# Collaboration on Analysis of 3D Image Data in the QIM Center

Anders Bjorholm Dahl

**Workshop on Perspectives and Applications of Deep Learning for Accelerated Scientific Discovery in Physics**

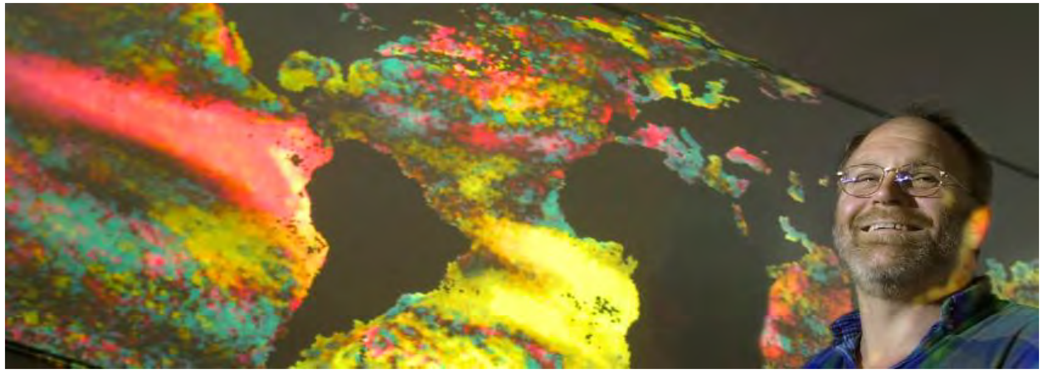
Image Analysis and Computer Graphics
QIM: The Center for Quantification of Imaging Data for MAX IV
Technical University of Denmark

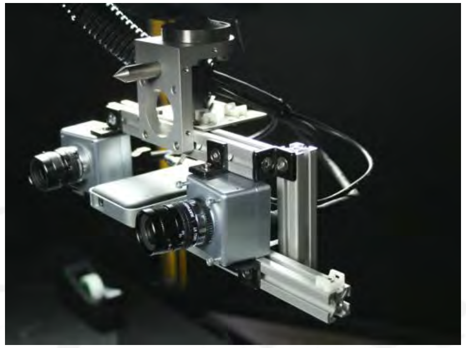
# Image Analysis and Computer Graphics – DTU Compute

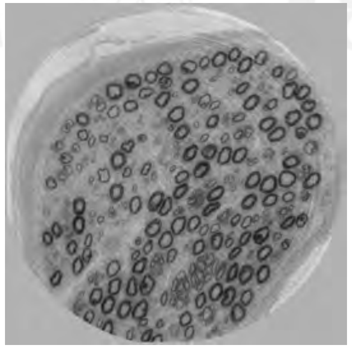
12 faculty – approx. 50 researchers

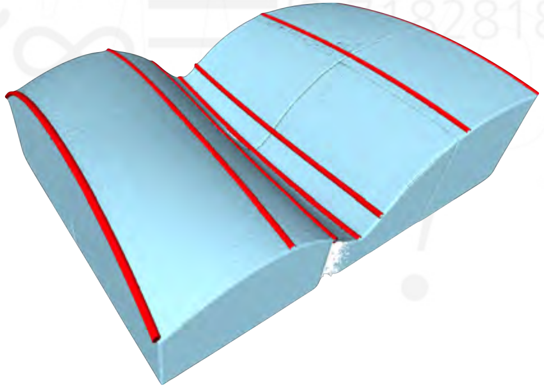
Research areas:

1. Computer vision
2. Geometry processing
3. Appearance modeling
4. Medical image analysis
5. 3D image analysis
6. Remote sensing



