UNIVERSITY OF BERGEN

Mohn Medical Imaging and Visualization Center

Advanced Geometric Analysis and Modeling of Blood Vessel Networks Using AI Techniques

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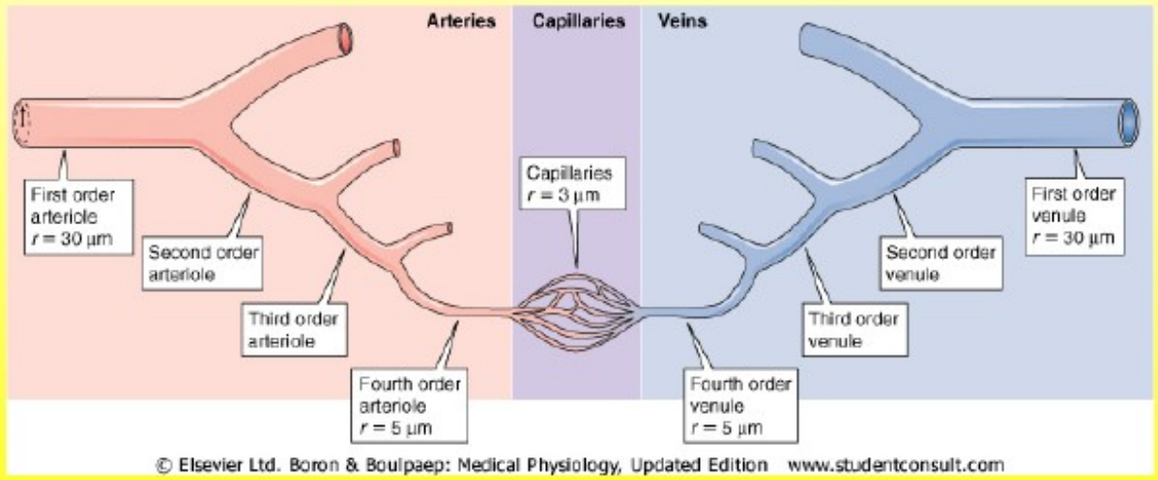
Bergen, 22nd April 2025

Nature of vascular system

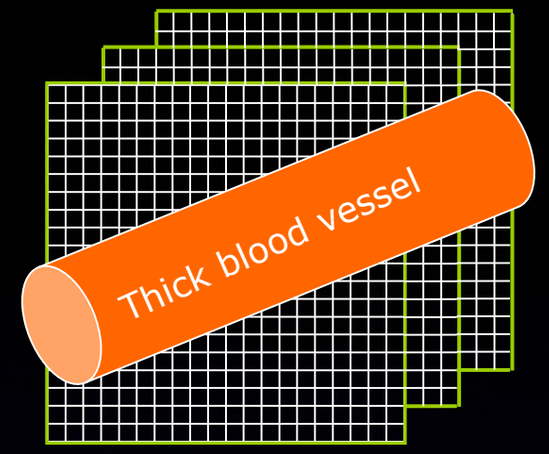
Circulation Physiology
Vascular tree models (M. Kocinski, TUL)
Tumor vasculature and angiogenesis (K. Oppedal, UiB)

Blood vessels:



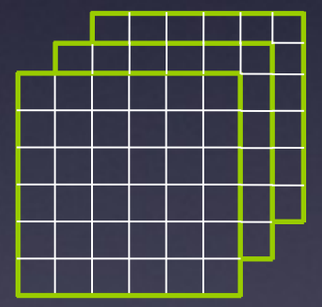
Arvid Lundervold & Marek Kocinski | Vascular model generation - COST B21 WG4, Lodz

I. Thick



II. Meso scale

III. Capillary



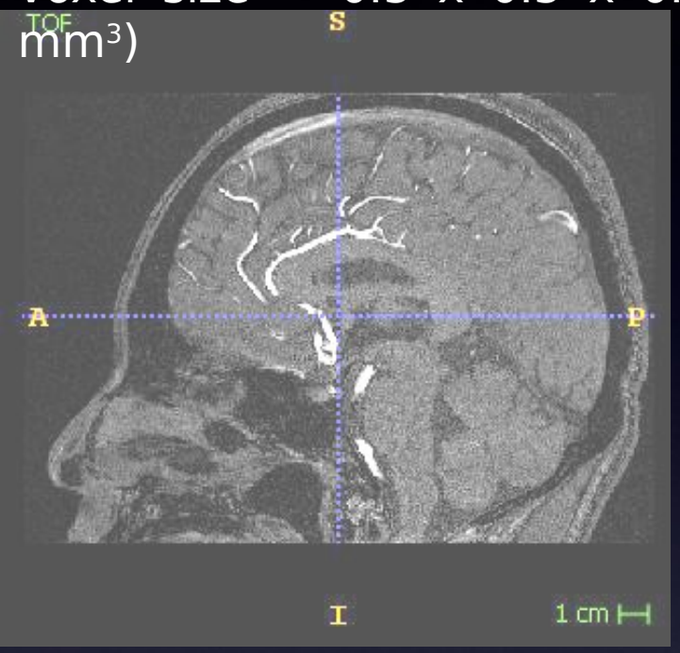
Problem

Reliable quantitative analysis each part of vasculartree

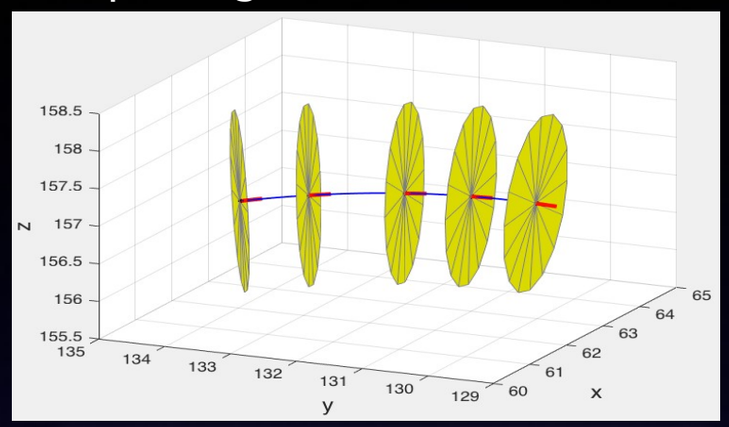
Thick vessels: reconstruct the surface vascular tree given its 3D MRA image - to aid medical diagnosis (blood flow simulation, detection of stenosis and aneurysms).

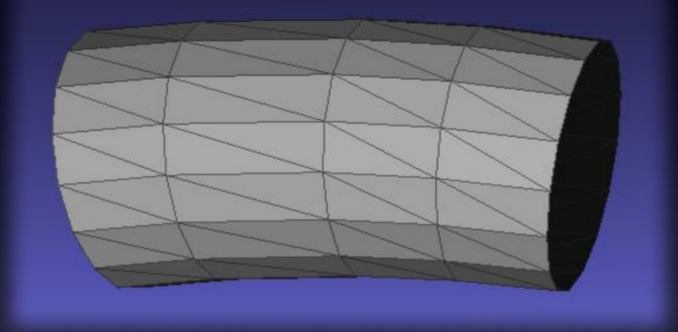
Modeling of thick blood vessels

Cross-section of3D ToF-MRI (346 x 448 x 319 voxels, voxel size = 0.5 x 0.5 x 0.5 mm^3)



