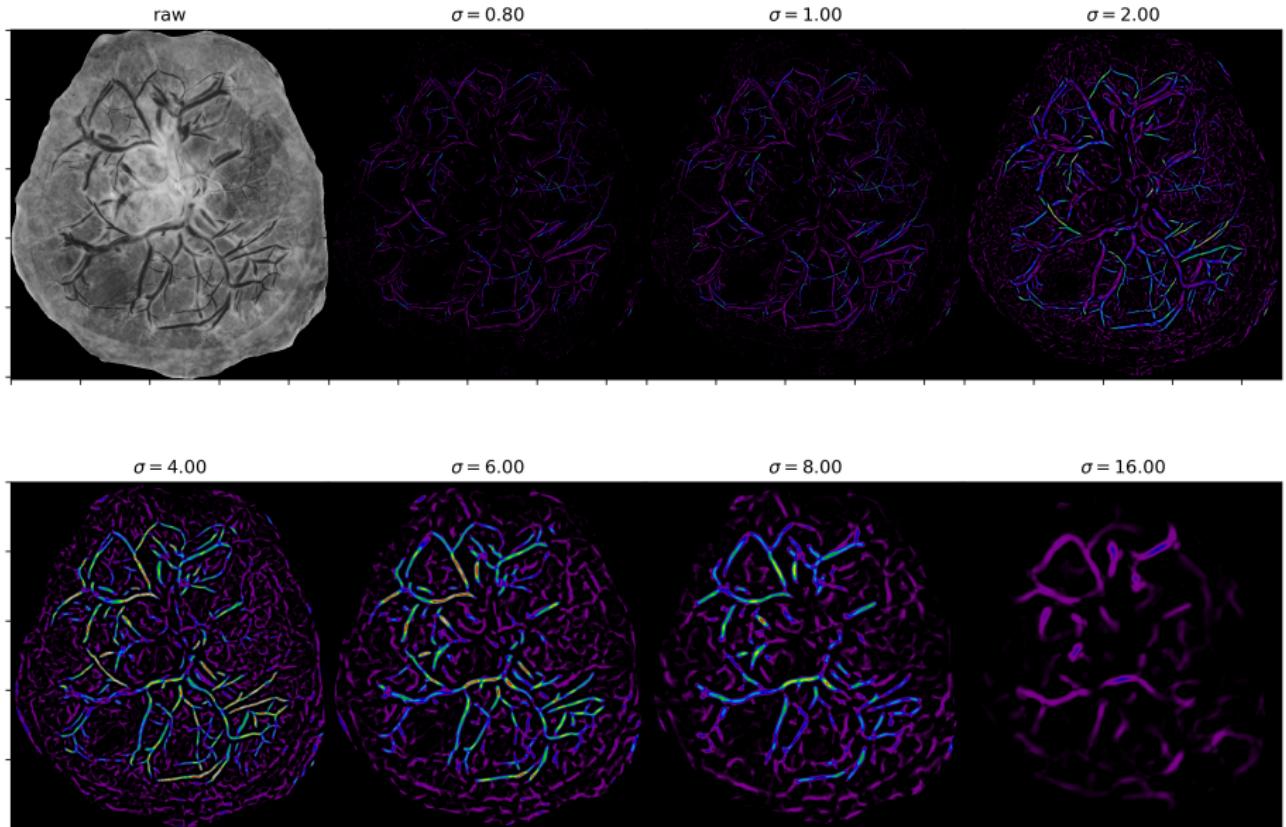
## Cake Defense

## └ The Frangi filter

## └ Frangi Filter Anatomy: Scale parameter

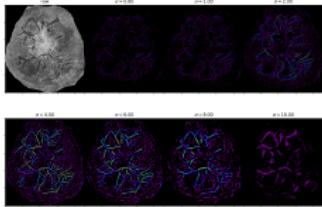


1. Mention general relationship between vessel width.
2. Describe relative strength of outputs and what's too large.
3. **META:** You kind of need to rerun this with rescaling etc. to make this point easier to make)