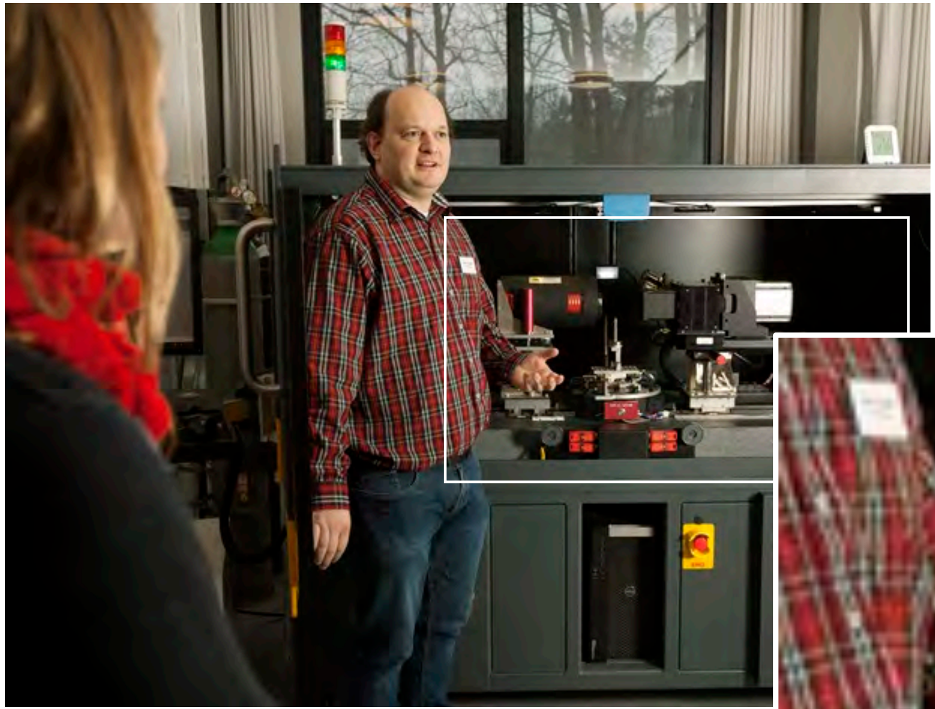


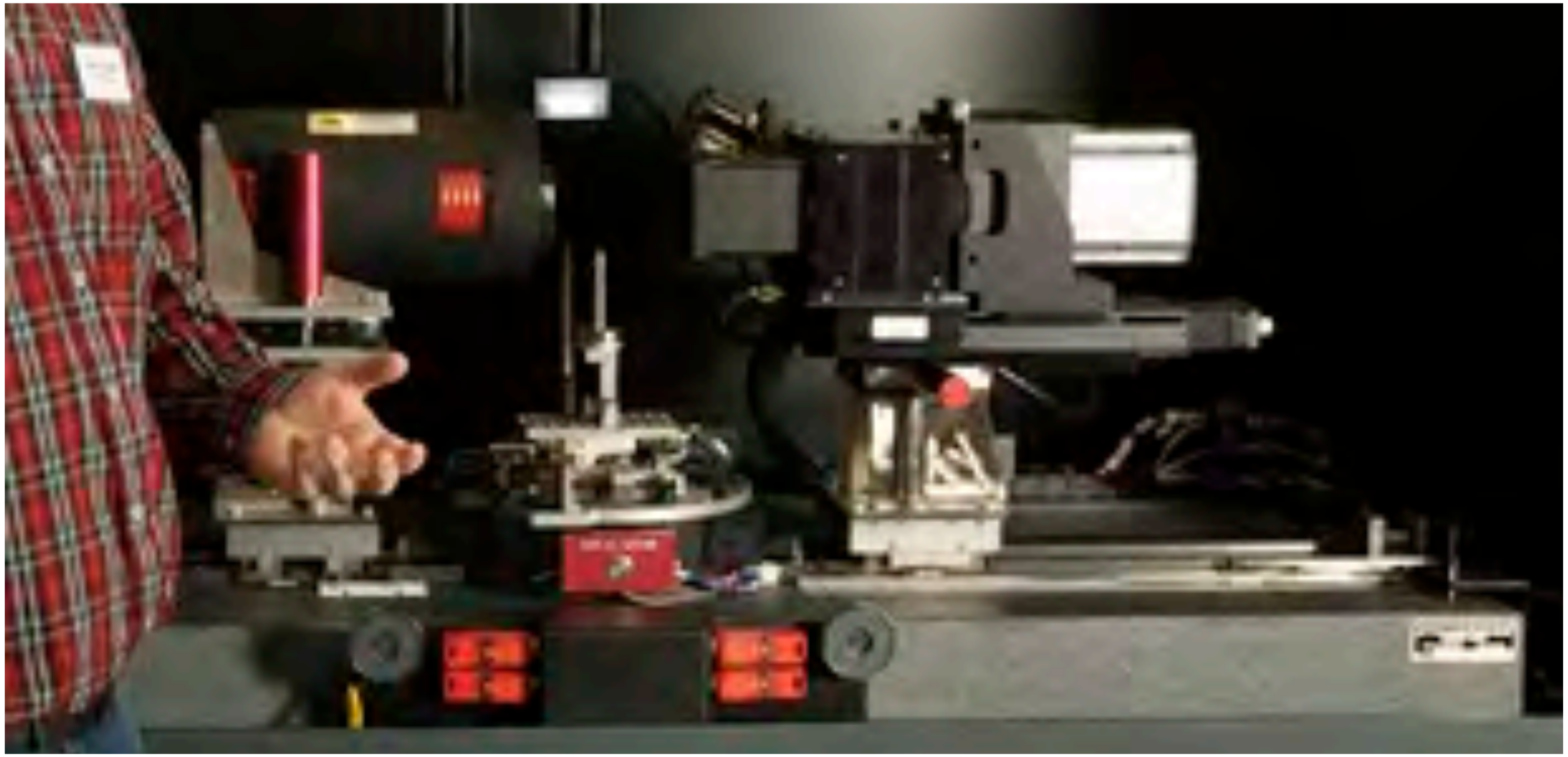




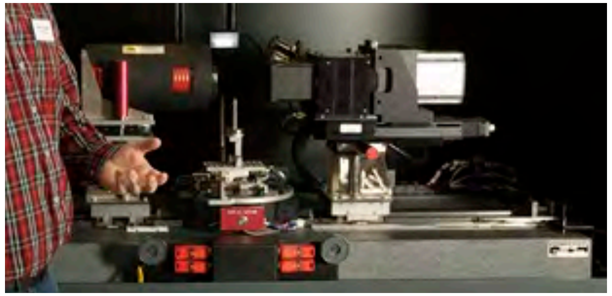

Imaging facilities

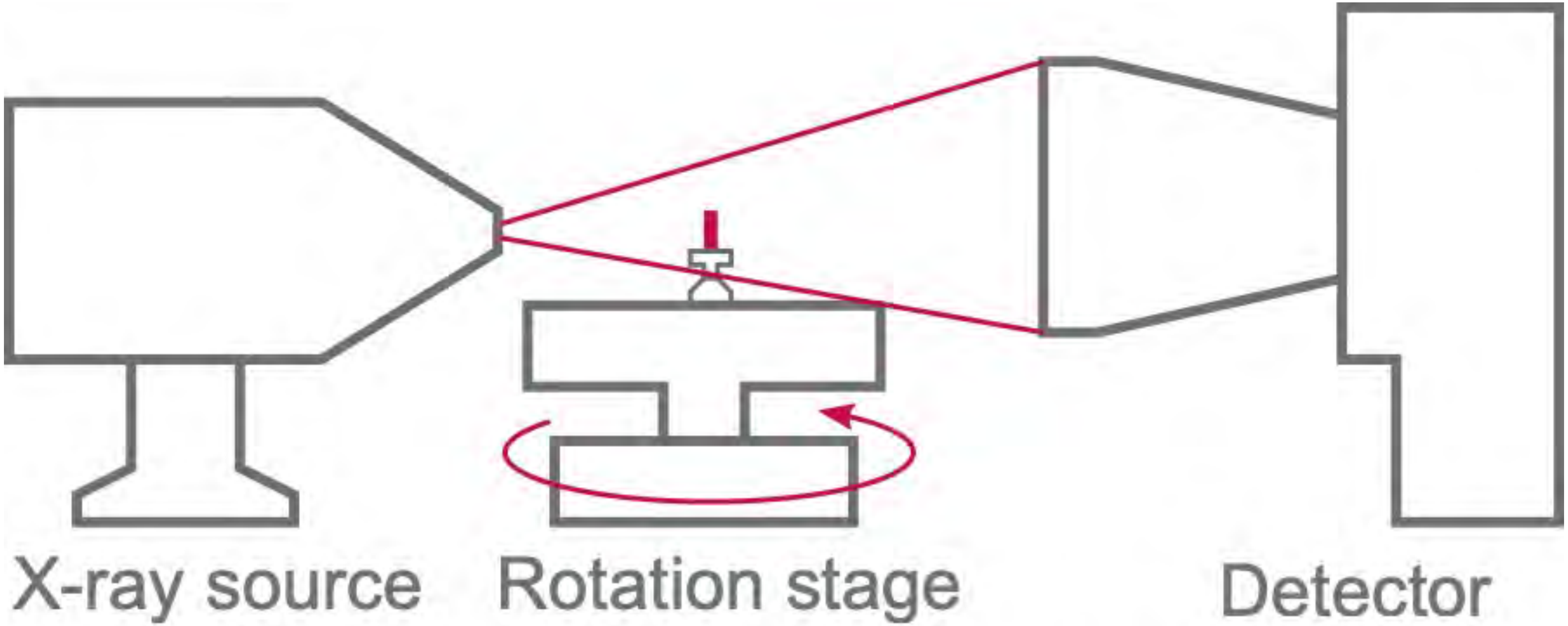

# Imaging principle





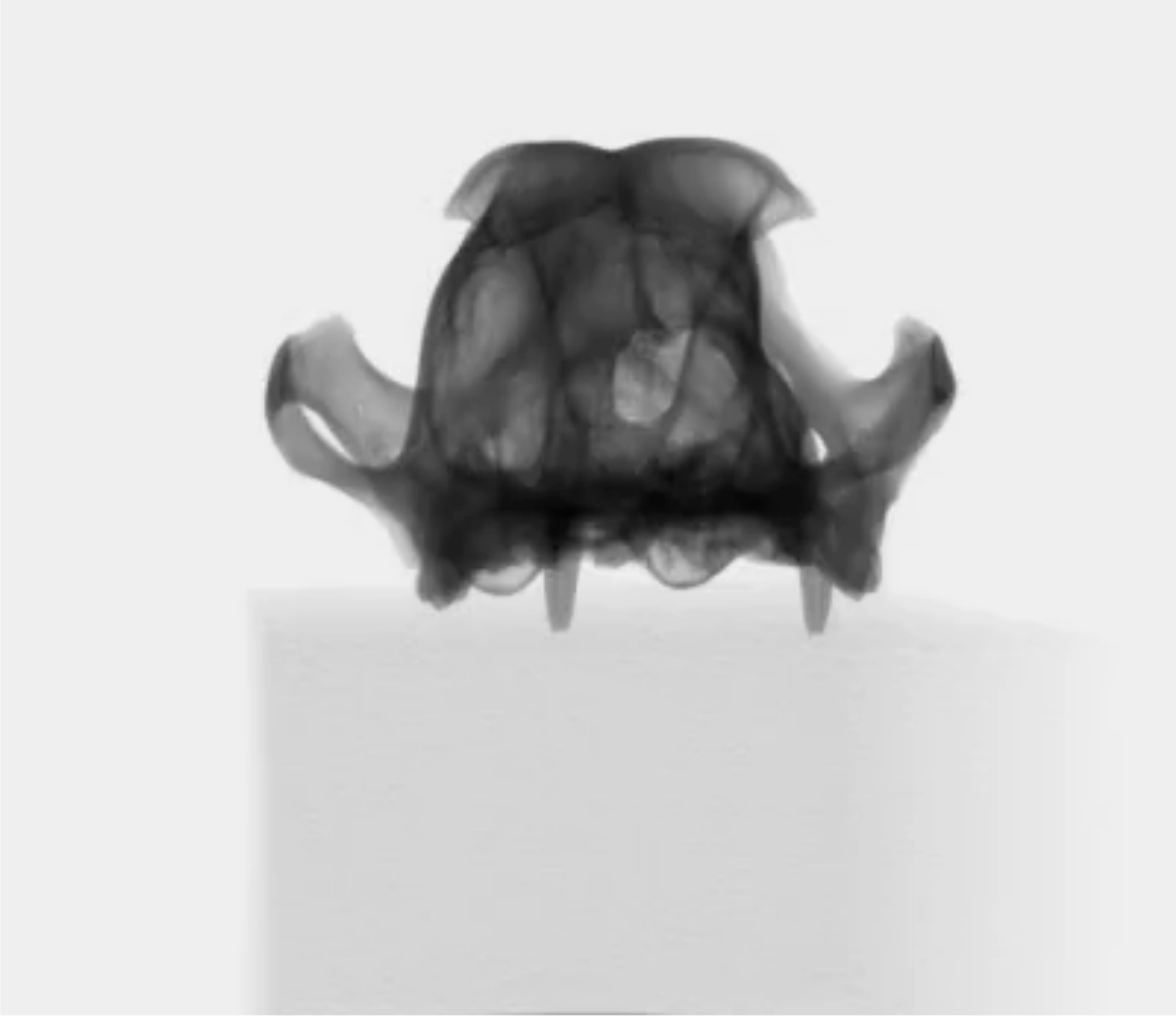
# Imaging principle



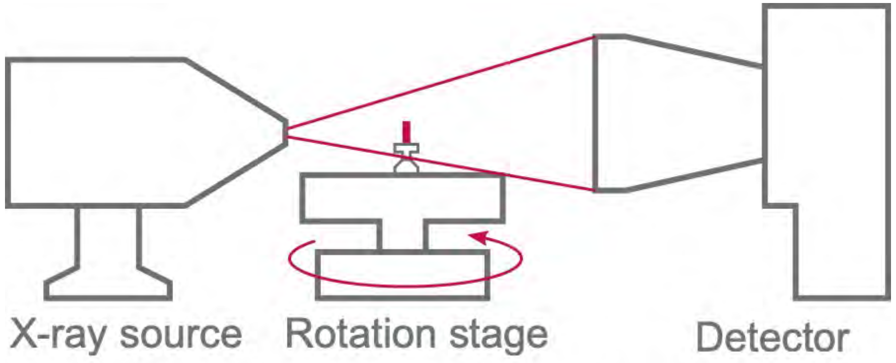



Micro-CT scanner setup

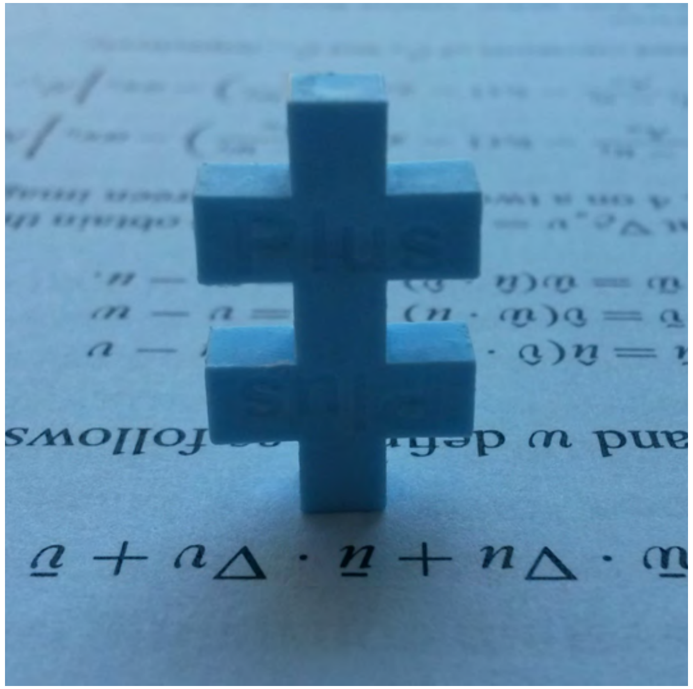
# Imaging principle

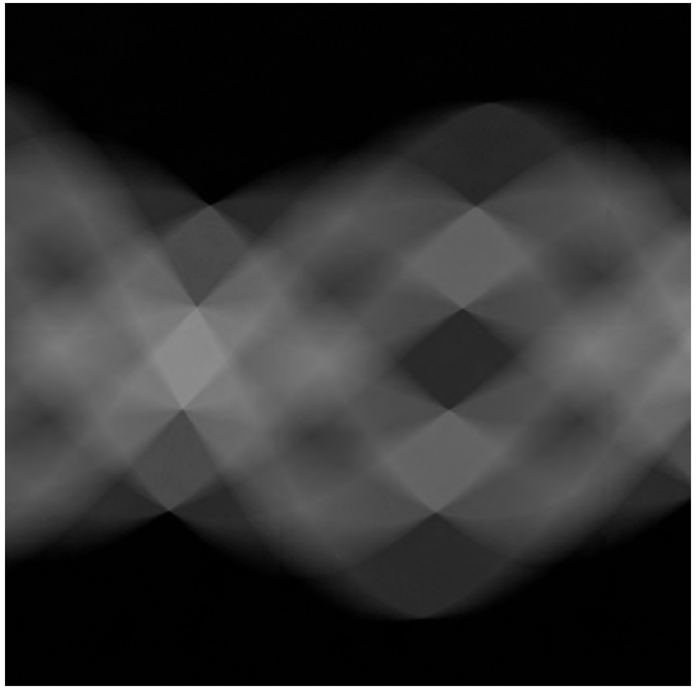


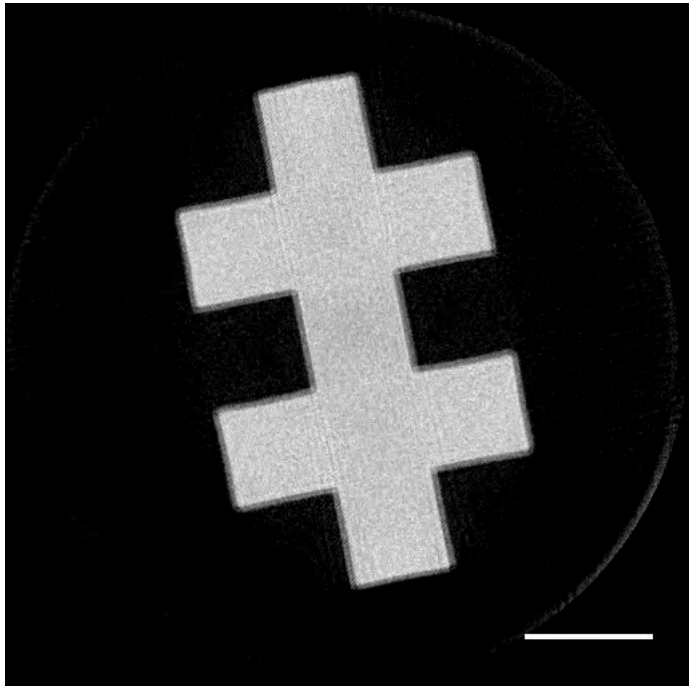
# Toy experiment



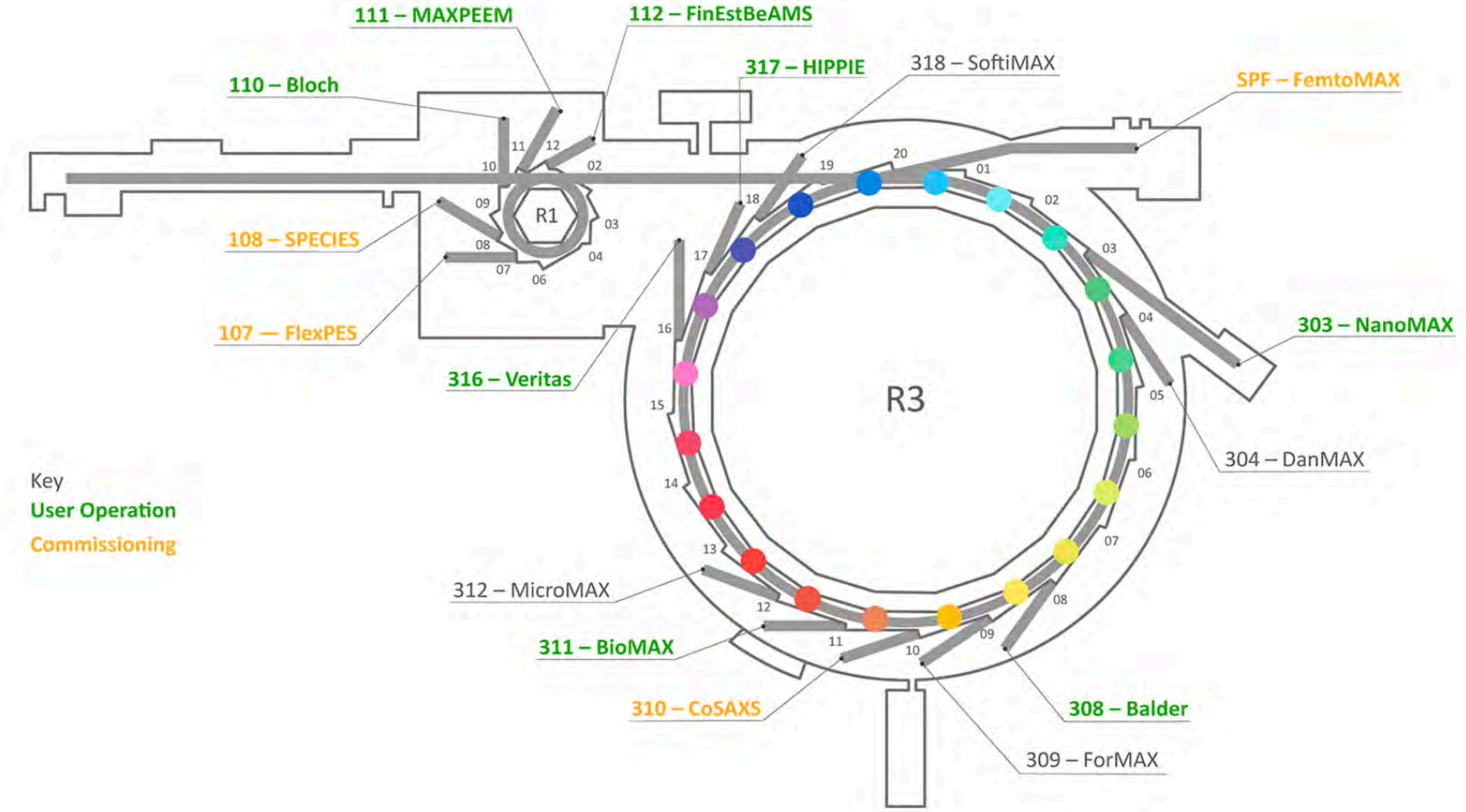
Micro-CT scanner setup







# Beamlines at MAX IV



# QIM: The center for quantification of imaging data form MAX IV

Imaging:

- Quantitative analysis a limitation
- Difficult to select relevant method
- Quantifying structures become the most time-consuming part of imaging

Goal of QIM:

- Support users at MAX IV & lab facilities with image analysis
  - Consultancy
  - Competence development
  - Development of tools and analysis pipelines


# The QIM team

Who we are:

- DTU








- Copenhagen University



- MAX IV




3D Imaging Center at DTU



# Quantitative X-ray tomography

**E. Maire*[1] and P. J. Withers[2]**

X-ray computer tomography (CT) is fast becoming an accepted tool within the materials science community for the acquisition of 3D images. Here the authors review the current state of the art as CT transforms from a qualitative diagnostic tool to a quantitative one. Our review considers first the image acquisition process, including the use of iterative reconstruction strategies suited to

## Concluding remarks and future trends

X-ray micro-CT has come a very long way over the last 20 years both in terms of spatial and temporal resolution, and the degree to which 3D images and 3D image sequences are quantified. It is now customary to spend 10–100× longer analysing datasets, compared to the time taken to capture them. Yet, many researchers are still only able to extract fairly rudimentary metrics to quantify the geometrical and temporal features of their images. The availability of open source and proprietary software toolboxes for image quantification are likely to expand the degree to which users can extract useful information about their samples non-destructively.