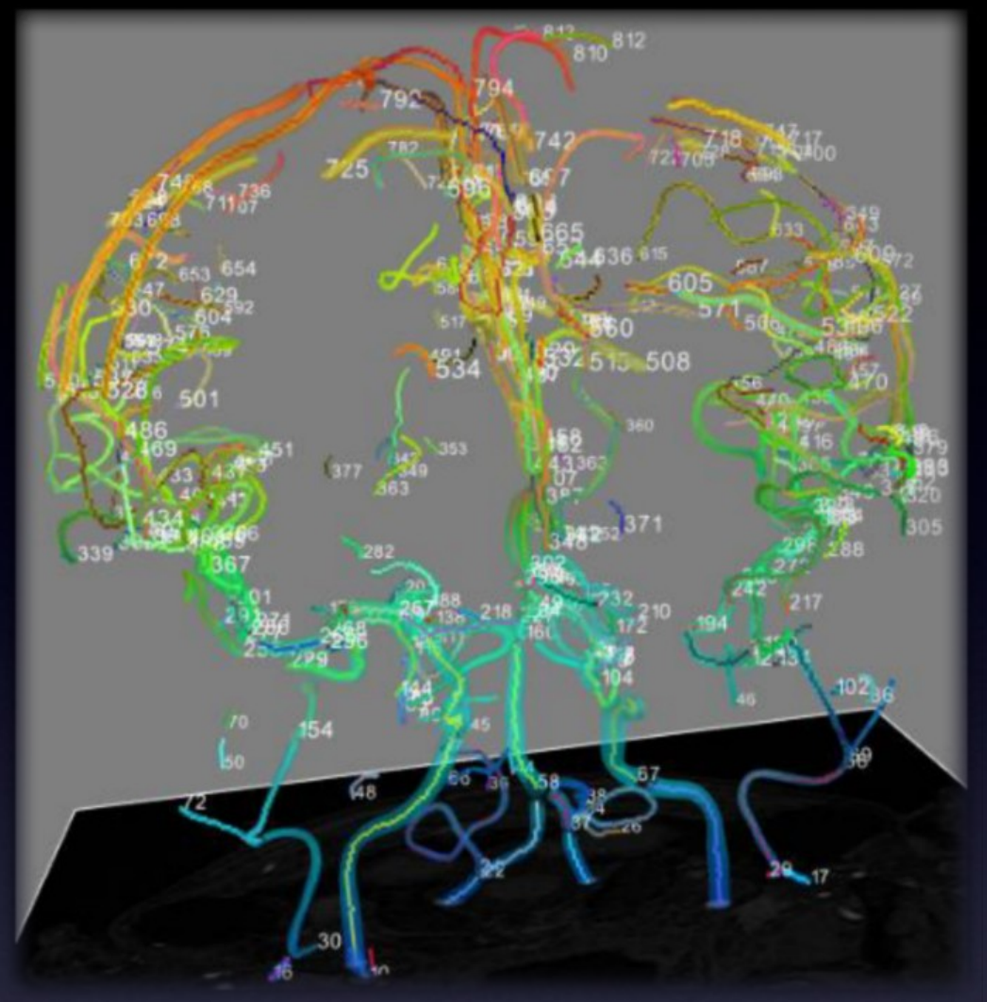
Short tubular segment comprising *K=5 voxels.*

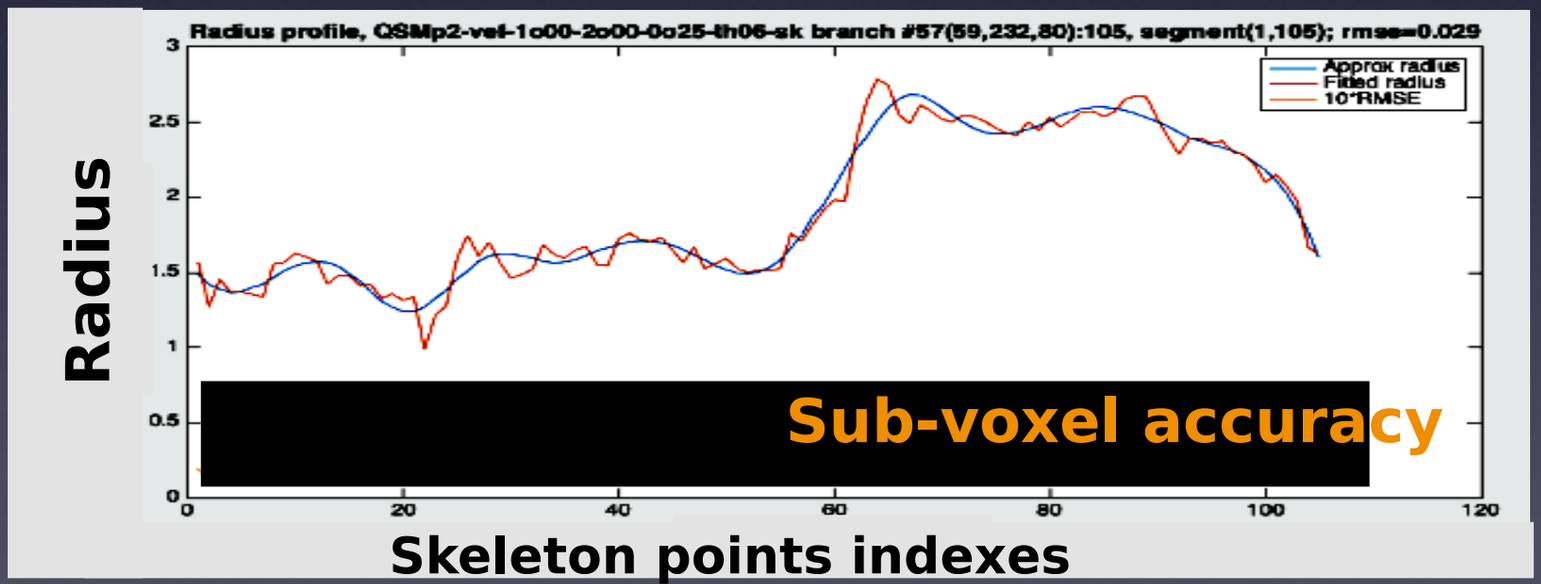


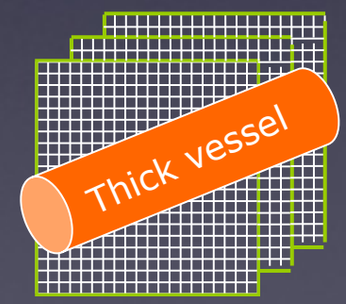


Wireframe model (STL)

Model of pipe-like arteries

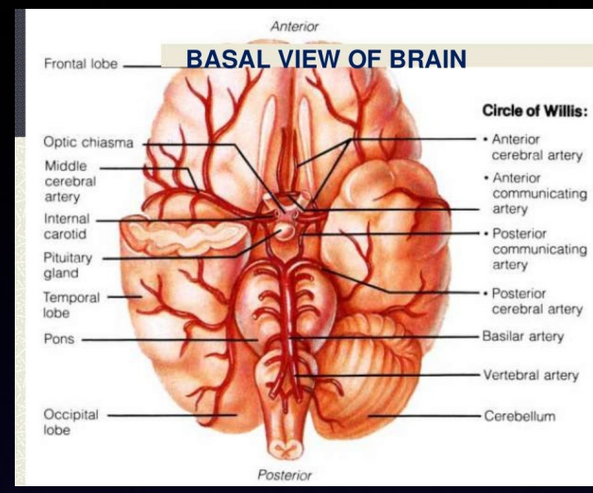






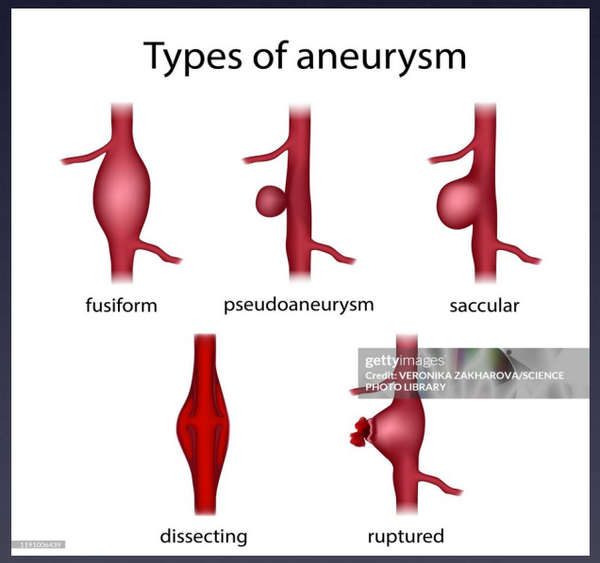
Project Objectives

1. Segmentation and 3D Visualization
- blood vessel segmentation with NN (center line extraction),
- full-waterproof mesh model and 3D visualization.



2. Identification and Anatomical Mapping:
- vessels division into segments with assigning appropriate anatomical names (AI graph algorithms)

3. Morphological Analysis:
- blood vessel shapes,
- curvature and tortuosity,
- segment length,
- radius profile,
- stenosis and dilations detection,
- aneurysms and abnormal curvatures detection.