# Cake Defense

## The Frangi filter



1. Same thing but whole plate. Show this for like 5 seconds.
2. "This is basically just to show that these trends work throughout the whole image, etc"

For a set of scales to probe,  $\Sigma := \{\sigma_0, \sigma_1, \dots, \sigma_n\}$ , the set of  $n$  scales at which to probe,

$$\mathcal{V}_{\max}(x_0, y_0) := \max_{\sigma \in \Sigma} \{\mathcal{V}_\sigma(x_0, y_0)\} \quad (8)$$

where  $\mathcal{V}_\sigma$  is the Frangi vesselness measure at scale  $\sigma$  for the pixel  $(x_0, y_0)$

## Notes

- The default “merging” strategy suggested by Frangi.
- Alternatively, we can process each scale by itself too if we want to.
- Decide what scales to use:
  - Logarithmic spacing makes some intuitive sense.
  - Need to experiment to determine what is large / small enough.
  - Smaller scales for smaller features, larger scales for larger features.

## Cake Defense

### The Frangi filter

#### Multiscale Frangi filter

For a set of scales to probe,  $\Sigma := \{\sigma_0, \sigma_1, \dots, \sigma_n\}$ , the set of  $n$  scales at which probe,

$$\mathcal{V}_{\text{mult}}(x, y) := \max_{\sigma \in \Sigma} \{\mathcal{V}_\sigma(x, y)\} \quad (8)$$

where  $\mathcal{V}_\sigma$  is the Frangi vesselness measure at scale  $\sigma$  for the pixel  $(x_0, y_0)$ .

#### Notes

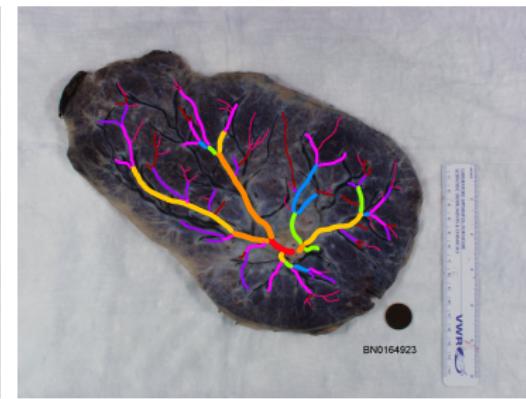
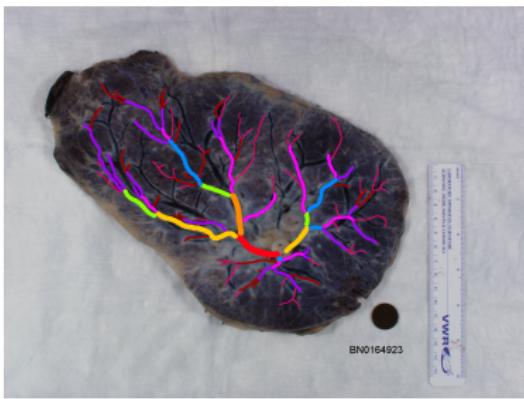
- ▶ The default “merging” strategy suggested by Frangi.
- ▶ Alternatively, we can process each scale by itself too if we want to.
- ▶ Decide what scales to use:
  - ▶ Logarithmic spacing makes some intuitive sense.
  - ▶ May need to experiment to determine what is large / small enough.
  - ▶ Smaller scales for smaller features, larger scales for larger features.

1. We can also keep track of  $\mathcal{V}_{\arg\max}$  etc.
2. Recall that this is a probability-like measure, so this is the probabilityish that it has the differential geometry of a curvilinear structure

## The data set

Show a number of samples, no words. Just talk about how some are better than others. Have one sample bad with bad perfusion. We'll get more into it in a minute.