[1]Université de Lyon, INSA-Lyon, MATEIS, CNRS UMR5510, F-69621 Villeurbanne, France
[2]Manchester X-ray Imaging Facility, School of Materials, Manchester, M13 9PL, UK and also The Research Complex at Harwell,Rutherford Appleton Laboratory, Didcot, Oxfordshire OX11 0FA, UK

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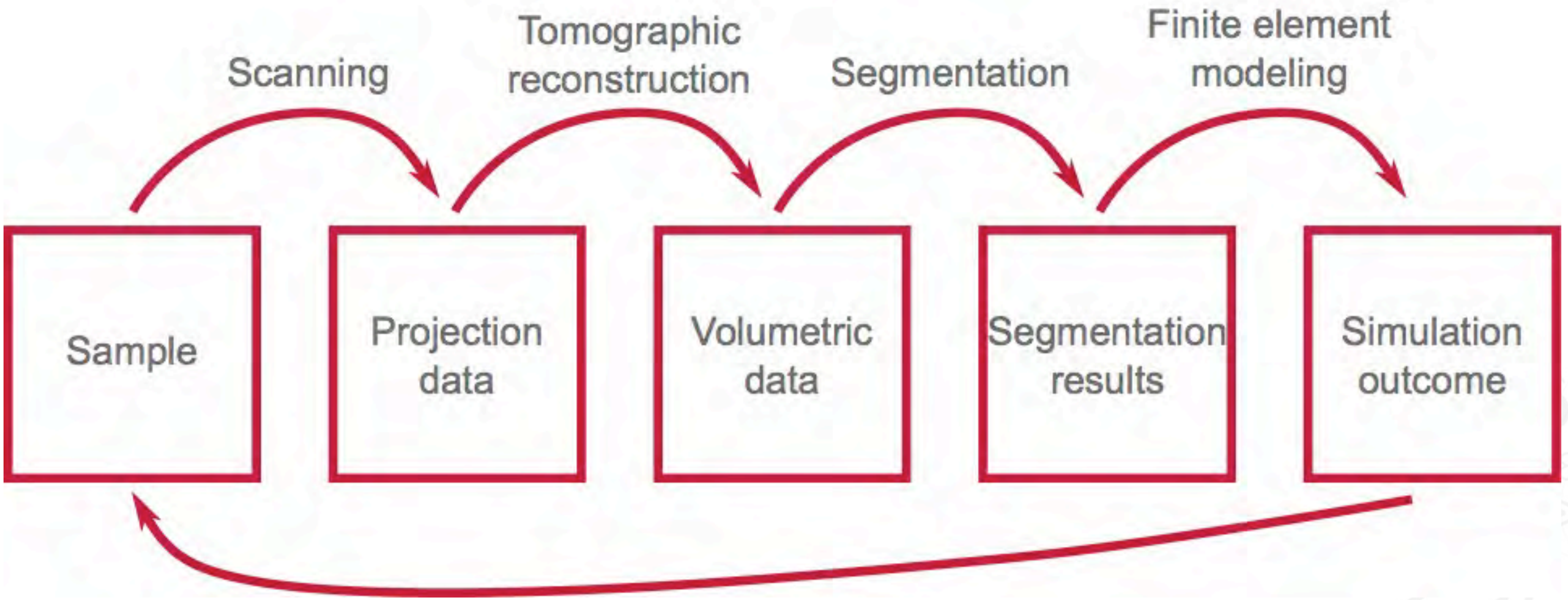
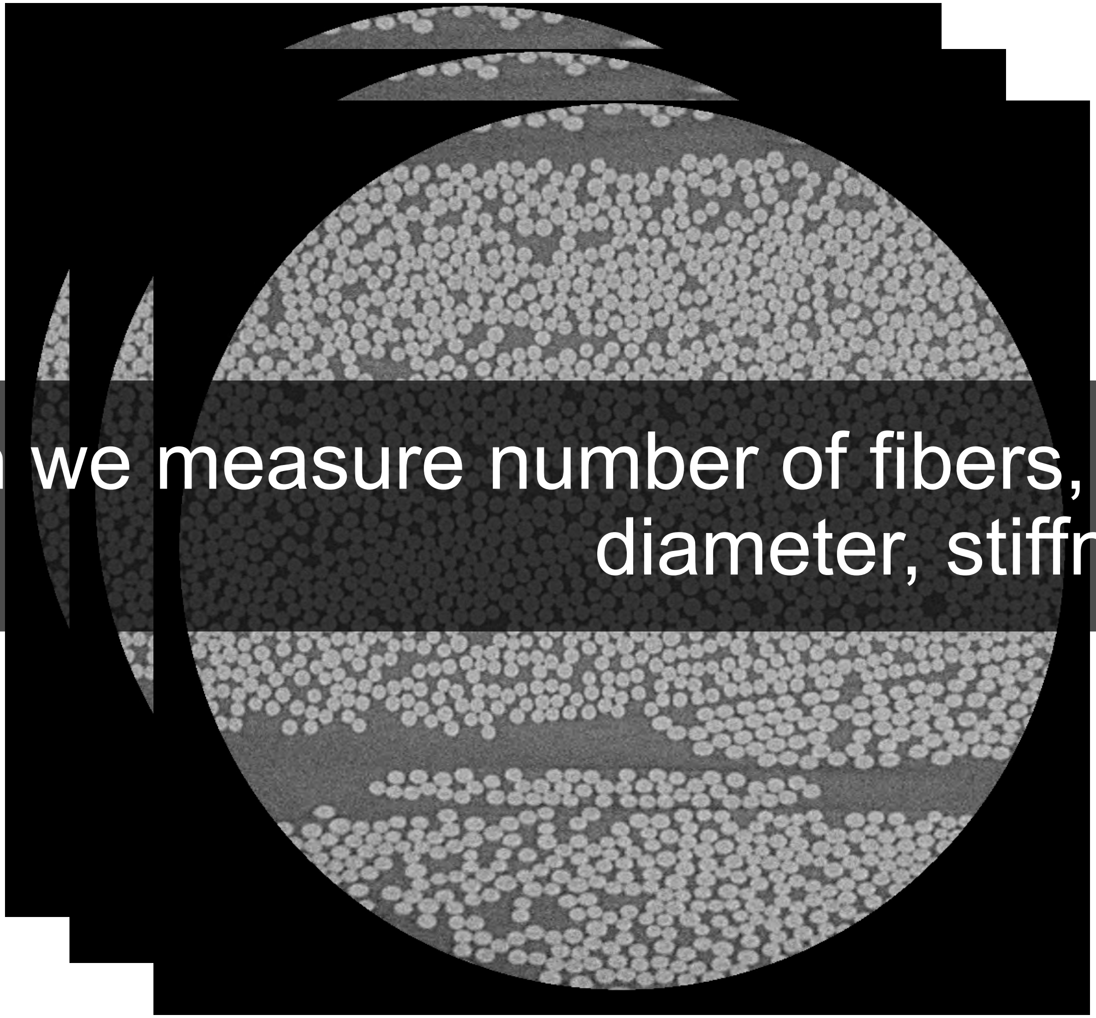
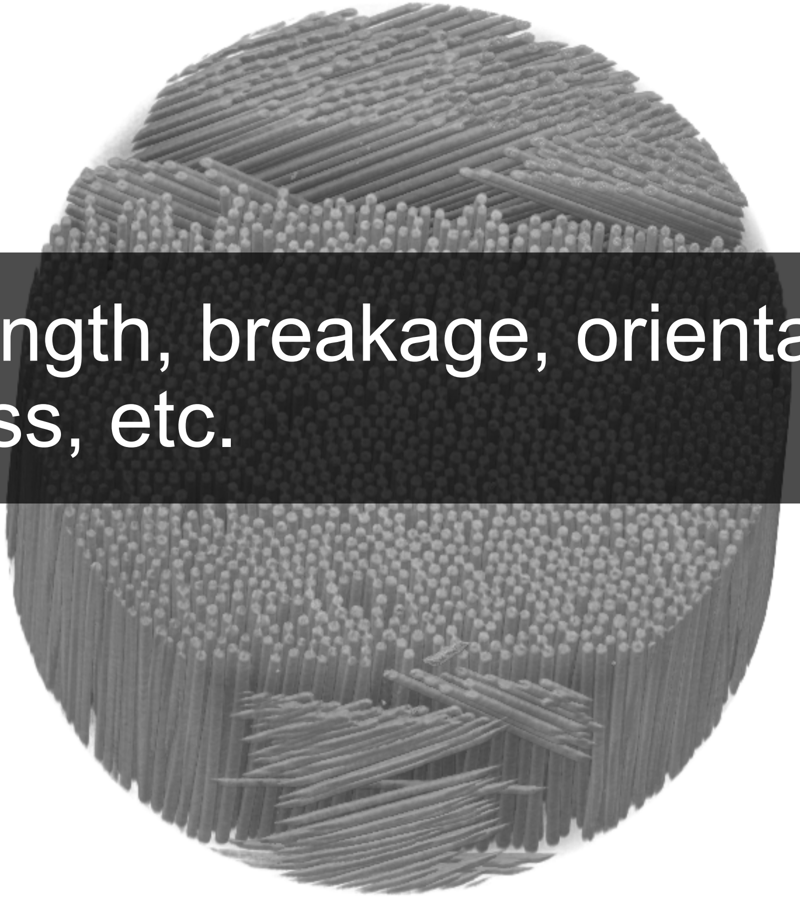
# Imaging pipeline

