Extraction of Cerebral Vasculature from Anatomical MRI

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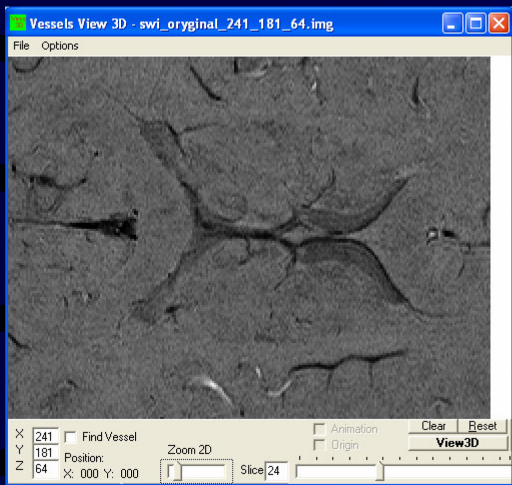
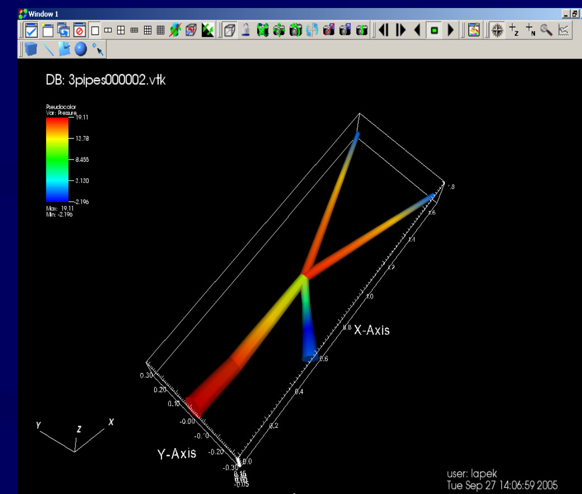
The purpose of our research