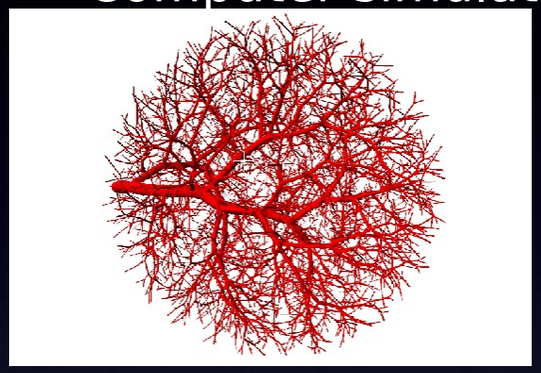


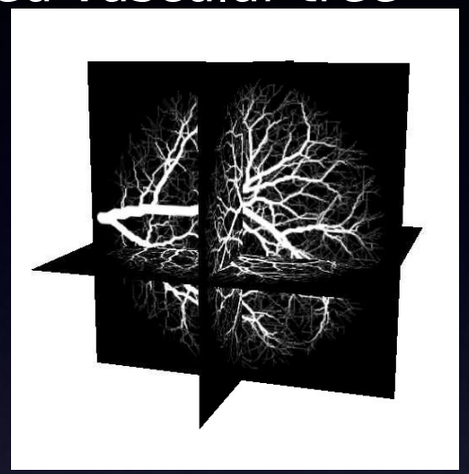
4. Relationship between blood vessel diameter and image voxel size (anisotropy / isotropy).

Validation of modeling algorithms

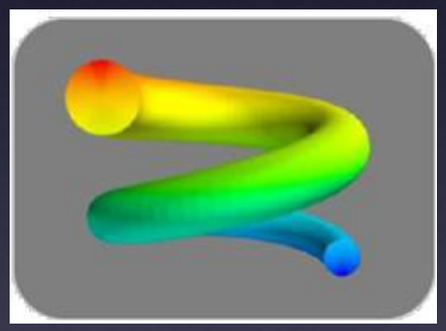
Numerical phantoms with
noise and artifacts

Computer simulated vascular tree

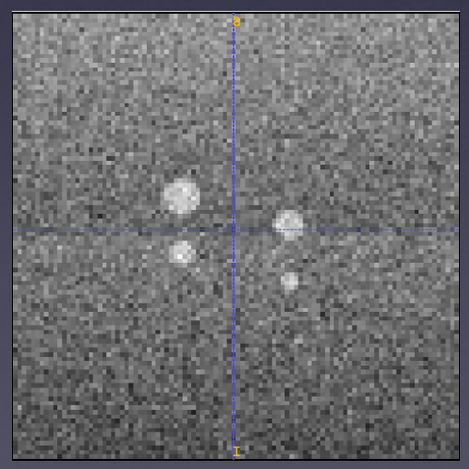


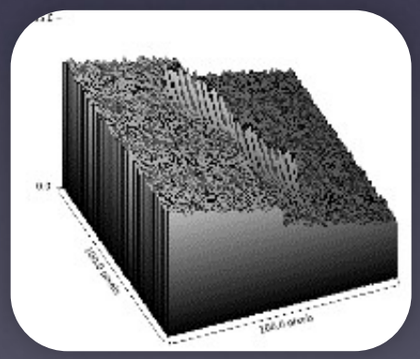


Helix

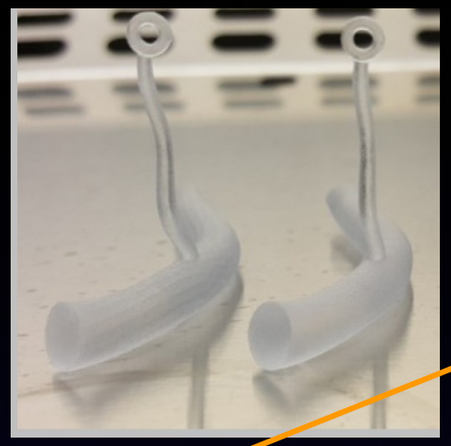


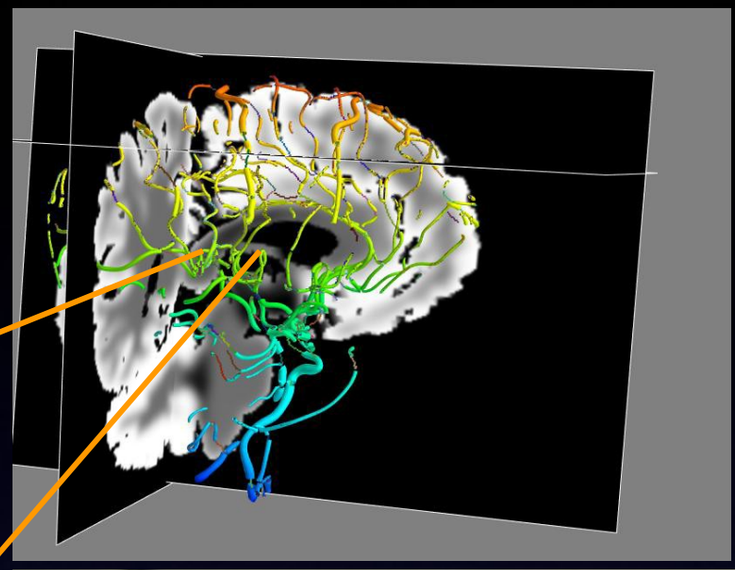
Tube

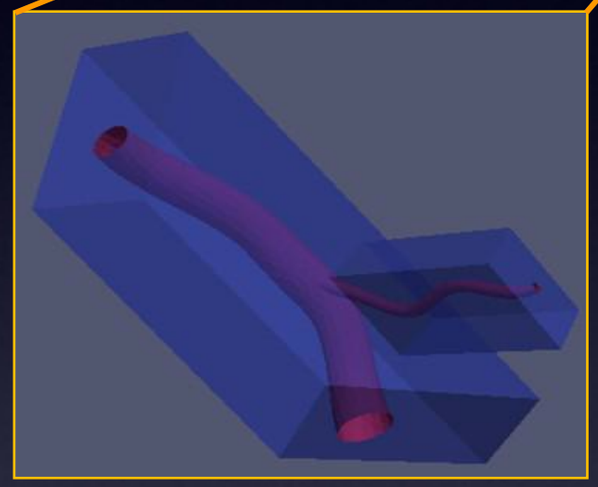




Model of arteries (from ToF MRI)







Geometry of selected
branches (STL file)

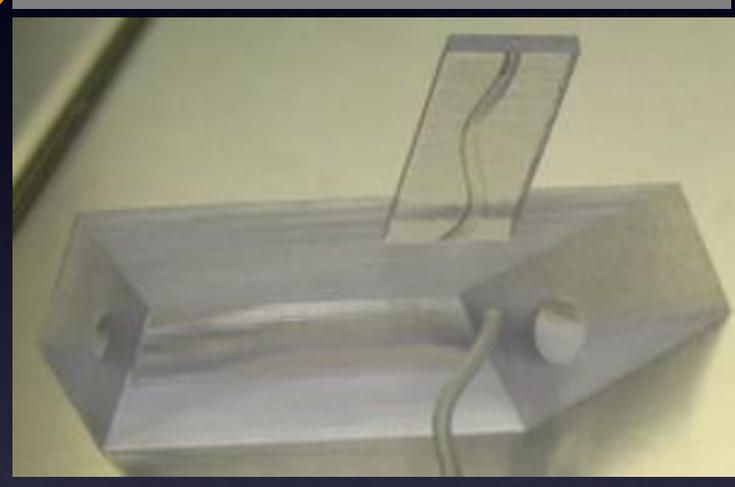
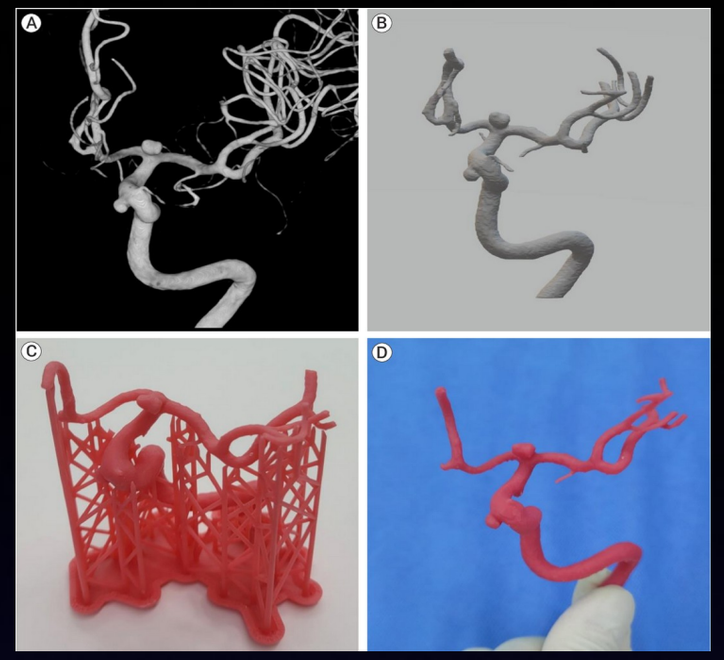