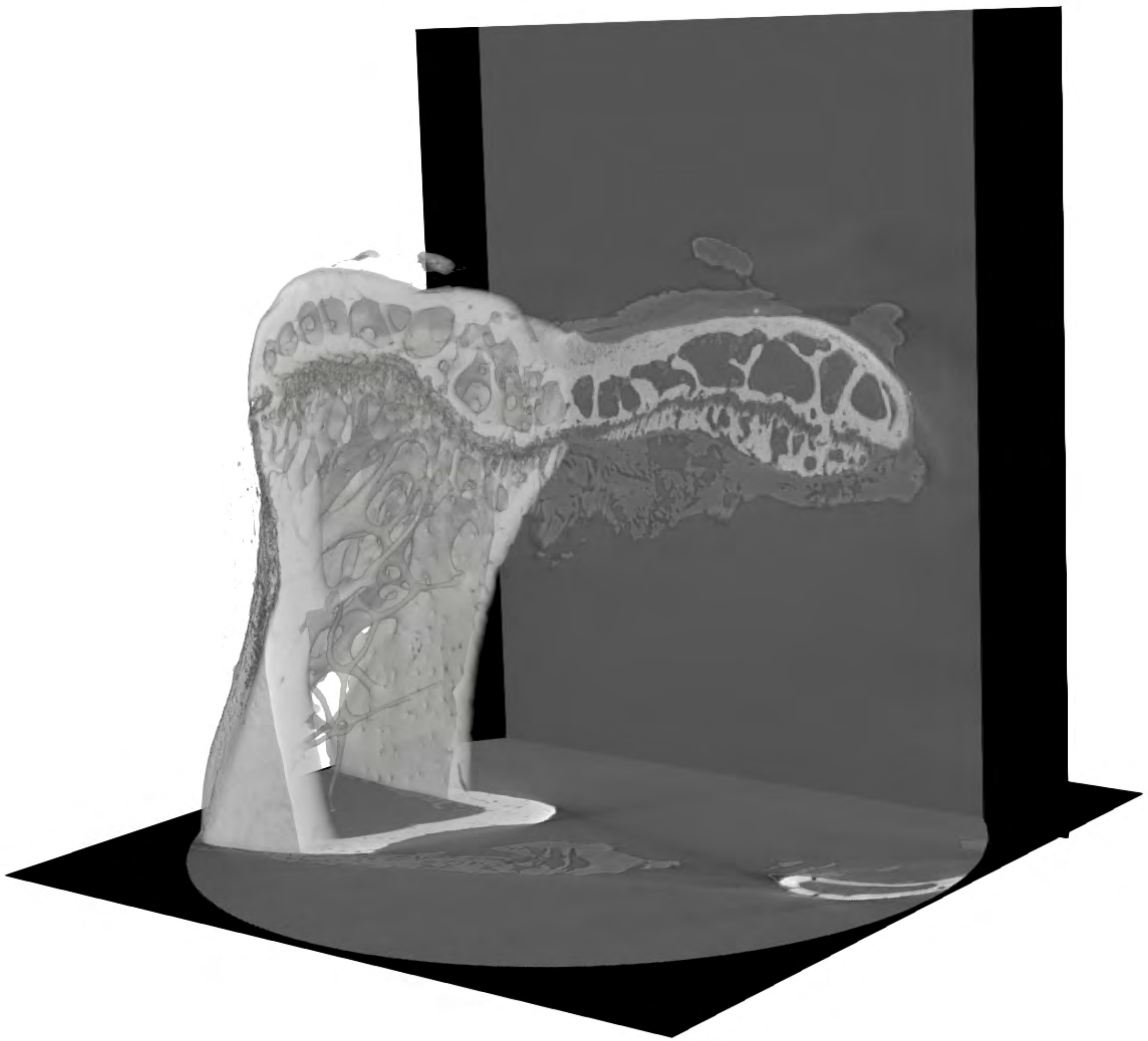


# 3D image analysis

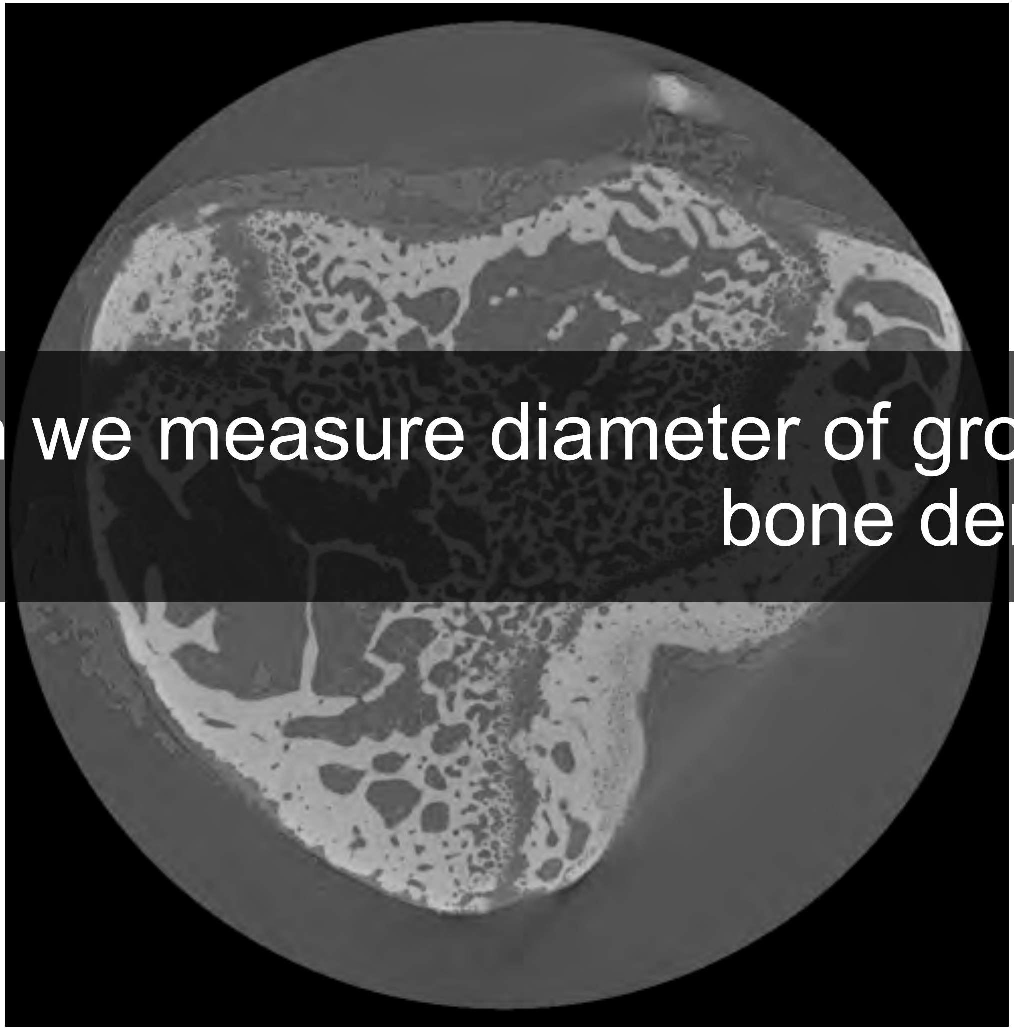


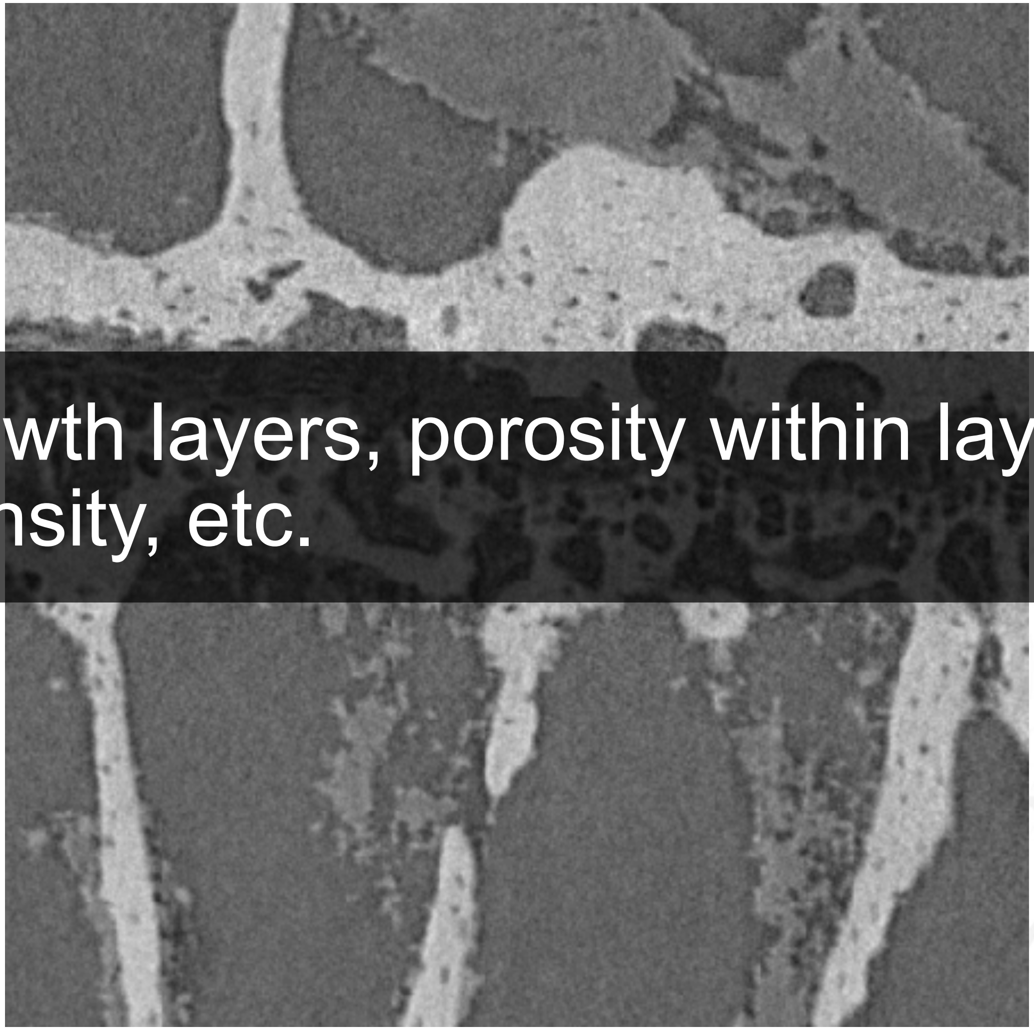


Can we measure number of fibers, length, breakage, orientation, diameter, stiffness, etc.



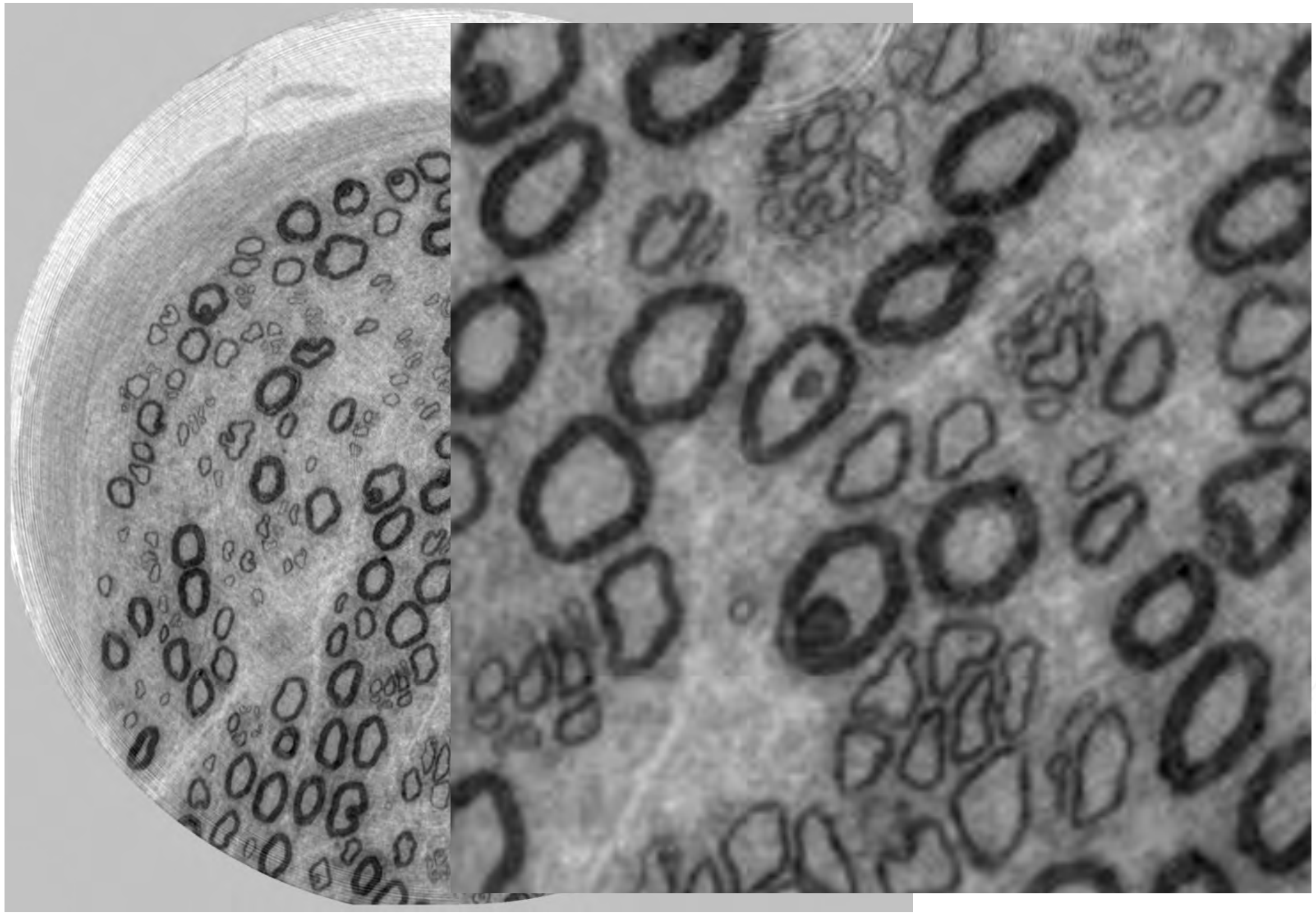

# 3D image analysis





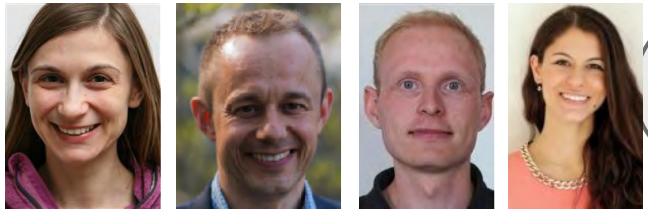
Can we measure diameter of growth layers, porosity within layers, bone density, etc.