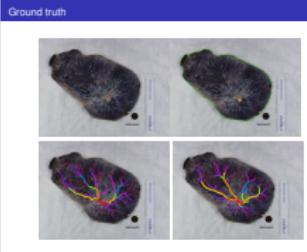
# Ground truth



## Cake Defense

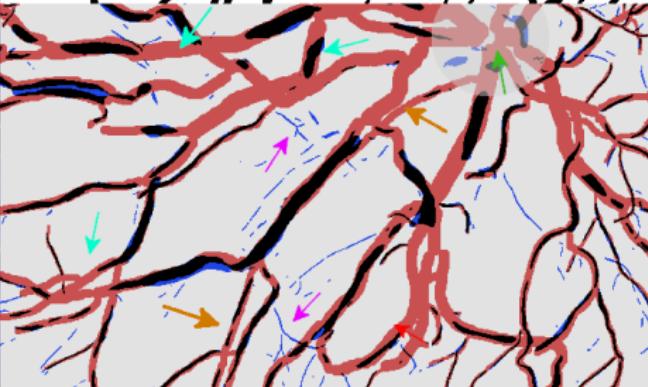
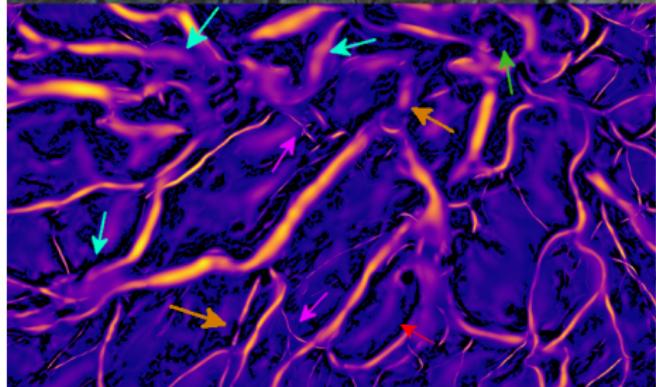
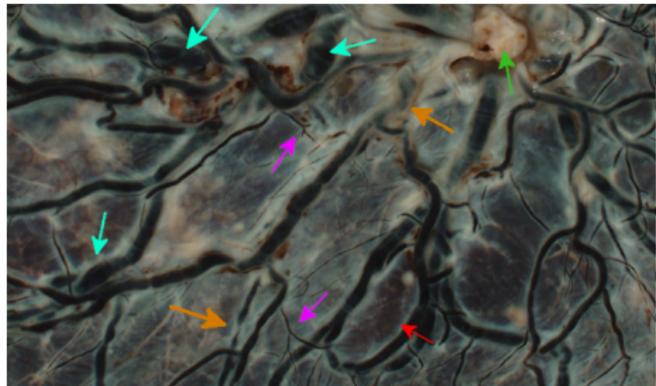
## └ Research Protocol

## └ Ground truth



1. Maybe show these cropped, who cares
2. Maybe show enlarged UCIP and border, IDK if these will show up well
3. Maybe show cropped, merged trace by itself on one slide (quickly)

# Imperfections/Complications in Data set

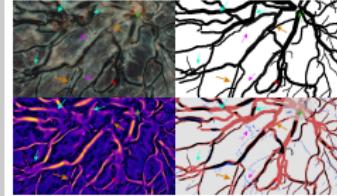


## Cake Defense

## └ Research Protocol

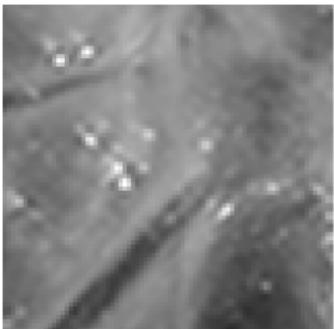
## └ Imperfections/Complications in Data set

Imperfections/Complications in Data set

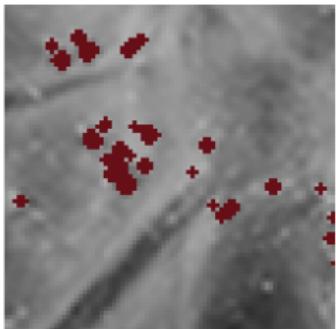


1. The  $2 \times 2$  annotations might be too complicated, might not show up on the projector. Maybe just switch between two slides? or show different colors of annotations on each slide?
2. Talk about:
  - UCIP noise
  - too small and too big
  - bad perfusion
  - crossings