Photo of 3D
printed model

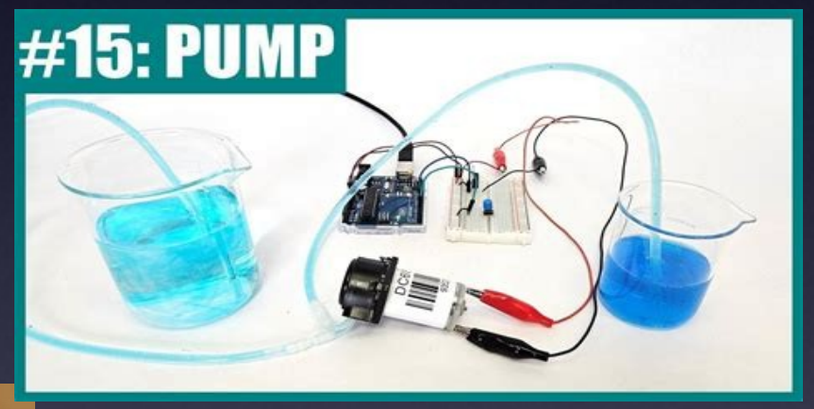
T2 weighted MRI slice of 3D printed model

Validation of modeling algorithms

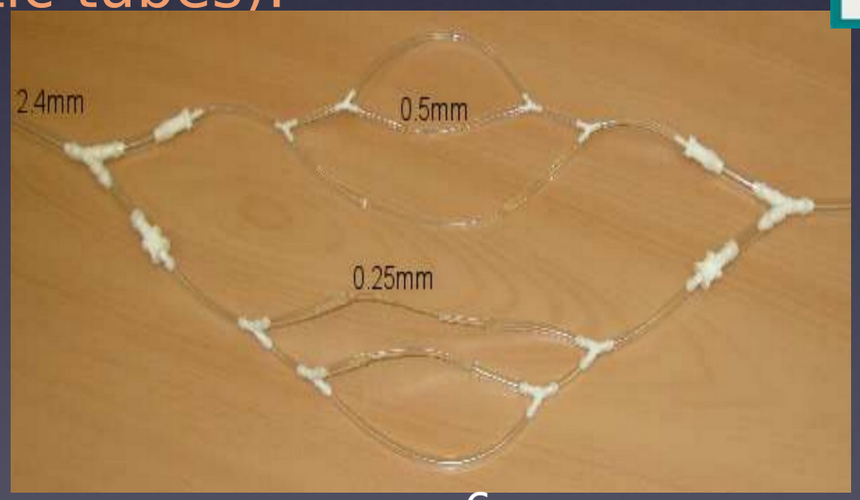
1. Digital phantoms



2. 3D Printed Physical Phantoms:
- stenosis, aneurysm, various curvature
- a model of a real blood vessel tree segmented from MR image



3. Flow Phantoms (plastic tubes):
- branching angles,
- various curvature,
- flow profile,
- turbulent flow,
- “blood” viscosity.



Expected Outcomes

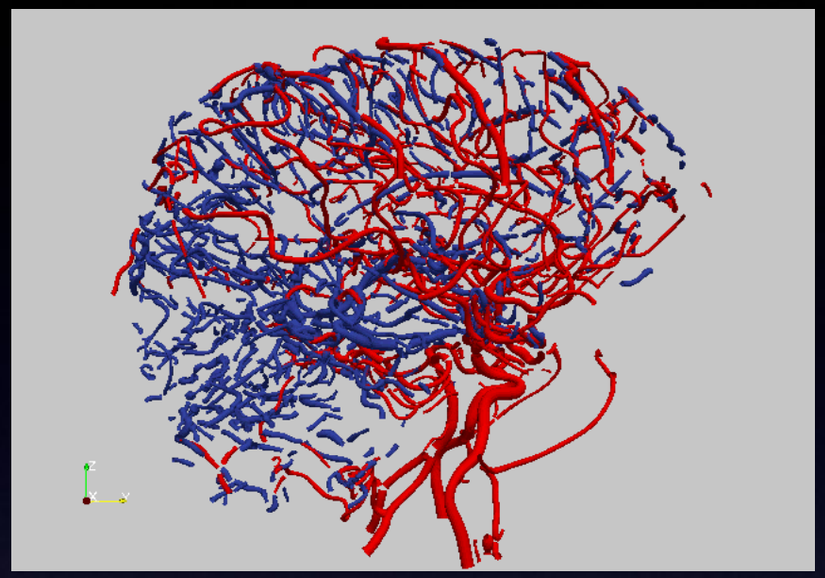
1. Novel AI-based algorithms for accurate blood vessel segmentation and centerline extraction anatomical segment identification

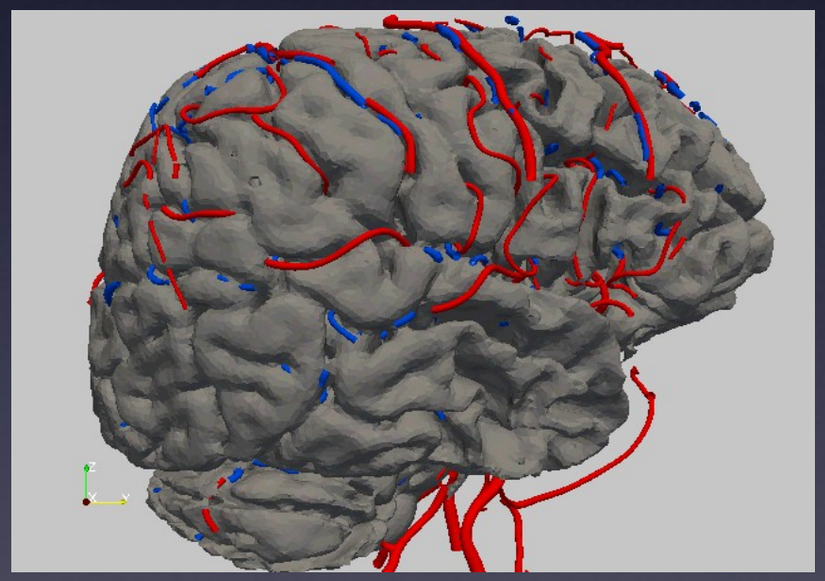
2. Validated quantification methods for vascular morphology across different vessel types and pathologies

3. Open-source tools for the research community to advance vascular image analysis

4. Clinical prototype applications for improved diagnosis of vascular abnormalities

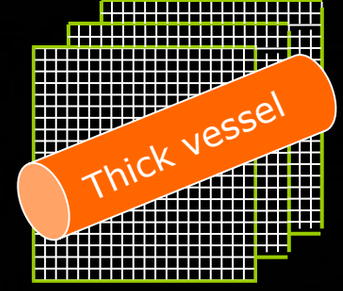
5. Standardized datasets of digital and physical phantoms for benchmarking future algorithms.





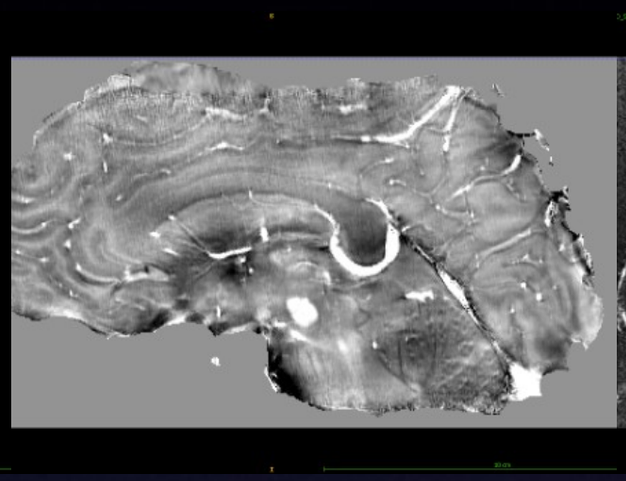
Thank you!