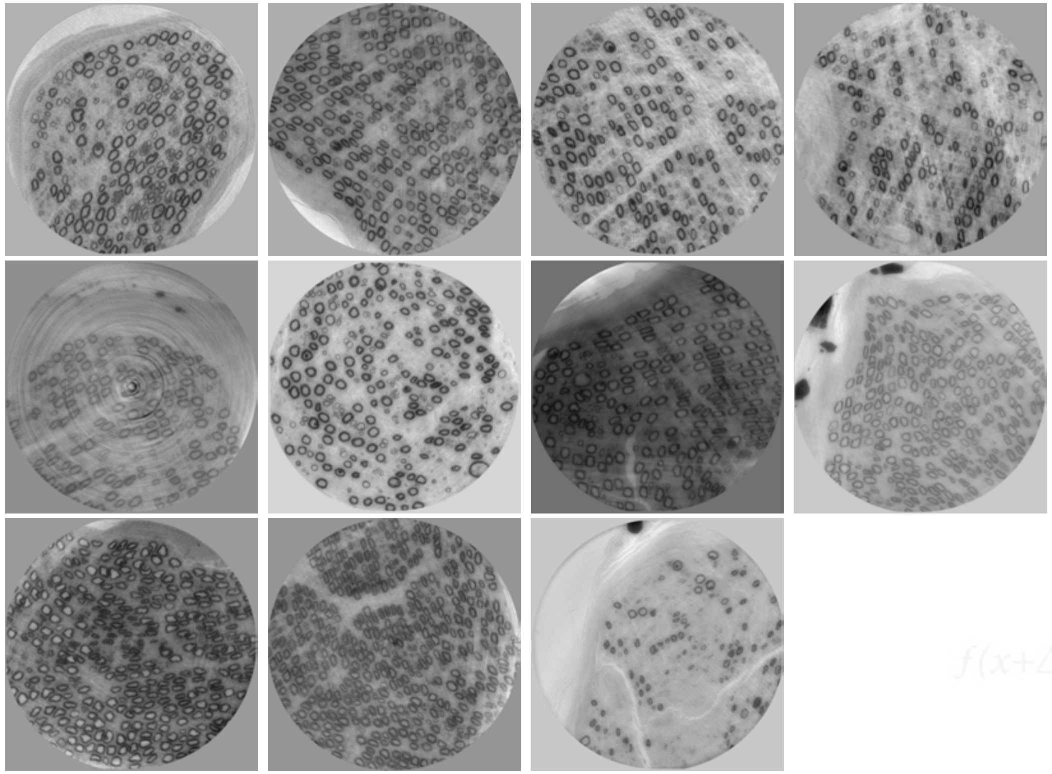
# Image segmentation



- Same intensity of different structures
- Size and intensity variation
- Boundaries are touching
- Shape variation
- Etc.

# Nerve dataset





Question: are nerves influenced by the disease?

# Nerve segmentation and tracking

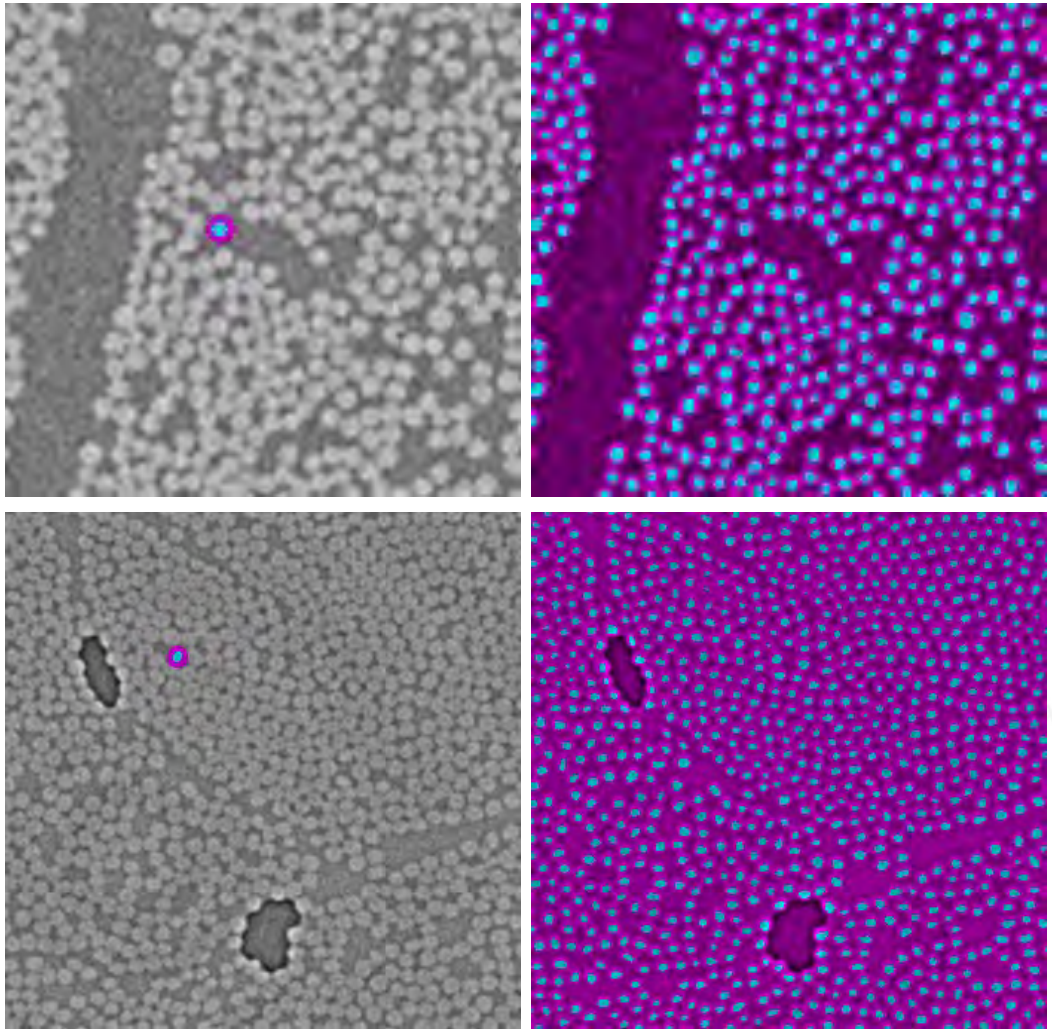
## Nerve segmentation

- Probabilistic segmentation into three classes: axon, myelin, background.
- Weakly supervised segmentation using a dictionary of image patches.
- Serves as an initialization for the subsequent nerve tracking.

## Nerve tracking

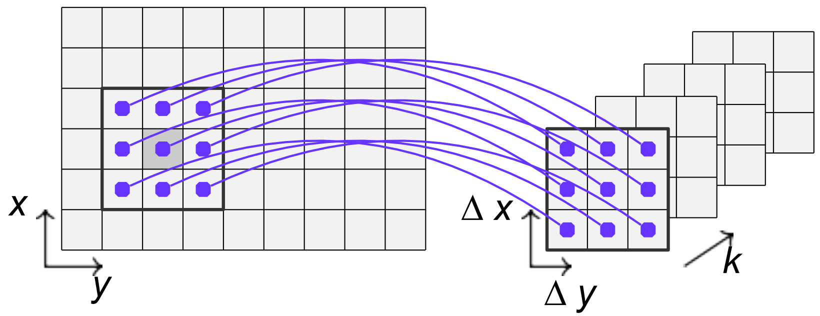
- Tracking each nerve using two discrete closed parametric curves.
- Utilizes the fact that nerves are predominantly unidirectional.
- Curve deformation found by graph-cut layered surface detection.
- Parametrized outcome suitable for subsequent quantification.

# Nerve segmentation, the method behind: Content-based propagation of user markings for interactive segmentation of patterned images



- A method which combines unsupervised clustering of image features and limited user input.
- Very powerful for segmenting patterned images.
- Used extensively for detecting unidirectional fibers in composite materials.
- Implemented as minimalistic GUI, which allows real-time interaction.

# Nerve segmentation, the method behind: Content-based propagation of user markings for interactive segmentation of patterned images




- Dictionary of image patches obtained by clustering the patches extracted from the image.
- Each patch from the image is assigned to one patch from the dictionary, similar image patches are, via clustering, assigned to the same dictionary patch.
- The patch assignment implies a relation between the image pixels and dictionary pixels,encoded by the biadjacency matrix **B**.
- User input is encoded in labeling **L**.
- Two diffusion matrices, derived from **B** diffuse user input from the image space to the dictionary space, and vice-versa.

$$\mathbf{T}_1 = \mathrm{diag}(\mathbf{B}^{\mathsf{T}}\mathbf{1}_{n\times 1})^{-1}\mathbf{B}^{\mathsf{T}}$$

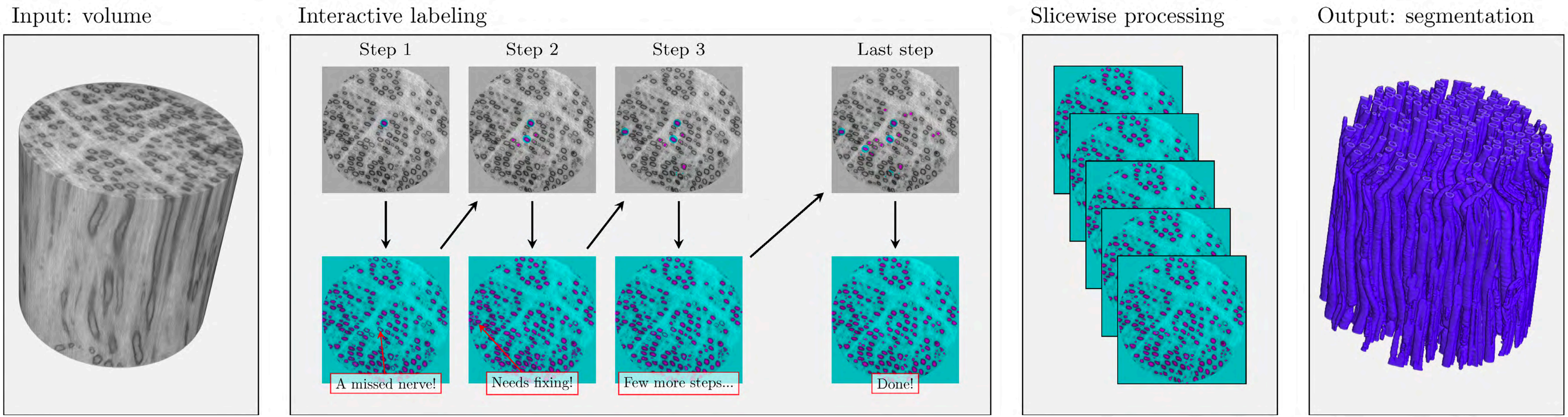
$$\mathbf{T}_2 = \mathrm{diag}(\mathbf{B}\mathbf{1}_{m\times 1})^{-1}\mathbf{B}$$

- Probabilistic labeling of a whole image is obtained by diffusion of the user input.

$$\mathbf{P} = \mathbf{T}_2\mathbf{T}_1\mathbf{L}$$

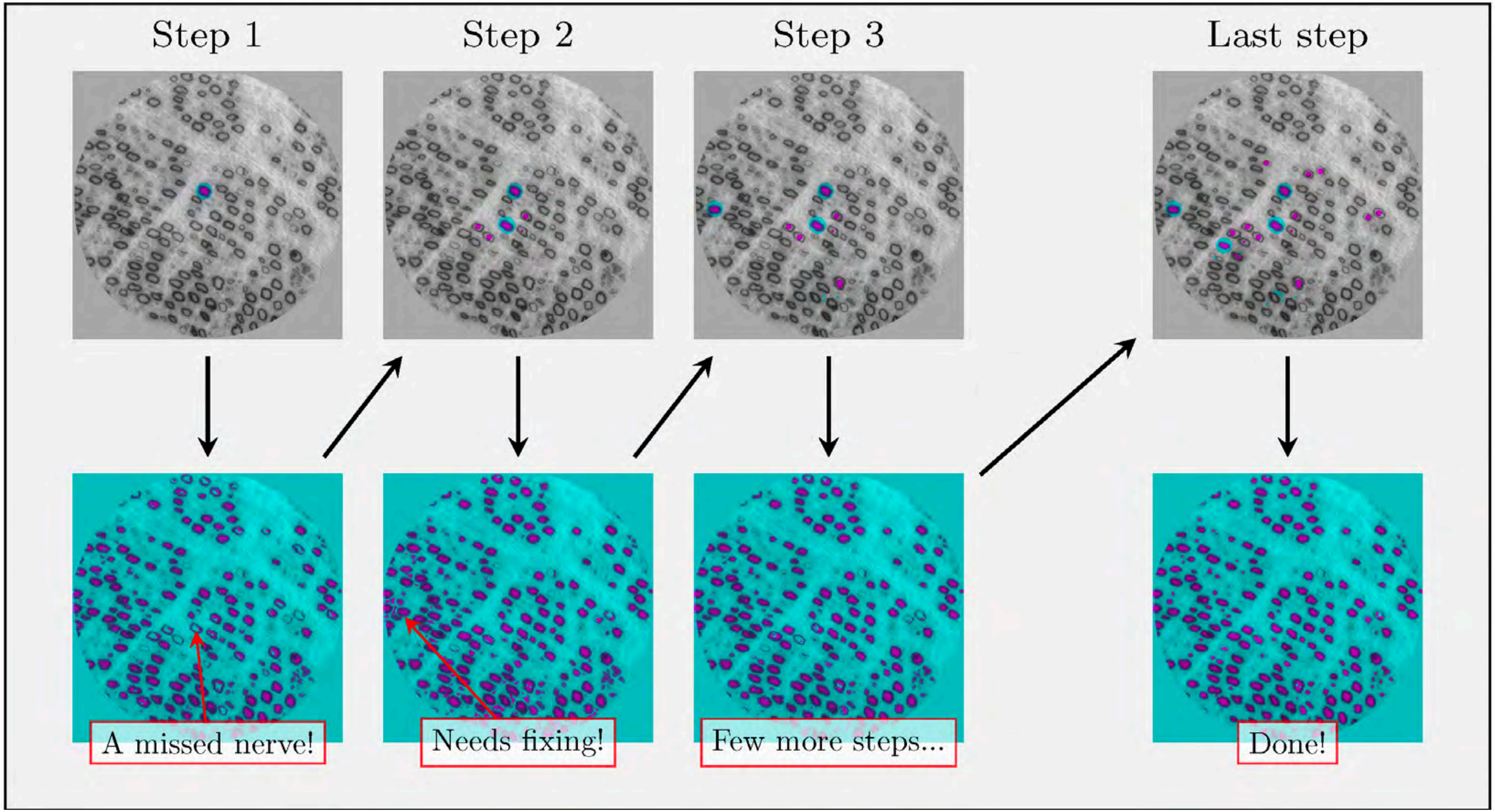
- Implementational details include: number of diffusion steps, treatment of un-labeled pixels, enhancement of labels.