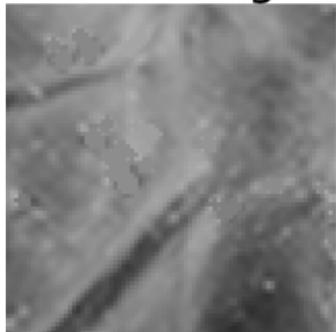
## Preprocessing: Dealing with Glare



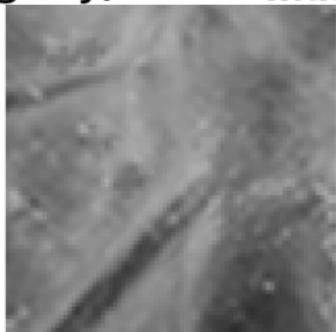
**original (glary)**



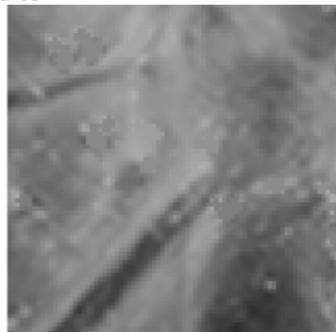
**masked**



**boundary  
median**



**biharmonic  
inpainting**



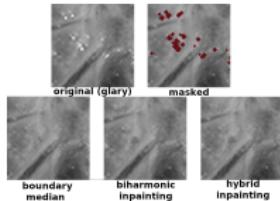
**hybrid  
inpainting**

## Cake Defense

## └ Research Protocol

## └ Preprocessing: Dealing with Glare

Preprocessing: Dealing with Glare



1. Glare isn't catastrophic in most cases, but it can throw off results.
2. We're looking for small abrupt peaks on the surface, want to smooth out.
3. For simplicity, we assume everything higher than 175/255 is glare
4. MATLAB has a technique called imfill that solves Laplace equation  $\nabla f = 0$ . We use built-in python that does biharmonic equation  $\nabla \nabla f = 0$ . It's pretty slow, so we speed it up by using an alternate strategy, where we just take the median of the boundary for smaller masked regions. You can see the lowest portion of the middle mask is fixed in the hybrid method.
5. Times to process a representative sample (whole thing not this inset):
  - biharmonic inpainting: 22 seconds
  - boundary median 4 seconds
  - hybrid method 6 seconds
6. Would be nice to have implementation details on the slide but I'm worried you can't

## Preprocessing: Umbilical Stump

Put ucip stump (cropped here) or with an arrow. Show a masked version.