Modeling of thick blood vessels

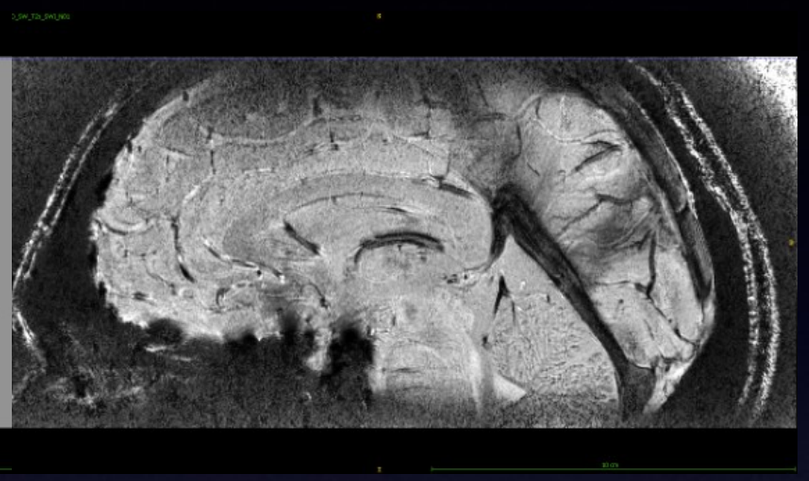


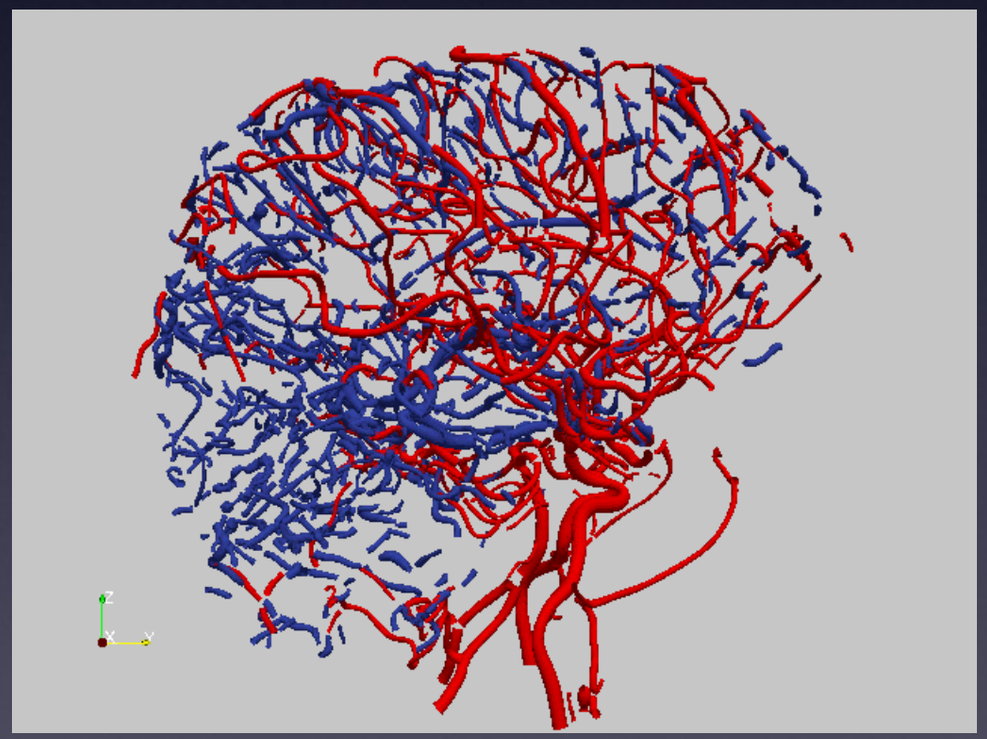
ToF (Arteries)

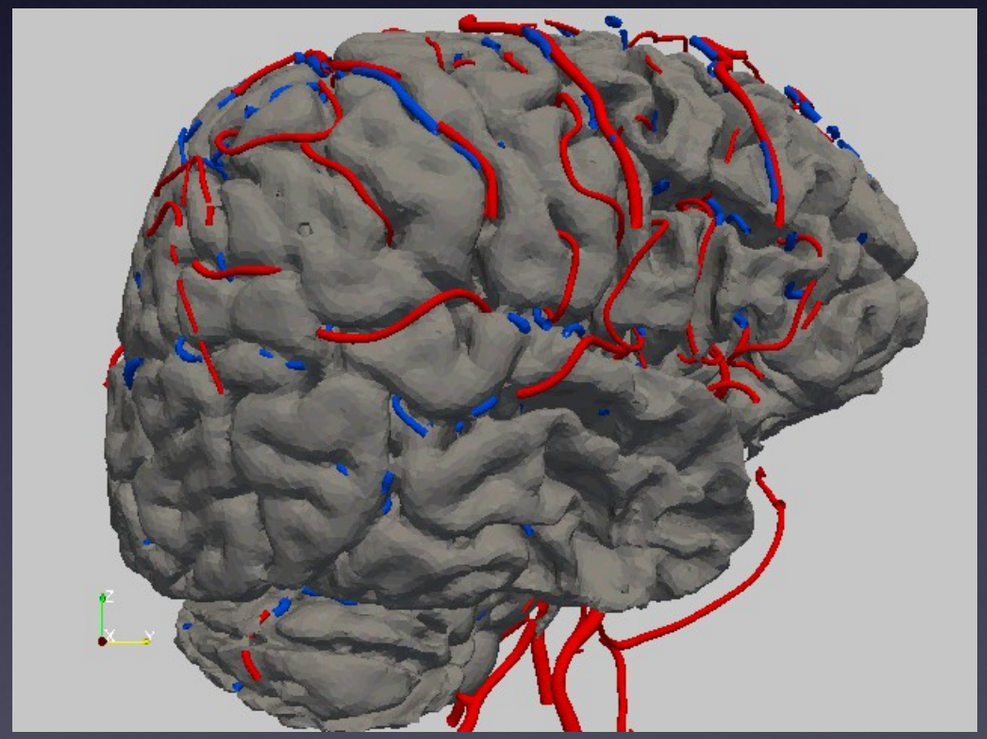
QSM (Veins)



SWI (Veins)