# Nerve segmentation

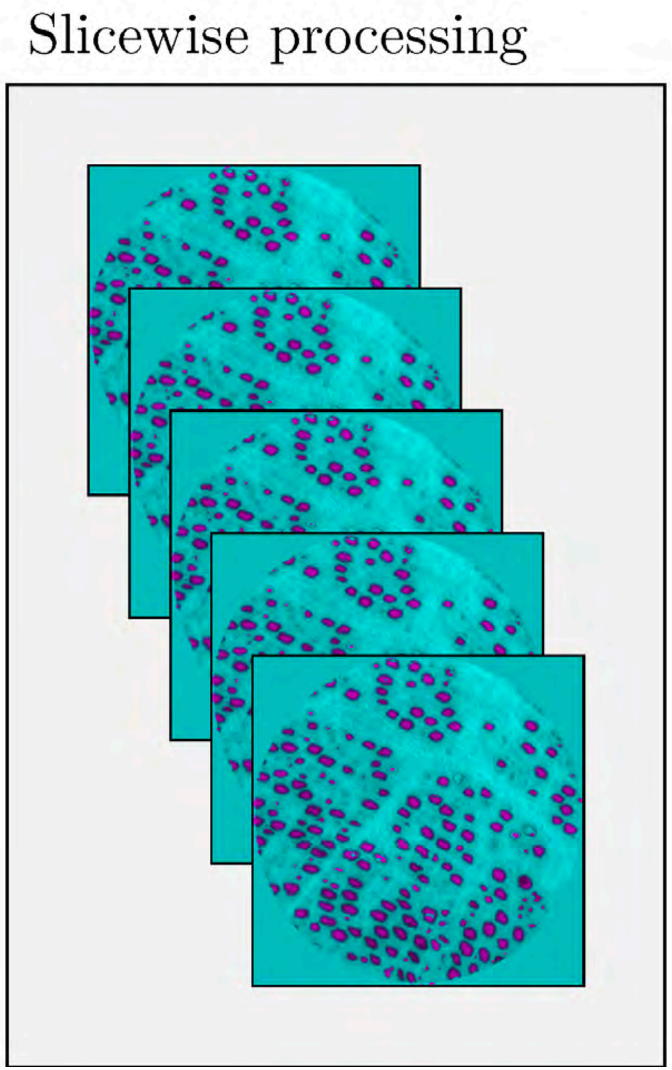


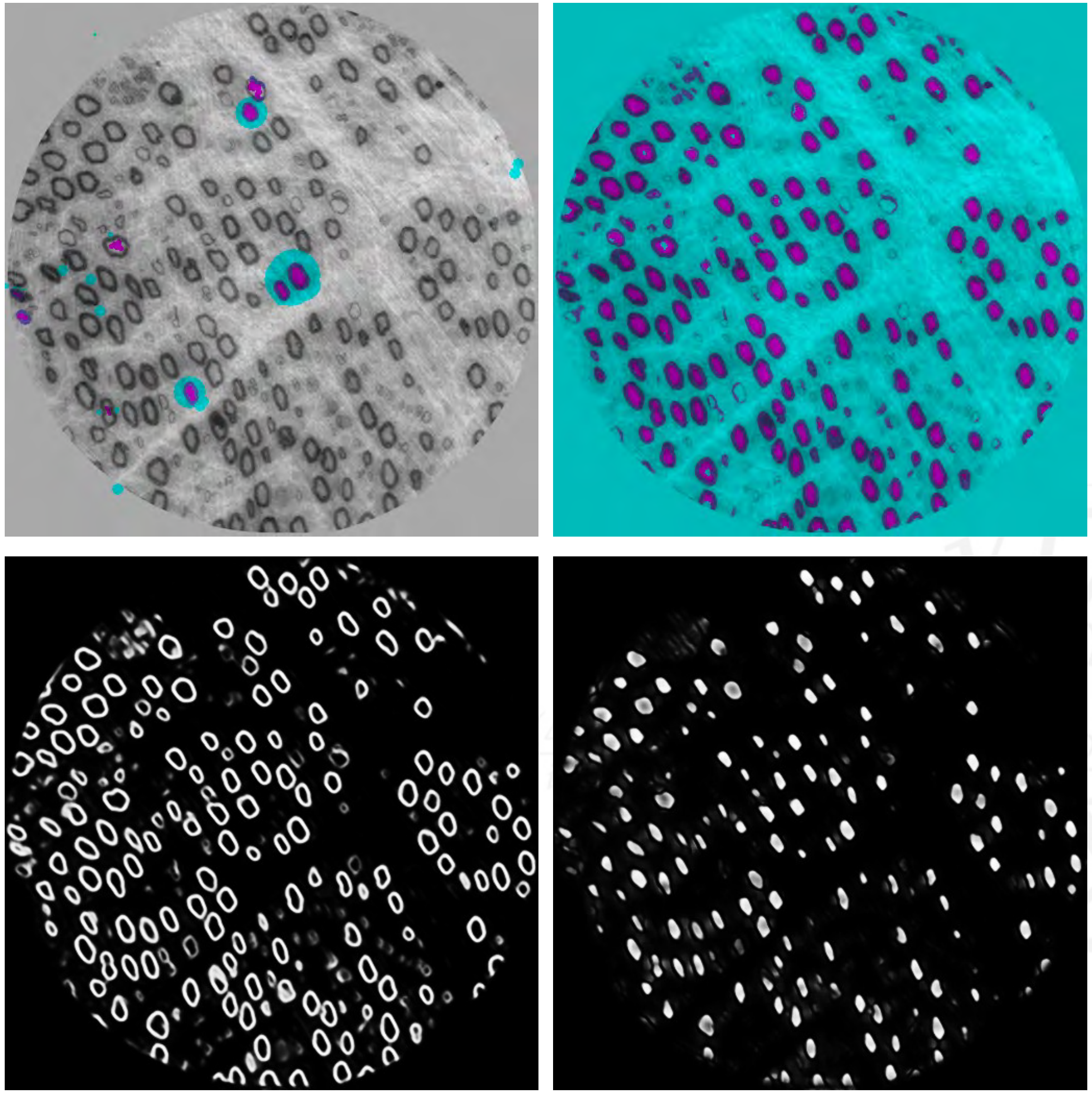
## Nerve segmentation

# Interactive labeling

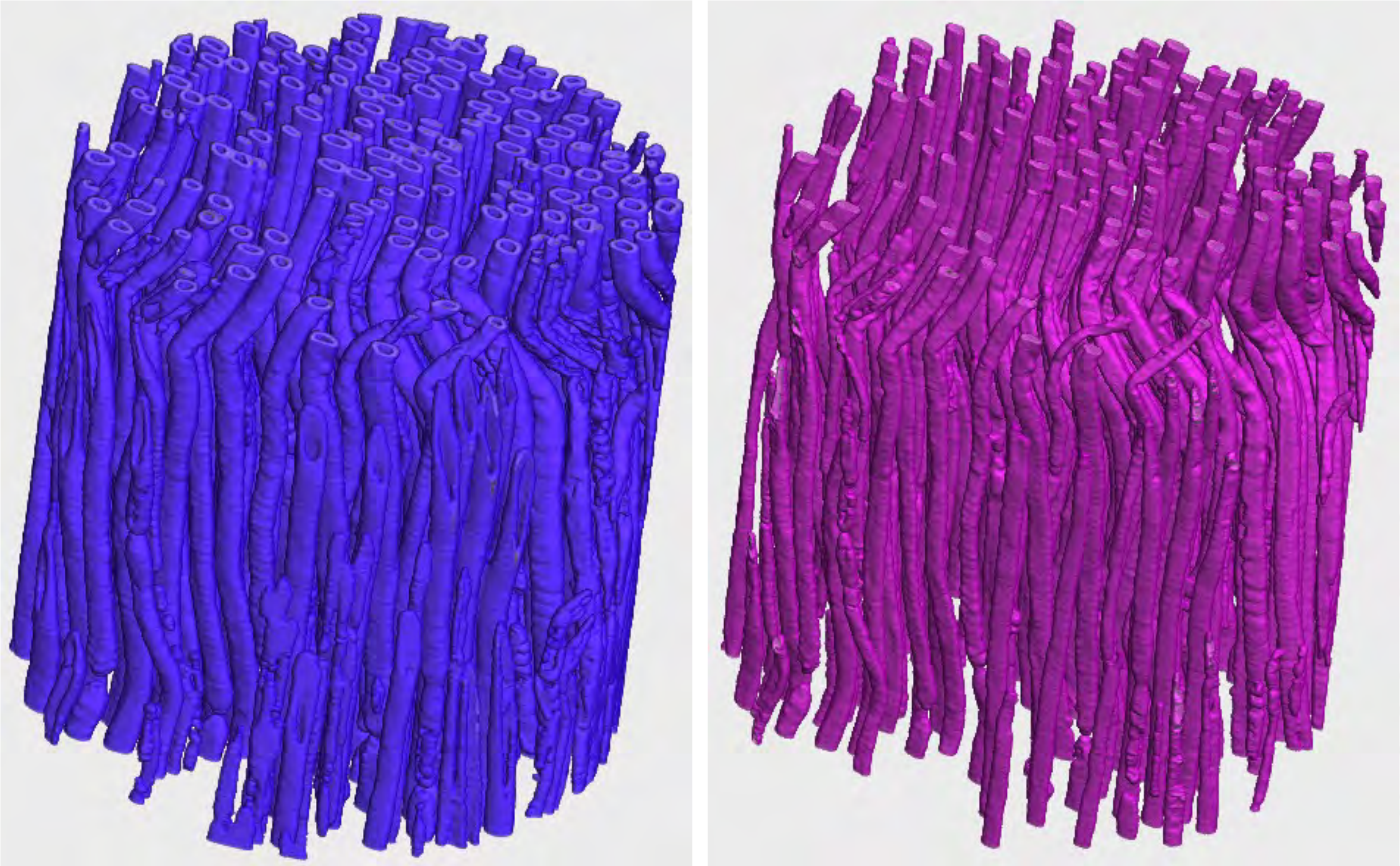


# Nerve segmentation



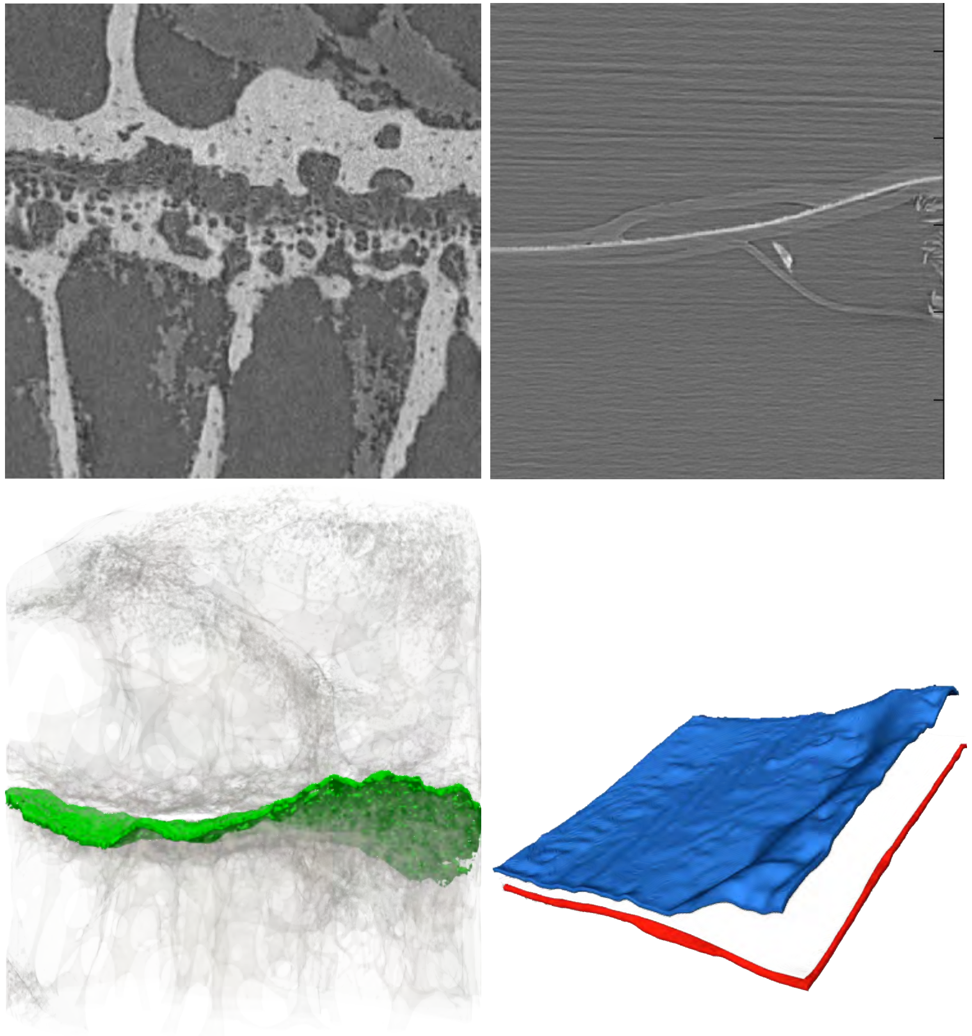



# Nerve segmentation result



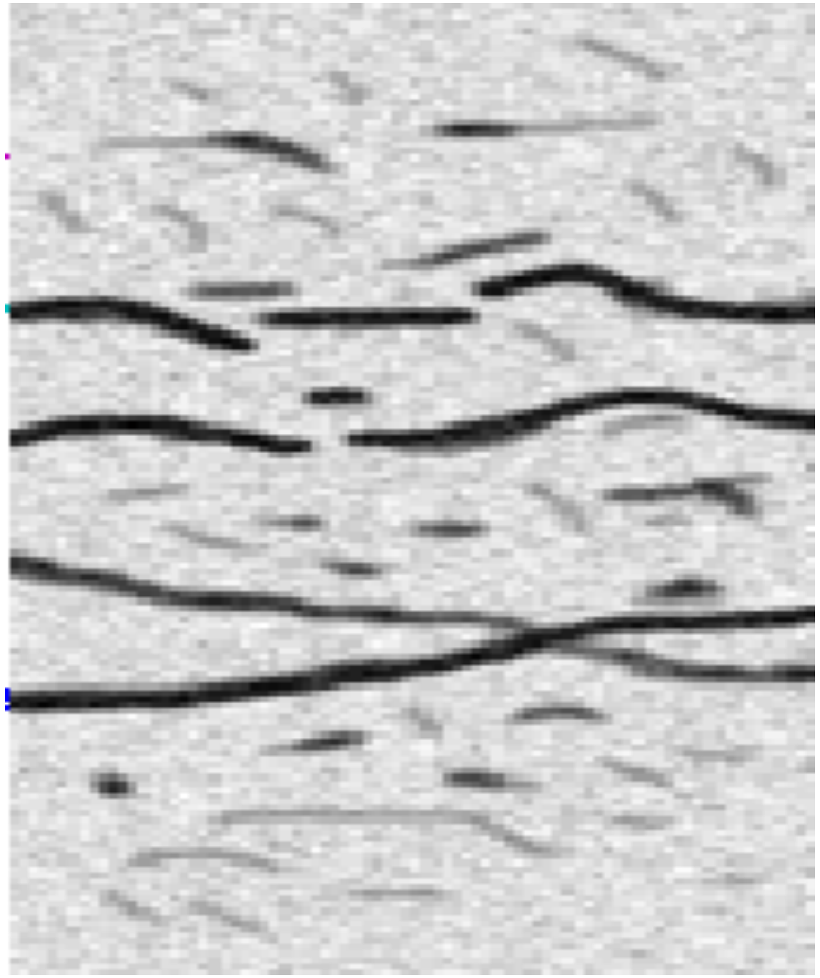
Probabilistic image segmentation serves as an initilization for the next step: nerve tracking.

# Nerve tracking, the methods behind: Layered surface detection



- Volumetric analysis often requires segmenting the volume in layers.
- Constraining the segmentation problem to detecting terrain-like surfaces greatly reduces the search space and improves the robustness of the method.
- The solution is efficiently found using an *s-t* graph cut.
- Works in 3D, can be generalized to tubular, closed and rolled surfaces.

# Nerve tracking, the methods behind: Layered surface detection



- Terrain-like surfaces