3D MRI Data



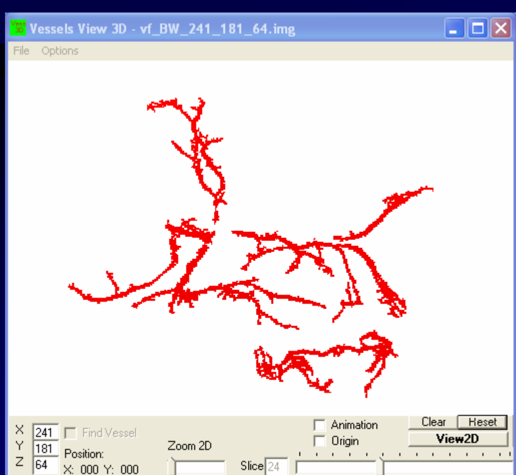
comparison

Pressure drop & flow simulation

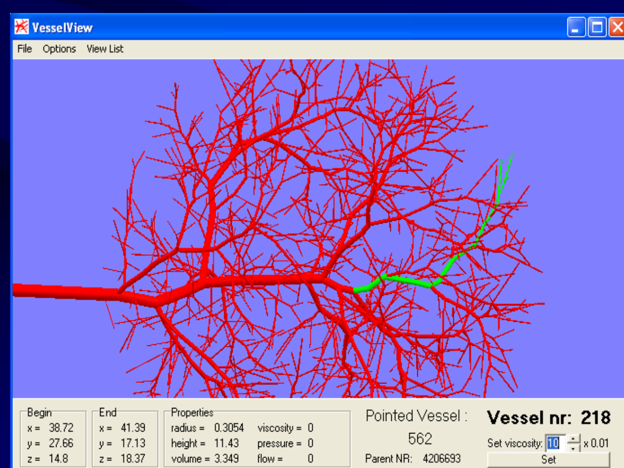


Vascular Tree Generation

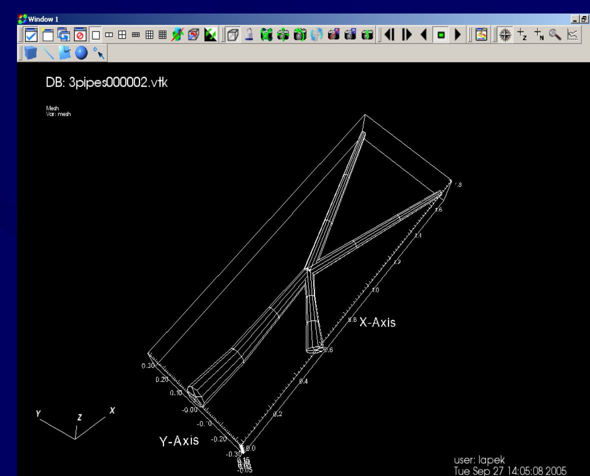
(geometry, flow, pressure drop, viscosity)



3D segmentation of a vessel



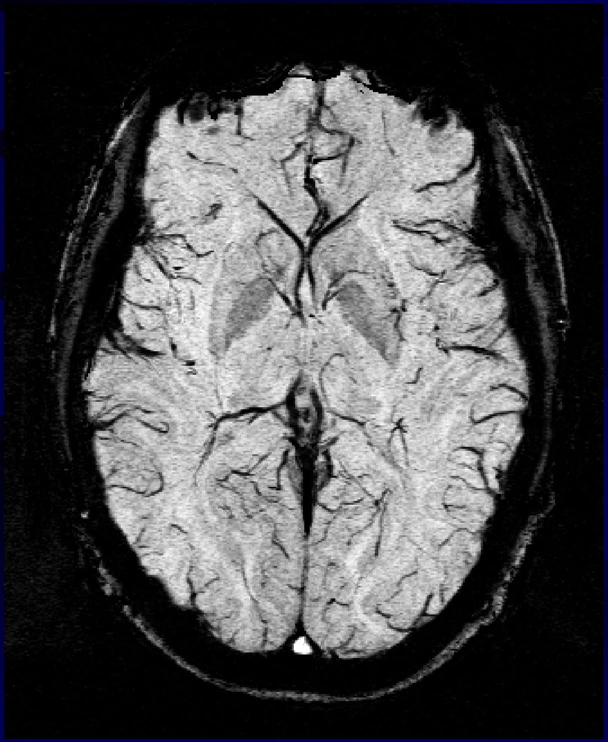
3D model of a vessel



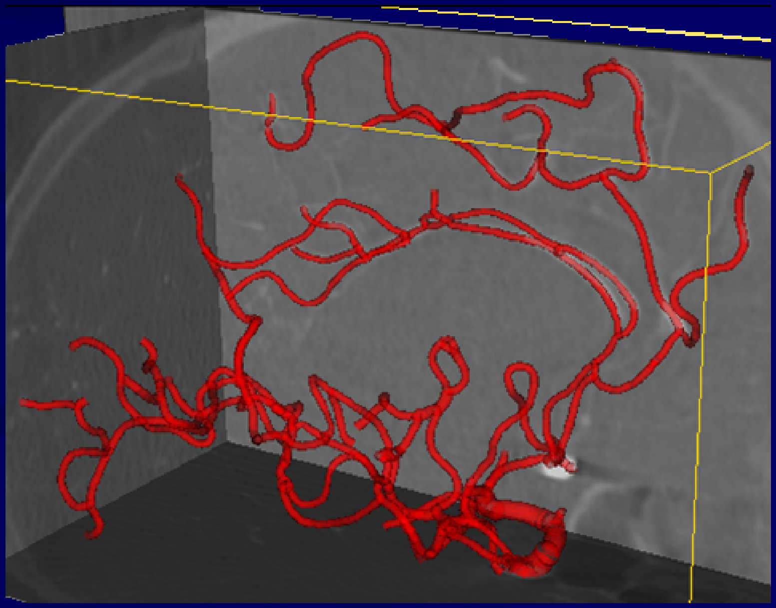
Mesh generation

What we focus on

3D MRI data
(selected cross-section)



The 3D vascular model



Knowledge-Based Extraction of Cerebral Vasculature
from Anatomical MRI

The algorithm

1. Multiscale vessel enhancement
   a. Gaussian filtering
   b. Hessian matrix computation
   c. Vesselness function
2. Center-line extraction
   a. 3D Segmentation
   b. Skeletonization
3. Surface smoothing
   with tube-like deformable models

Gaussian Filtering

- Derivatives of image *L* is a convolution with derivatives of Gaussian:

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

Where γ is a normalization parameter
and s is a scale parameter $s_{\min} \leq s \leq s_{\max}$.
For a typical diameter of a vessel s_{min}=0.2, s_{max}=2.