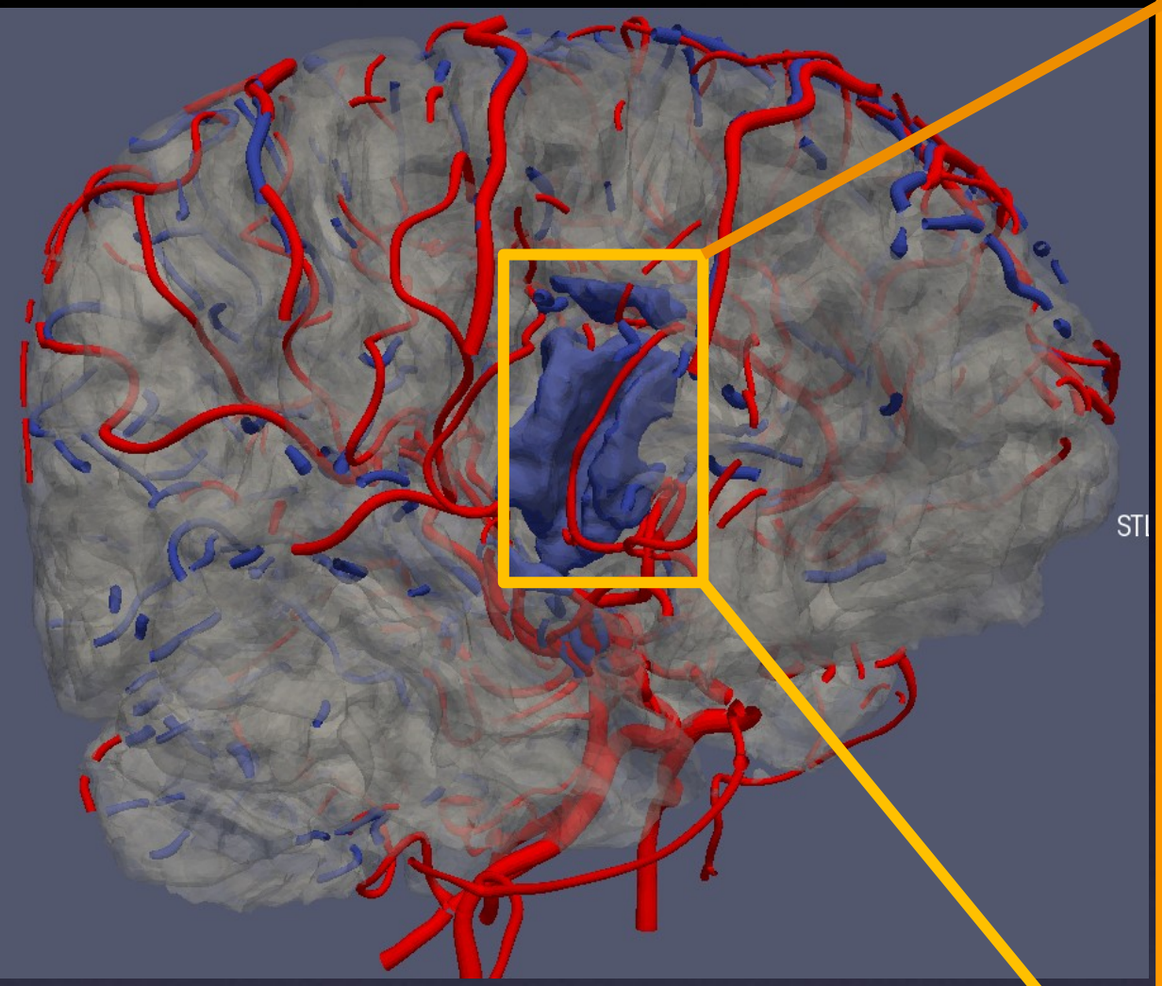




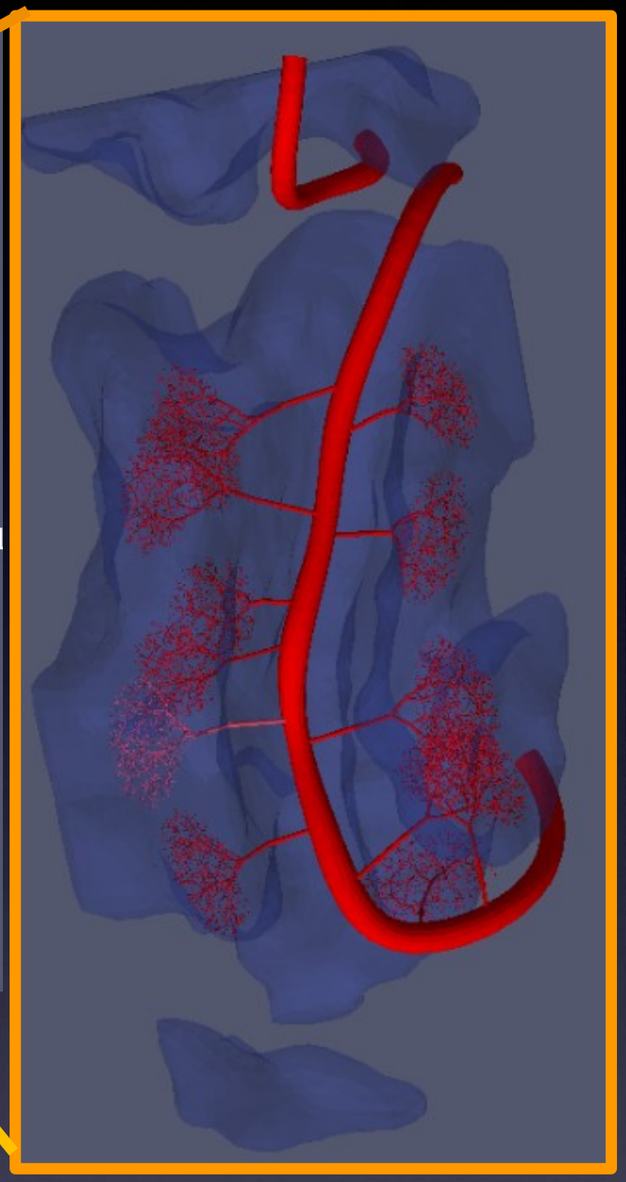


3D model of arteries (red, ToF) and veins (blue, QSM), grey matter (grey, T1).

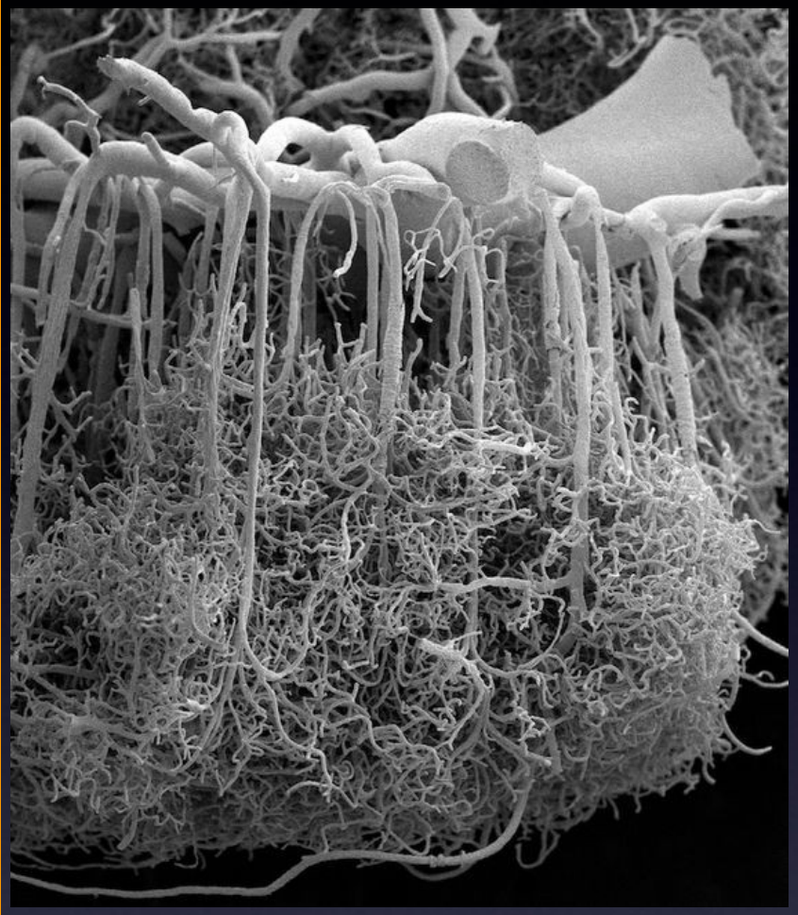
Towards multi-scale personalized modeling



Visualization of geometric models of tubular sections of the arterial (red) and venous (blue) trees superimposed over the surface of gray matter (right hemisphere)

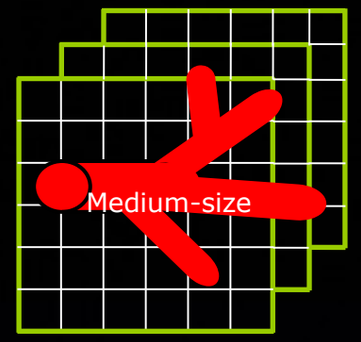


Synthesized mesoscopic scale trees build upon cortex penetrating arteries which bifurcate from the segmented selected brain artery



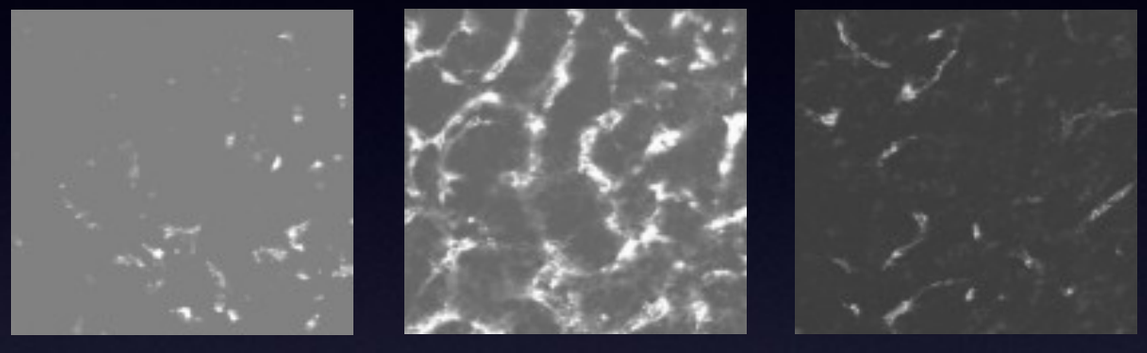
A photomicrograph of microscopic blood vessels from “Portrets of the Mind”, 2010, pp. 216-217. Reproduced with a kind permission of the authors: Alfonso Rodríguez-Baeza and Marisa Ortega-Sánchez from Department of Morphological Sciences, Medicine Faculty at the Universitat Autònoma de Barcelona, Spain