## Cake Defense

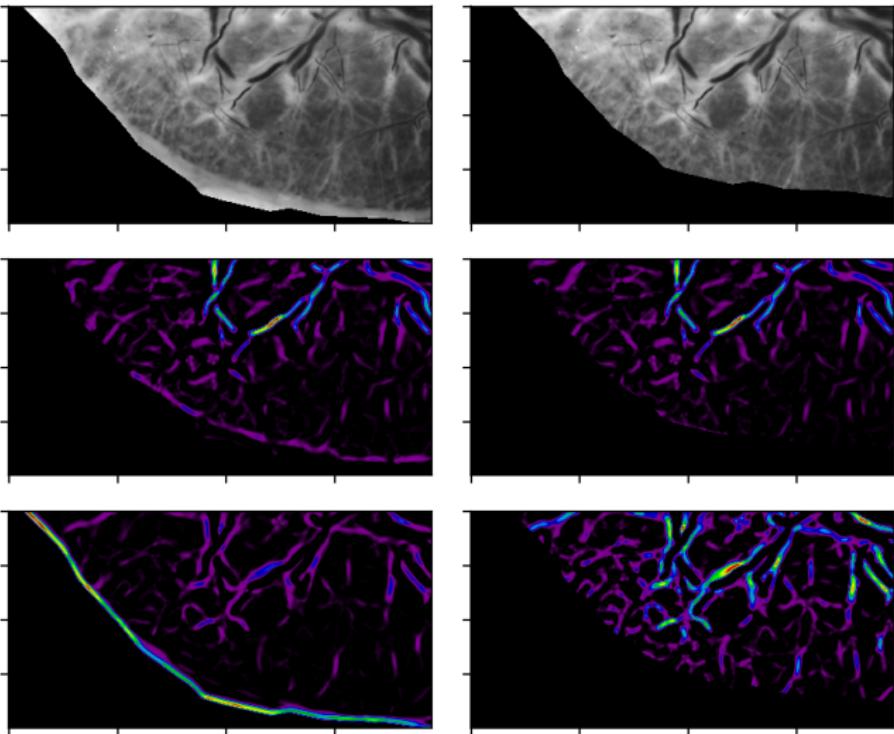
## └ Research Protocol

## └ Preprocessing: Umbilical Stump

Put ucp stump (cropped here) or with an arrow. Show a masked version.

1. It was hard to remove these in an automated way that worked for all samples. You could do a white top hat and have it work a good amount of the time, but I ran out of time to do it effectively. There isn't any good data here due to diffgeo anyway as far as I can tell. Tracing protocol seems to estimate a lot.
2. This was with a radius of 50 pixels
3. When do we dump these? We never see a ring around, so it's not processed as a 0, but this region definitely isn't used to calculate Smax at the very least.
4. This prevents area around the stump from being misconstrued as part of vascular network.
5. Basically picked this particular one because you can see that the radius we picked doesn't exactly fix the issue, but it does make it better. Hard to tell that the signal is *too* much better, but we see (also from the lack of reporting these as false positives) a minor improvement in precision and MCC scores throughout.

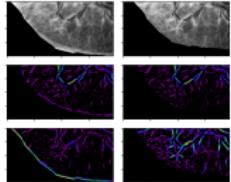
## Preprocessing: Dealing with Boundaries



## Cake Defense

## └ Research Protocol

## └ Preprocessing: Dealing with Boundaries

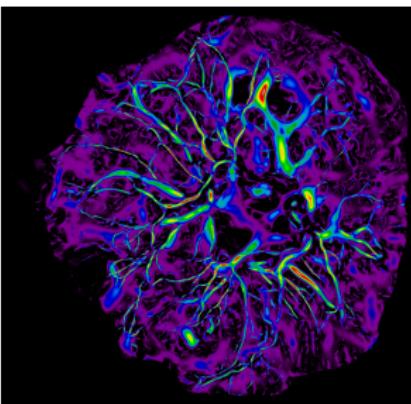


1. Prevent curvilinear content around the edges from being interpreted as curvilinear (especially with bounding structureness).
2. This can be especially significant with certain choices of dark/light BG and at small or large scales. Doesn't matter sooooo much, it's more of a quality of life thing.
3. Mostly because we want the background to be ignored, not treated as minimum (or maximum) intensity.
4. Since we already know where the mask is, we can just dilate it by a fixed amount (this is by 25 pixel radius)
5. Label rows/columns to make this readable
6. Pick something where the output is easier to tell the difference with...
7. This is fucked because of watershedding you do. Make a slide/demo for that.

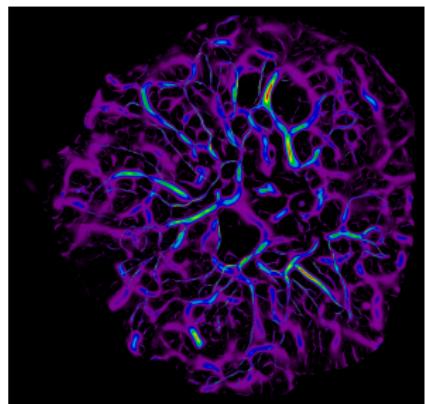
# Comparing Frangi Hessian to Frangi with Weingarten Map



(g) Raw Sample



(h)  $\mathcal{V}_{\max}$  (Hessian eigenvals)