The *D*-dimensional Gaussian is defined:

$$G(\mathbf{x}, s) = \frac{1}{\sqrt{2\pi s^2}^{D}} e^{-\frac{\|\mathbf{x}\|^2}{2s^2}}$$

Multiscale vessel enhancement

- A Taylor expansion of the image L in the neighborhood of point $\mathbf{x_0}$

$$L(\mathbf{x_0} + \delta\mathbf{x_0}, s) \approx L(\mathbf{x_0}, s) + \delta\mathbf{x_0}^T \nabla_{0,s} + \delta\mathbf{x_0}^T \mathrm{H}_{0,s} \delta\mathbf{x_0}$$

where:

$\nabla_{0,s}, \mathrm{H}_{0,s}$ is a gradient and Hessian matrix of an image computed at $\mathbf{x_0}$ coordinates, at scale *s.*

Multiscale vessel enhancement

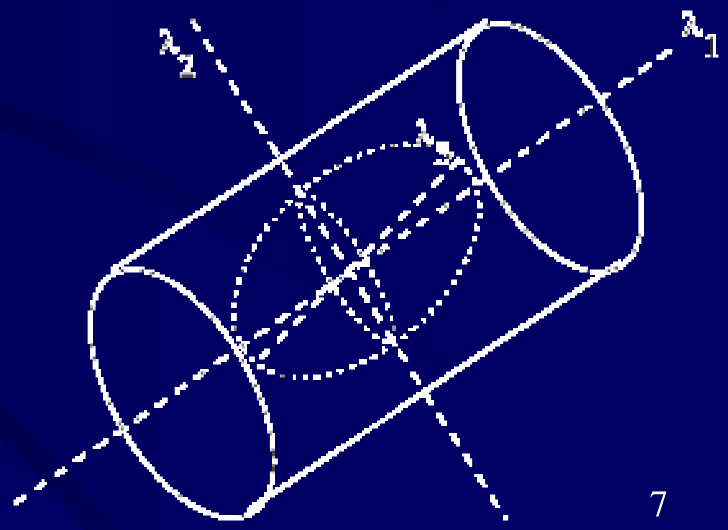
- Hessian matrix computed at coordinates $\mathbf{x_0}$:

$$H = \begin{bmatrix} L_{xx} & L_{xy} & L_{xz} \\ L_{yx} & L_{yy} & L_{yz} \\ L_{zx} & L_{zy} & L_{zz} \end{bmatrix}$$

- Eigenvalues are sorted

$$|\lambda_3| \leq |\lambda_2| \leq |\lambda_1|$$

- The eigenvector of the highest eigenvalue indicate a direction of the vessel at coordinates $\mathbf{x_0}$



Multiscale vessel enhancement

	3D	2D
Blob like structures:	$R_B = \frac{\lvert\lambda_1\rvert}{\lvert\lambda_2 \cdot \lambda_3\rvert}$	$R_B = \frac{\lambda_1}{\lambda_2}$
Plate-like structures:	$R_A = \frac{\lvert\lambda_2\rvert}{\lvert\lambda_3\rvert}$	–

Hessian norm:

$$S = \lVert \mathrm{H} \rVert_F = \sqrt{\sum_{j \leq 3} \lambda_j^2}$$

Vesselness function

Vesselness function :

3D case:

$$V_0(s,\gamma)=\begin{cases}0 & \lambda_2>0 \text{ and } \lambda_3>0\\ \left(1-\exp\left(-\frac{R_A^2}{2\alpha^2}\right)\right)\exp\left(-\frac{R_B^2}{2\beta^2}\right)\left(1-\exp\left(-\frac{S^2}{2c^2}\right)\right)\end{cases}$$