$$z = f(x, y) .$$

- Smoothness

$$|f(x + n, y) - f(x, y)| < \Delta ,$$

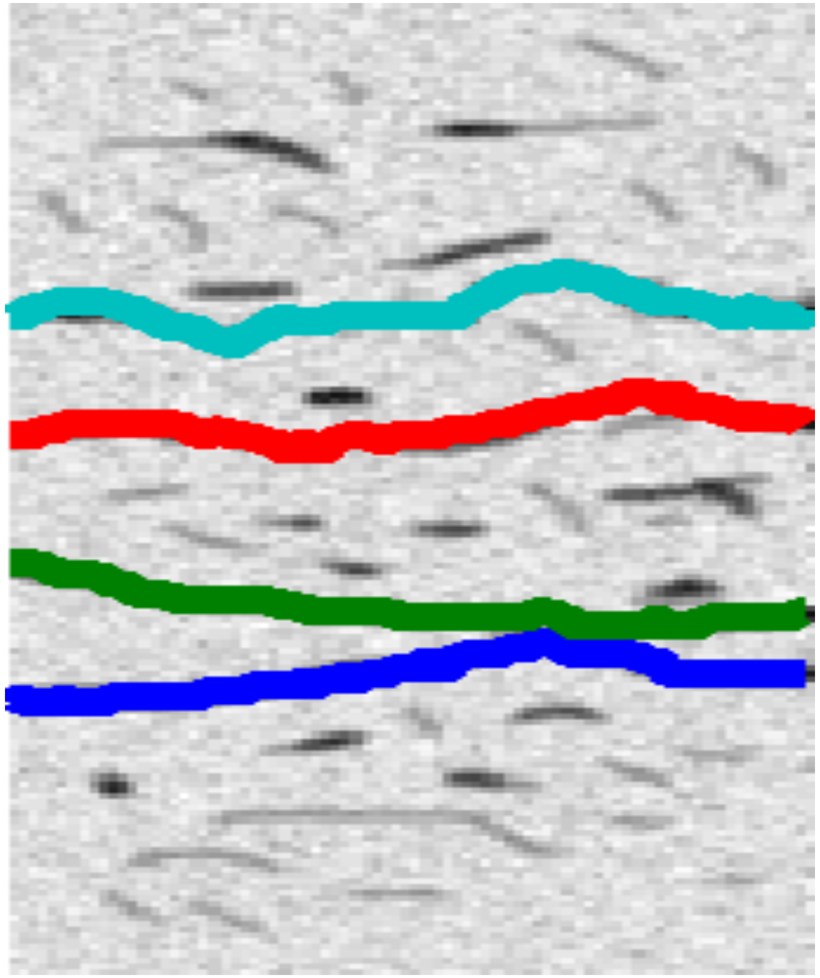
$$|f(x, y + n) - f(x, y)| < \Delta .$$

- Optimality (surface cost)

$$\min_{x,y} c(x, y, f(x, y)) .$$

- Geometric constraints reduce the number of acceptable outcomes.
- Optimal solution can be found using a graph-cut based search.
- Additional modelling options: layered surfaces, region based cost.

# Nerve tracking, the methods behind: Layered surface detection



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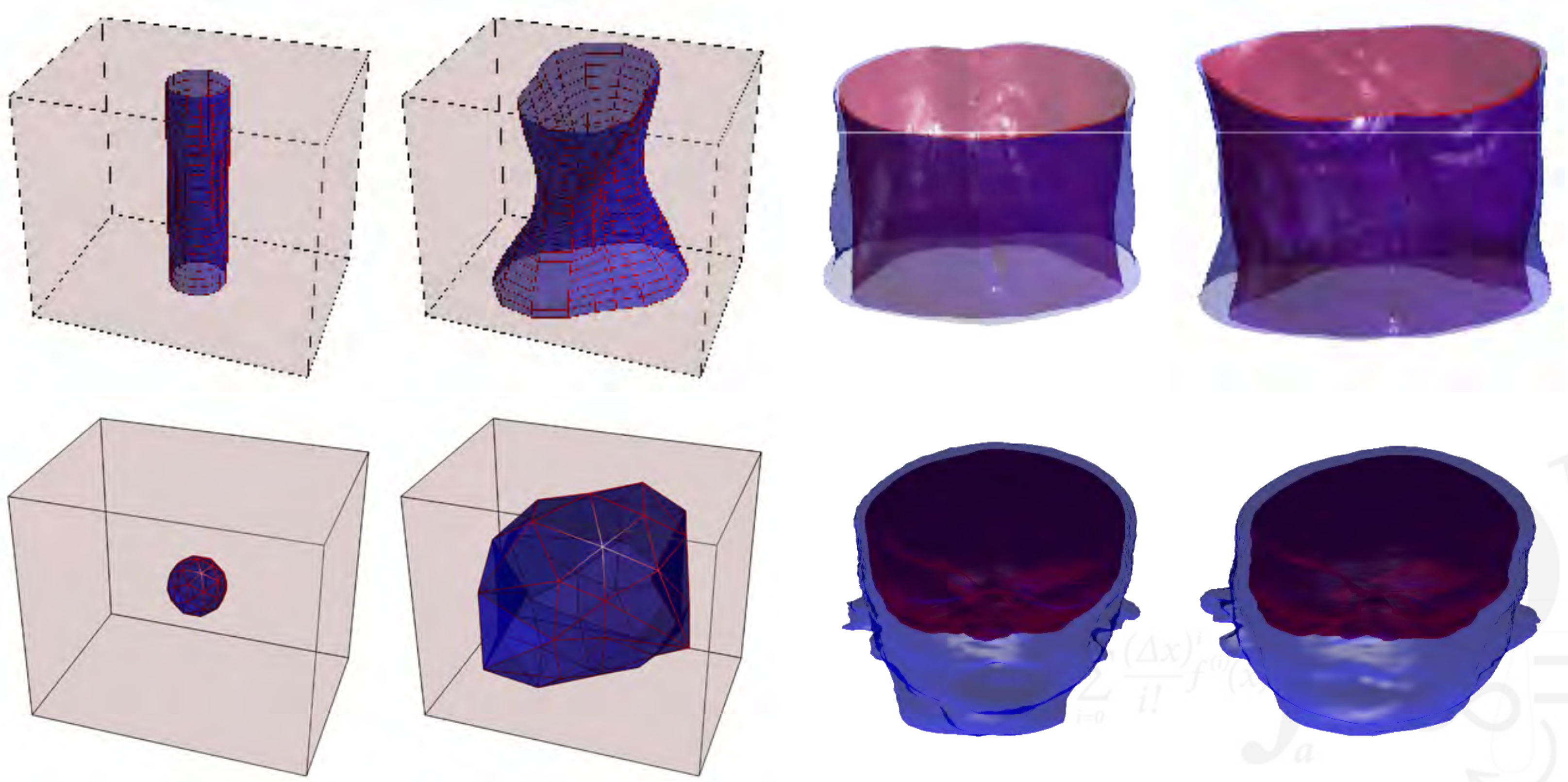
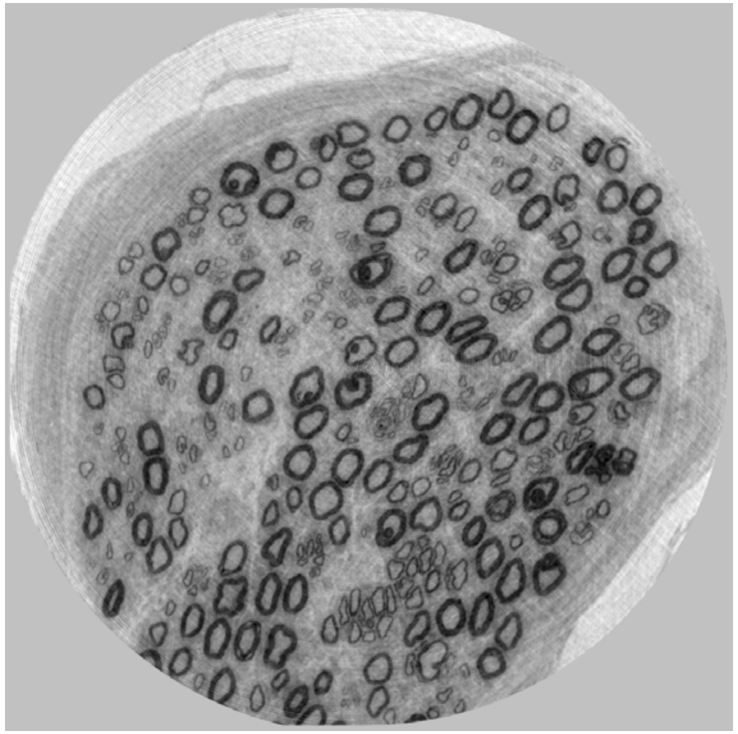
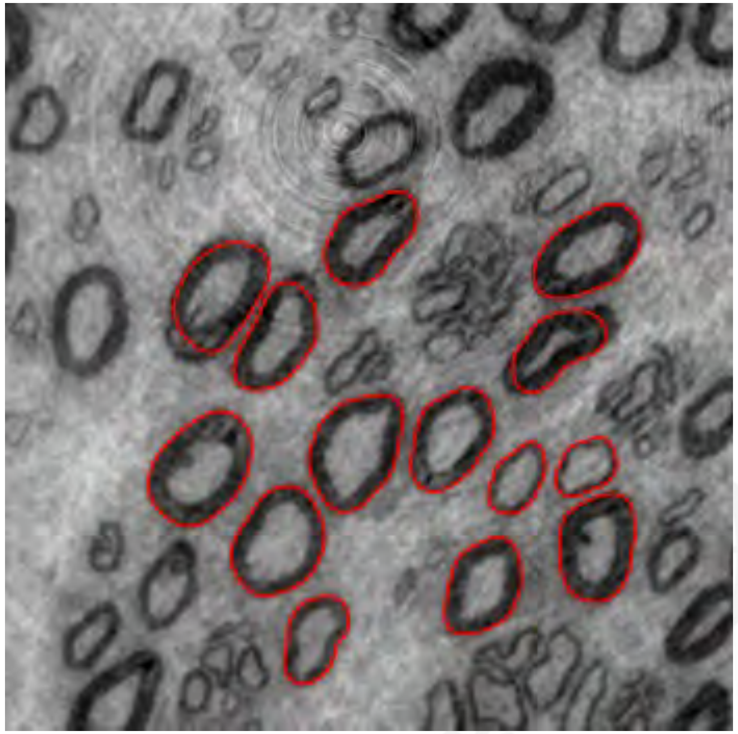
# Nerve tracking, the methods behind: Layered surface detection



Volume is sampled according to the initial geometry – normal to mesh vertices.
Solution is found by displacing geometry, possibly iteratively.