Medium size blood vessels



PhD thesis (in the field of computer science)
Quantitative analysis of vascular trees represented by digital images

3D confocal microscope data – rat brain (UiB, 2006)

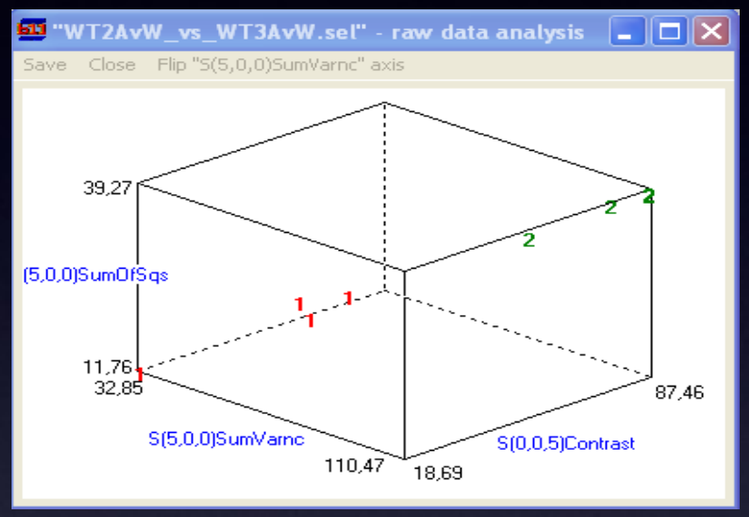


Tumor cells:

transfected with empty vector

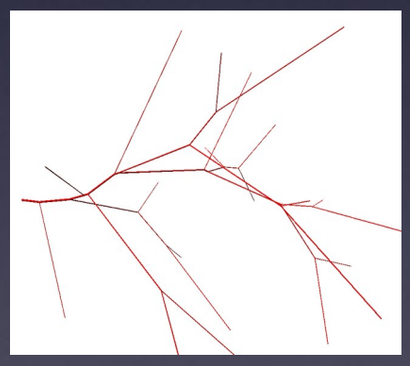
native state, unmanipulated

transfected with CDNA for Neuron glial-2 proteoglycan

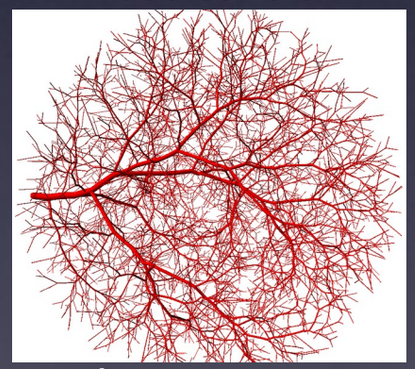


3D texture features

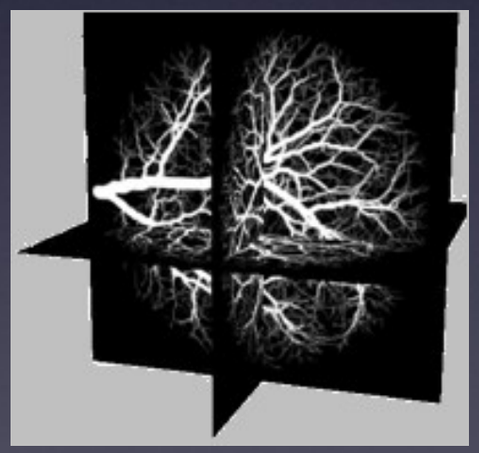
20 outlets



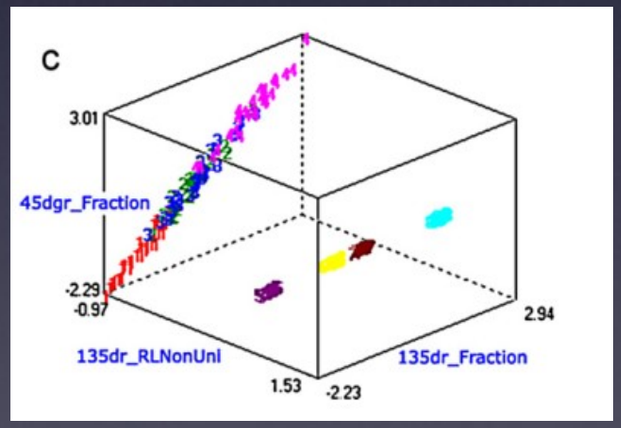
4000 outlets



Vascular tree growth computer simulation.
Parameters: blood viscosity; nr of branches; inflow; outflow (vector model)



3D raster image

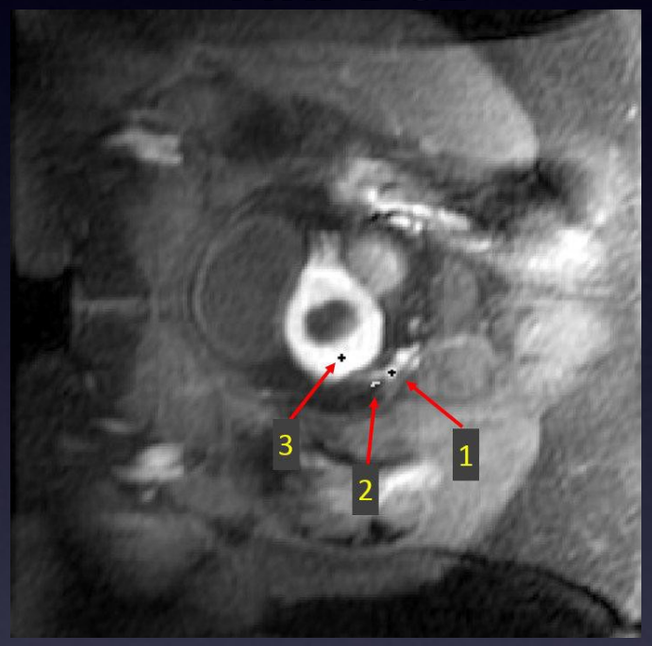


2D & 3D texture features

E-Derived Blood Pharmacokinetic Maps (UiB, 2015)

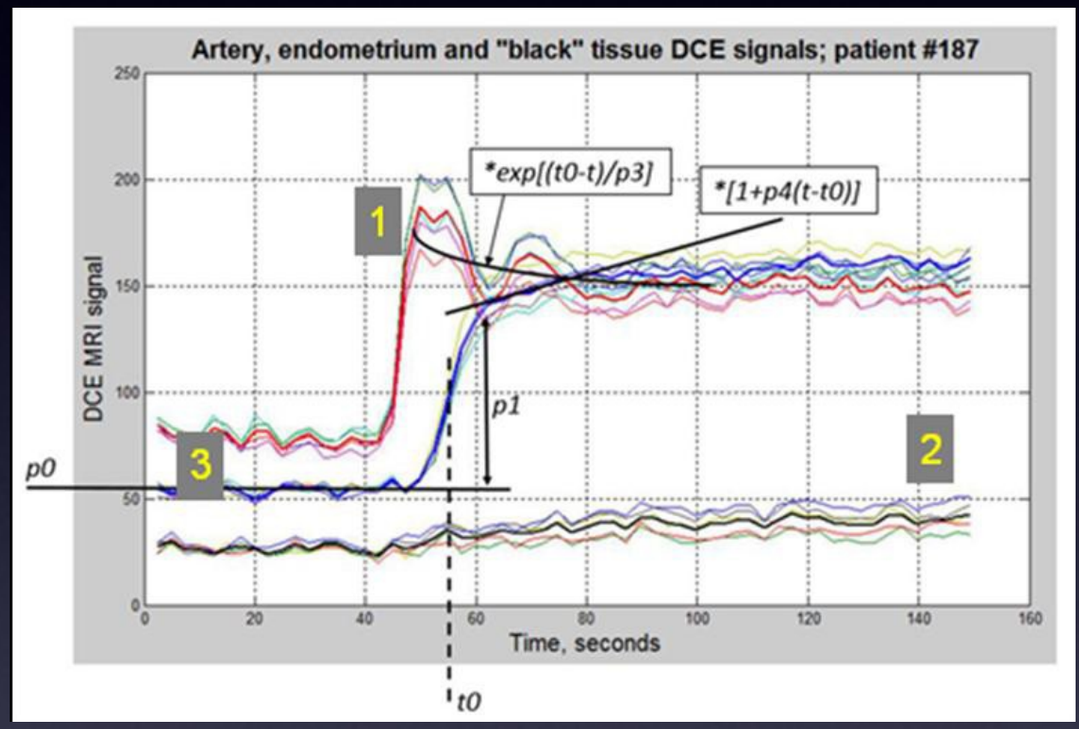
Quantitative analysis and modeling of DCE images for tissue characterization of endometrial carcinoma (grade classification)