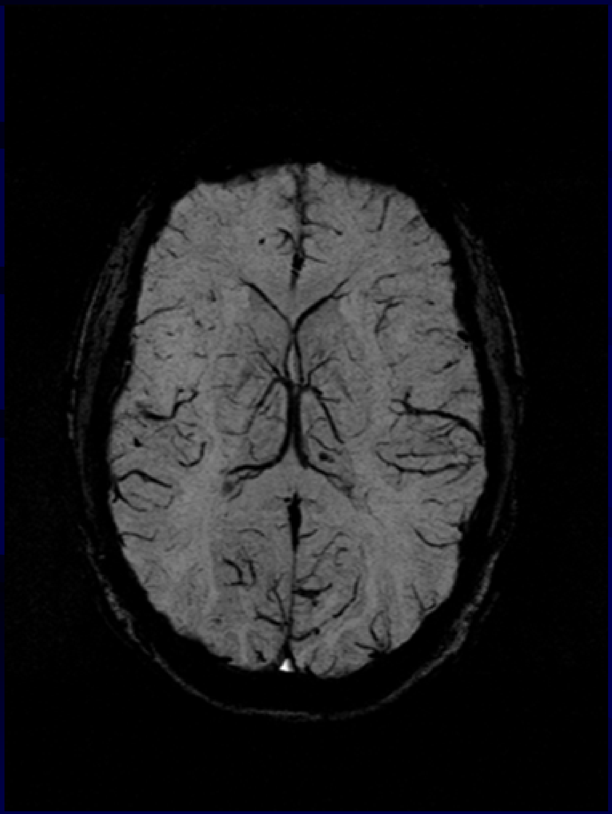
2D case:

$$V_0(s,\gamma)=\begin{cases}0 & \lambda_2>0\\ \exp\left(-\frac{R_B^2}{2\beta^2}\right)\left(1-\exp\left(-\frac{S^2}{2c^2}\right)\right)\end{cases}$$

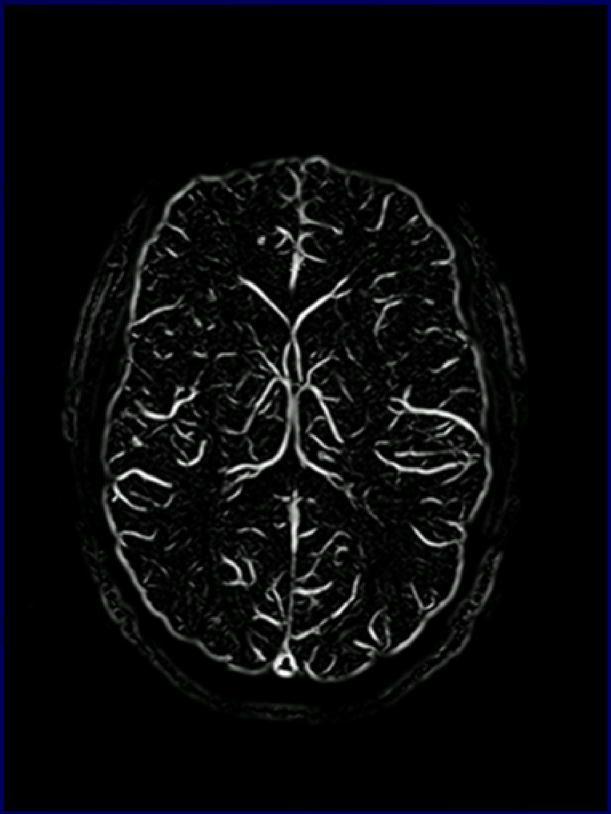
Finally:

$$V_0(\gamma)=\max_{s_{\min}\le s\le s_{\max}} V_0(s,\gamma)$$

Multiscale Filtering Results

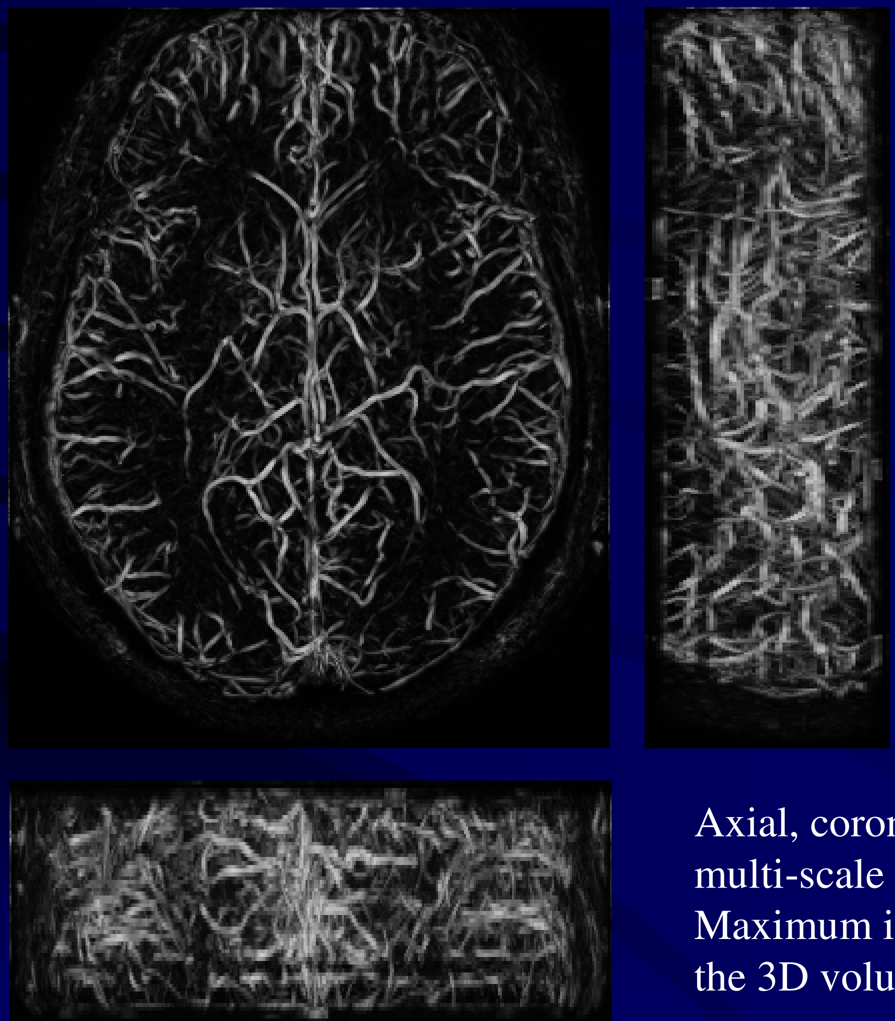


Slide before filtering



Vesselness function representation

Multiscale Filtering Results

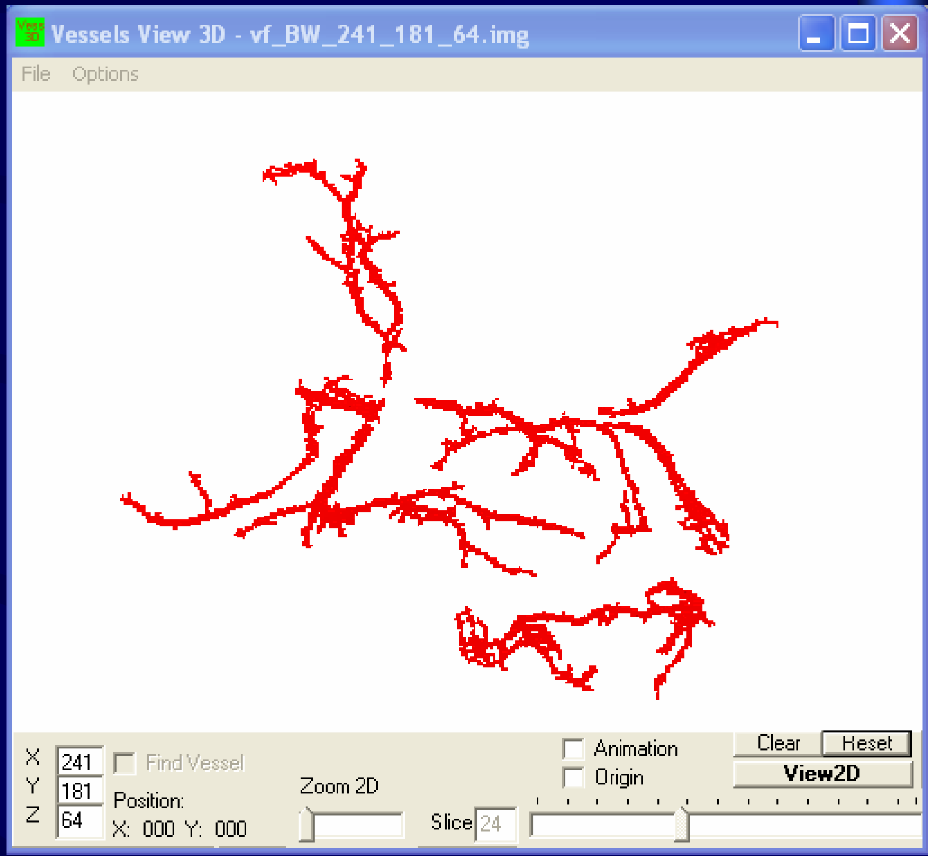


Axial, coronal and sagittal planes of the multi-scale enhancement filtered volume. Maximum intensity projections through the 3D volume.

3D Visualization Results

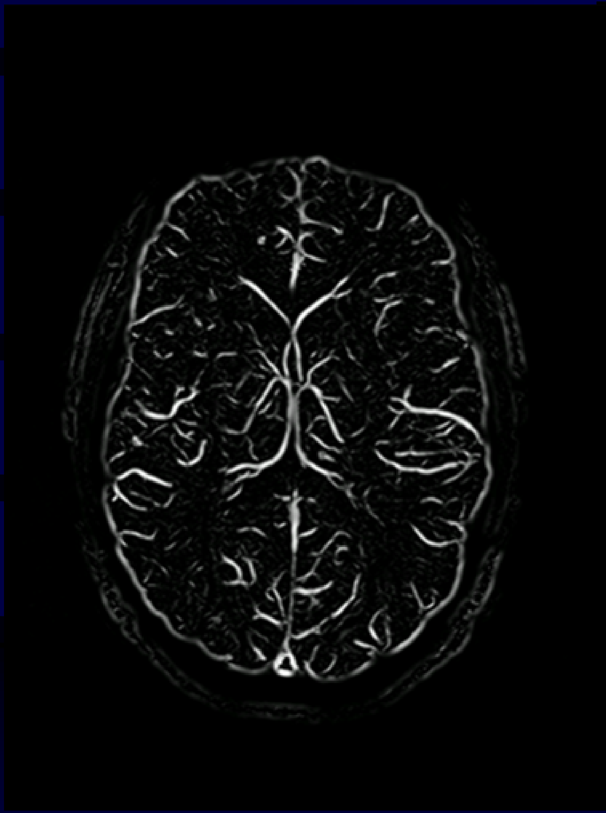
Visualisation of a selected vessel after 3D vesselness function thresholding and data segmentation with flood-fill (seed growing) algorithm.

The surface is rough and uneven. Applying a surface smoothing methods is needed.



Center-line extraction results

the first step for surface smoothing with deformable models



Vesselness function

after masking
and thresholding

after applying
a skeletonization
algorithm

Plans for the future work

- Improving a 3D data filtering algorithm,
- Applying tube-like deformable models for surface smoothing,
- Modelling a viscosity, blood flow and pressure drop.

References:

- Knowledge-Based Extraction of Cerebral Vasculature from Anatomical MRI – L.R. Ostergaard, O.V. Larsen, J. Haase, F.V. Meer, A.C. Evans, D.L. Collins
- Multiscale vessel enhancement filtering – A.F.Frangi, W.J. Niessen, K.L. Vincken, M.A. Viergever
- Edge Detection and Ridge Detection with Automatic Scale Selection – T. Lindberg

Thank you for your attention