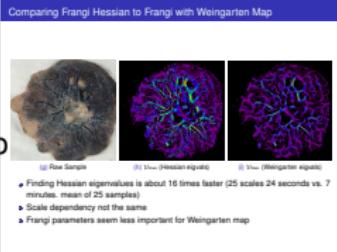
(i)  $\mathcal{V}_{\max}$  (Weingarten eigenvals)

- Finding Hessian eigenvalues is about 16 times faster (25 scales 24 seconds vs. 7 minutes. mean of 25 samples)
- Scale dependency not the same
- Frangi parameters seem less important for Weingarten map

## Cake Defense

## └ Analysis (Pre-segmentation)

## └ Comparing Frangi Hessian to Frangi with Weingarten Map



1. Hessian matrix is symmetric
2. Admit that this came pretty late into my research adventure so I need to look at this more. Weingarten map gives valid response at higher scales than the Hessian. Better at outlining just the ridge. Would like to compare strict Frangi to just Weingarten map
3. Note, noise is noise; still present.
4. You could potentially do a hybrid, i.e. recalculate significant Frangi responses like this. Also there could be a speedup by not doing *every* non-masked point, i.e. make sure that hessian magnitude is large enough first. that would be fast.
5. Move to late in talk, otherwise rest of this shit kinda feels weak.
6. Also, need to look at `skimage.feature.hessian_matrix_eigvals` to figure out other reasons for speedup/ask von Brecht
7. Scales are kinda wrong for optimal Hessian-Fangi, hence more noise there

## Cumulative Vesselness Ratio

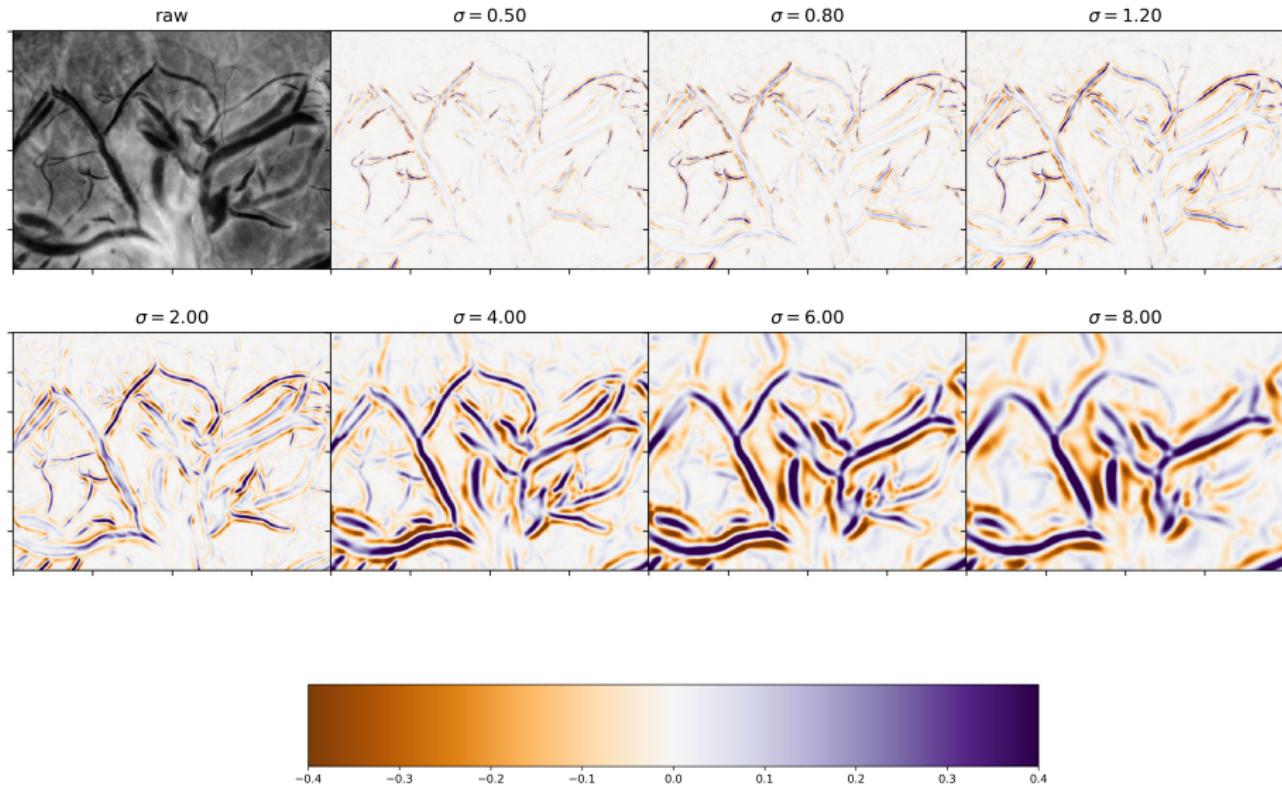
Just show a few parametrization methods, don't show all