MRI-DCE

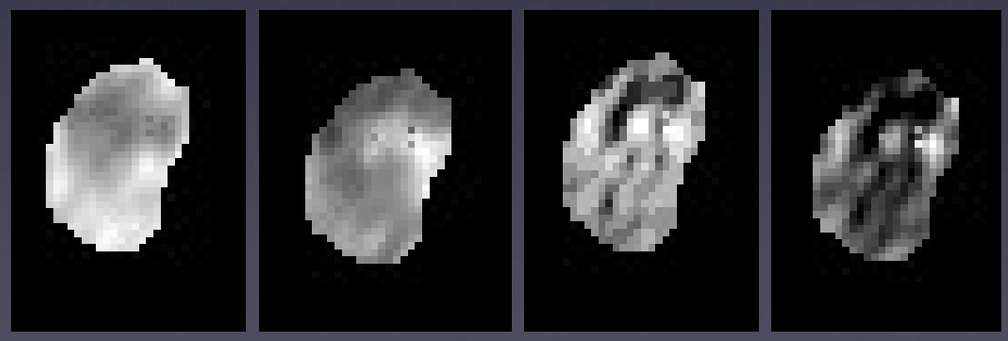


1 – an artery
2 – weak enhancement
3 – endometrium

An empirical, continuous, 6-parameter mathematical model of actual DCE-MRI signal at each ROI voxel



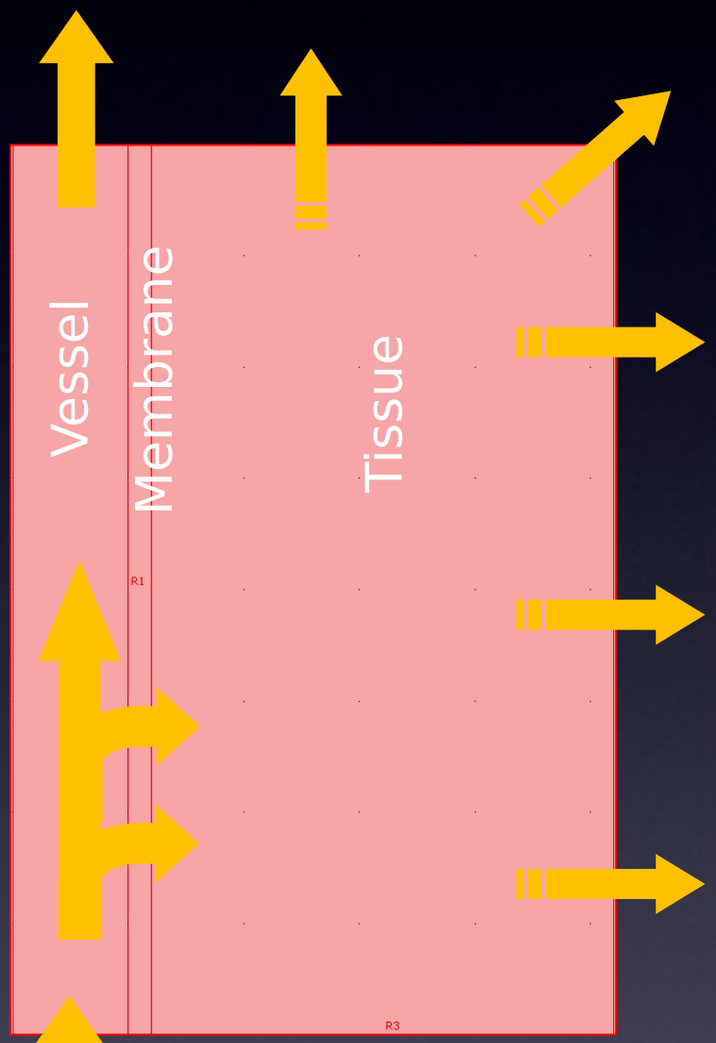
Pharmacokinetic parameter maps



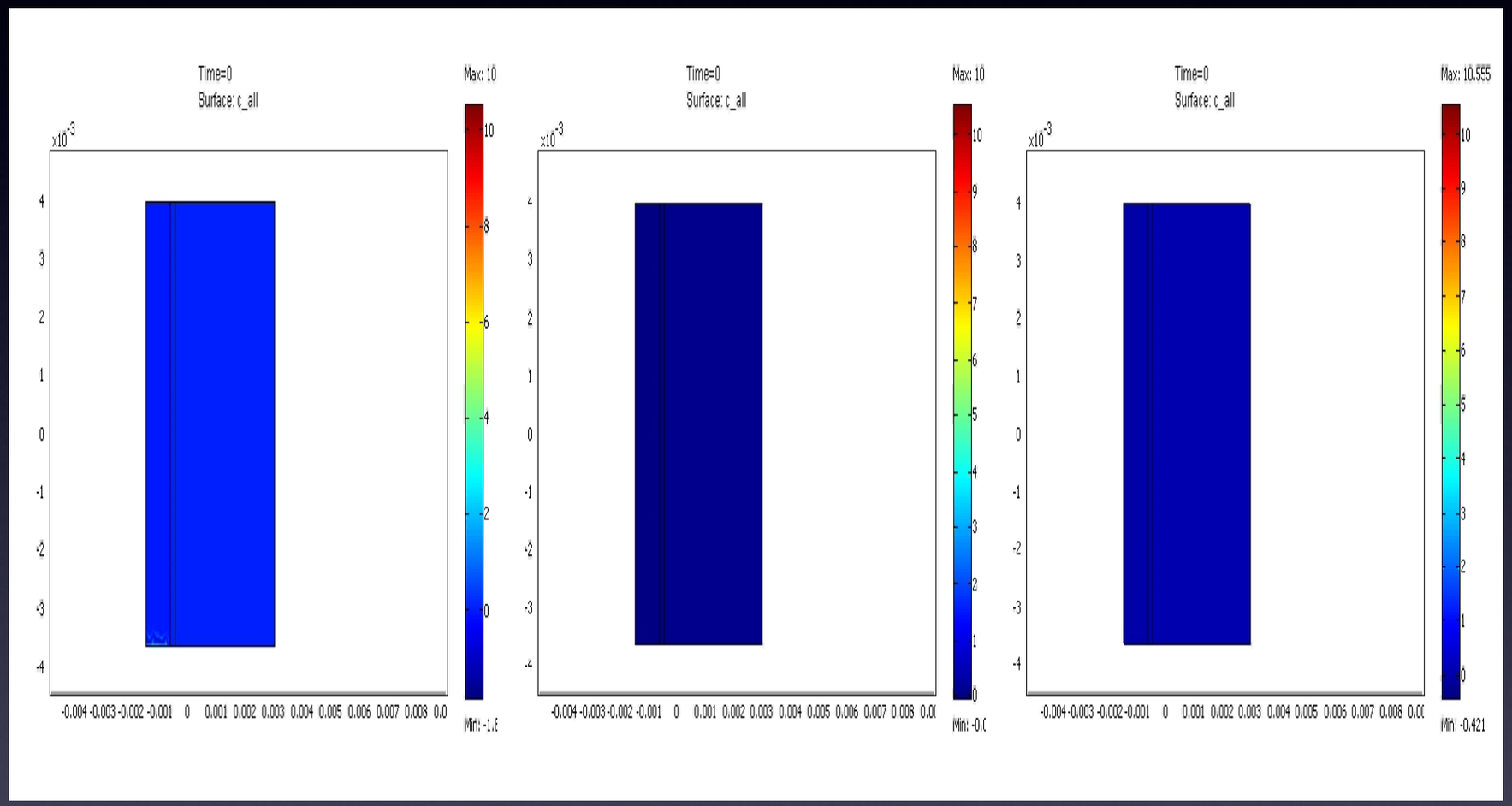
1 p_1 t_0 p_3 p_4
2

od vessel – tissue exchange model (UiB, 2006)

Simple multiphysics compartmental model



Inflow of fluid,
BOLUS injection



High membrane leakage.
Low tissue porosity

High membrane leakage.
High tissue porosity

Closed tissue compartment

Thank you!

Erasmus students from TUL in BBB, May 2015