## Fixed threshold of Vmax

# Scalewise percentile filtering



# Signed Frangi



## A non-Fangi segmentation method: ISODATA

This represents a good idea that doesn't rely on diffgeo or local anything

## Cake Defense

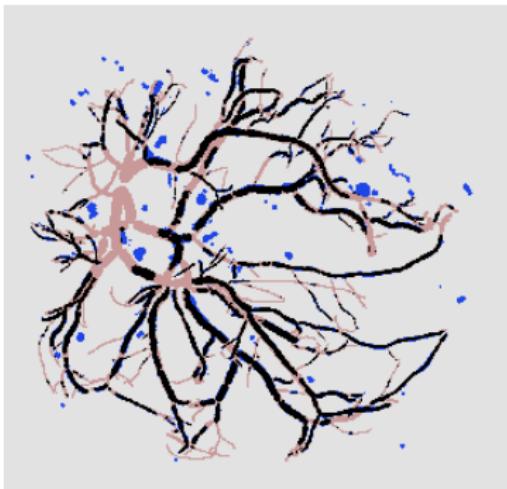
## └ Frangi Segmentation Methods

## └ A non-Fangi segmentation method: ISODATA

A non-Fangi segmentation method: ISODATA

This represents a good idea that doesn't rely on diffgeo or local anything

1. Find histogram figure
2. Put an output here



- TP
- FP
- FN
- TN

## Scoring Methods

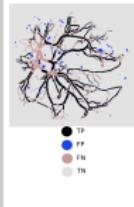
$$\text{precision} = \frac{\text{TP}}{\text{TP} + \text{FP}}$$

$$\text{MCC} = \frac{\text{TP} \times \text{TN} - \text{FP} \times \text{FN}}{\sqrt{(\text{TP} + \text{FP})(\text{TP} + \text{FN})(\text{TN} + \text{FP})(\text{TN} + \text{FN})}}$$

## Cake Defense

## └ Frangi Segmentation Results

## └ Binary Classification of Segmentation Methods



Scoring Methods

$$\text{precision} = \frac{\text{TP}}{\text{TP} + \text{FP}}$$

$$\text{MCC} = \frac{\text{TP} \times \text{TN} - \text{FP} \times \text{FN}}{\sqrt{(\text{TP} + \text{FP})(\text{TP} + \text{FN})(\text{TN} + \text{FP})(\text{TN} + \text{FN})}}$$

● TP

● FP

● FN

● TN

1. **META:** Use GIMP to merge legend with image and put horizontal under image.  
maybe add precision and mcc of this particular example
2. There are a lot of different choices in terms of scoring, like accuracy (list more)
3. Rationale behind MCC, the benefit
4. Explain that MCC is good but precision is important too
5. Would be good to have a scoring method based on network, but that's definitely nontrivial to define

## Example Segmentation Results

Spend a couple slides here talking about

- parametrization choices effect
- threshold choices effect
- talk about “good” false positives and “bad” false positives
- talk about good samples and bad samples

# Boxplots

# Conclusion

# Appendix

Put some proofs / extra things here

extra blah blah

another extra slide