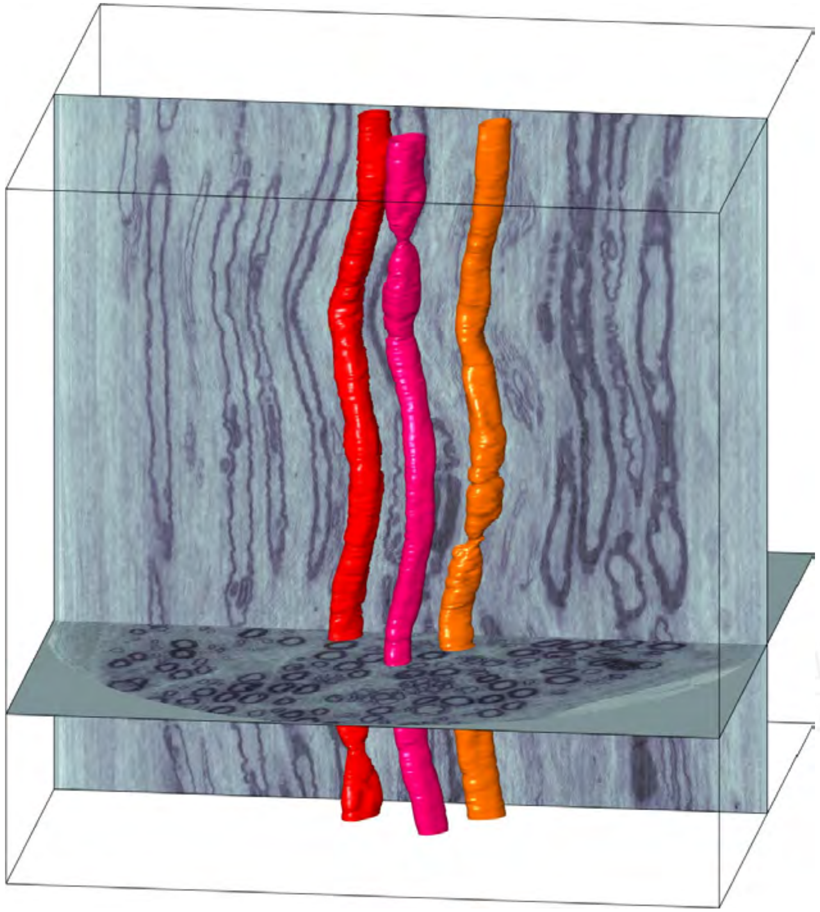
# Nerve tracking, slice-by-slice approach



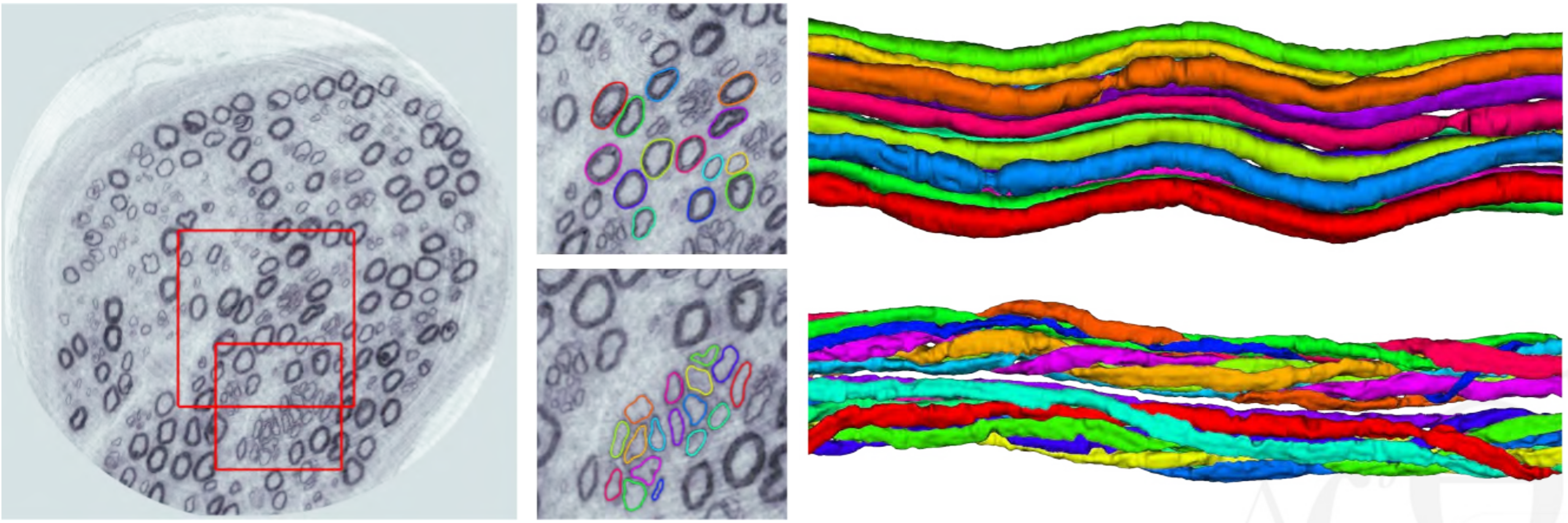


Discrete closed parametric curve: snake. Result from one slice serves ad initialization for the next  slice.

# Nerve tracking, volumetric results

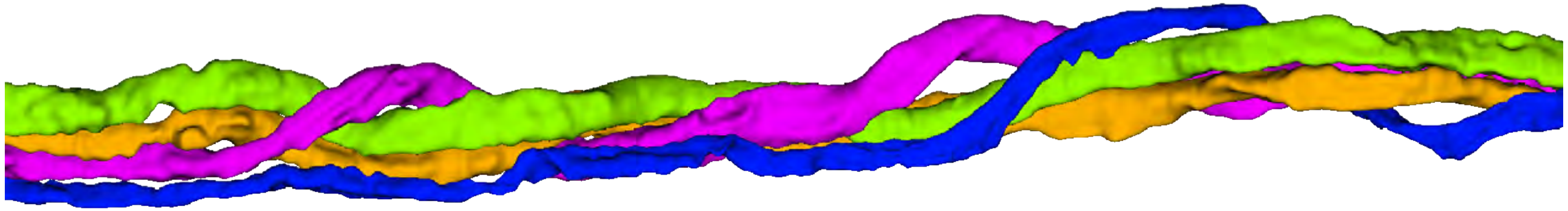


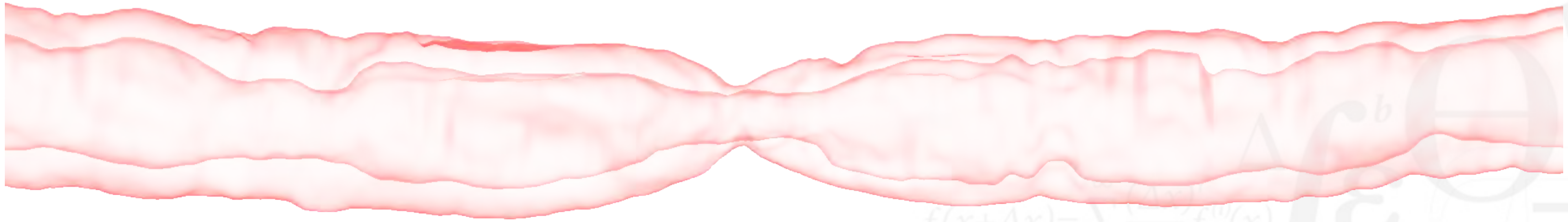
# Nerve tracking, volumetric results



We can investigate nerve trajectories and quantify undulation. We can investigate organization of nerves in clusters and quantify nerve twisting.

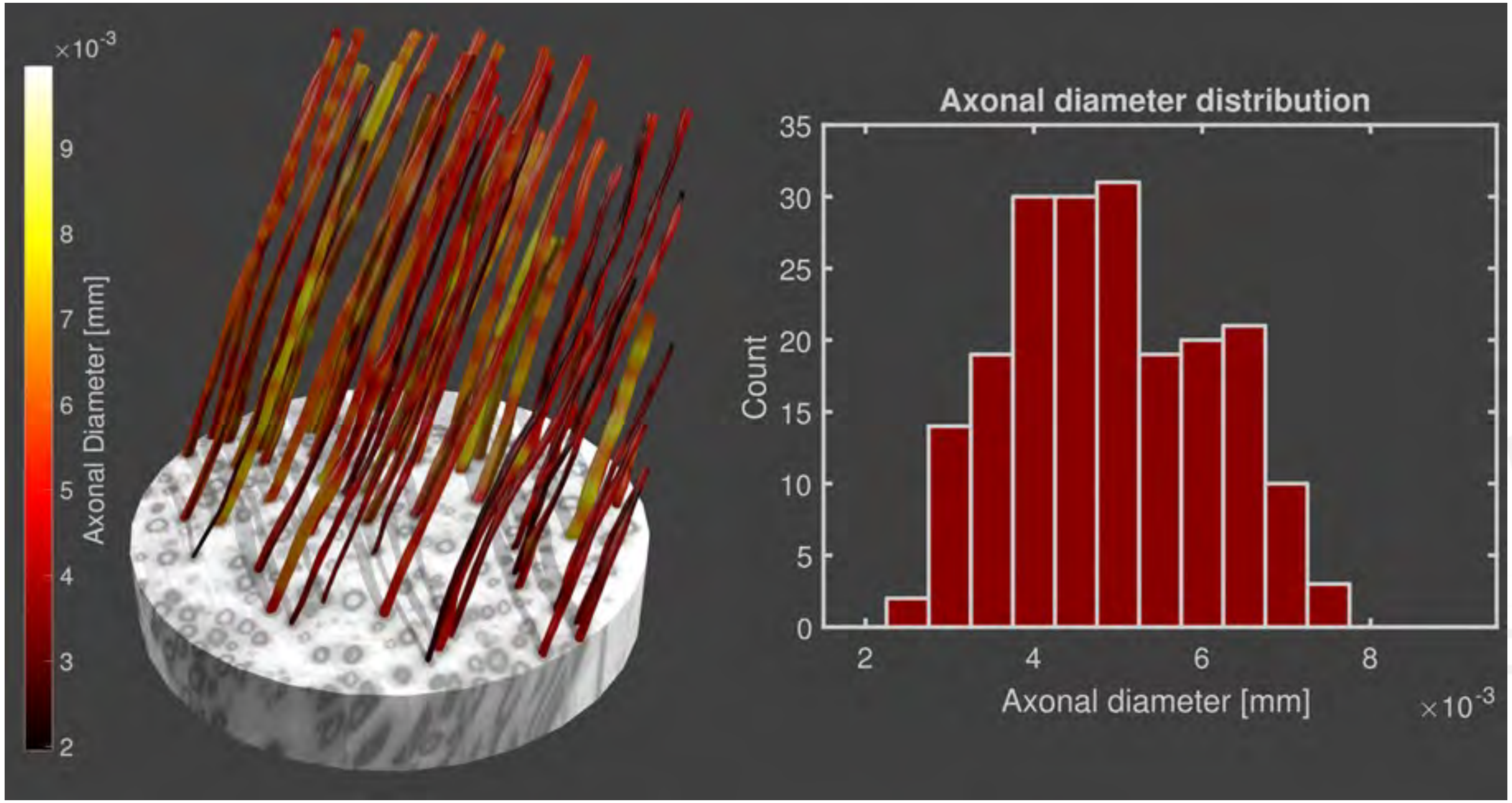
# Nerve tracking, volumetric results





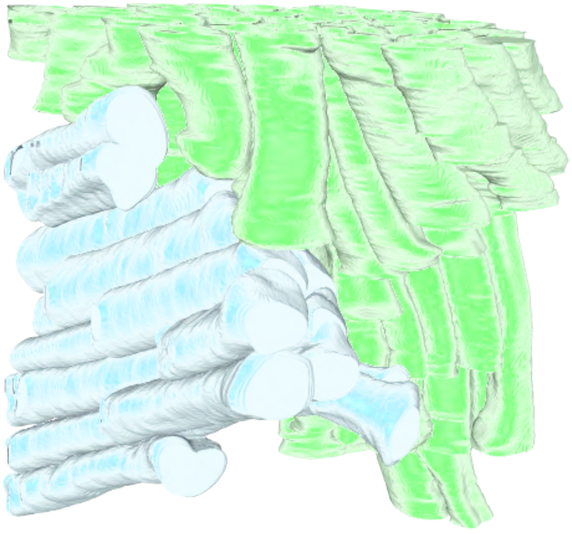
We can investigate myelin thickness on the both side of node of Ranvier.

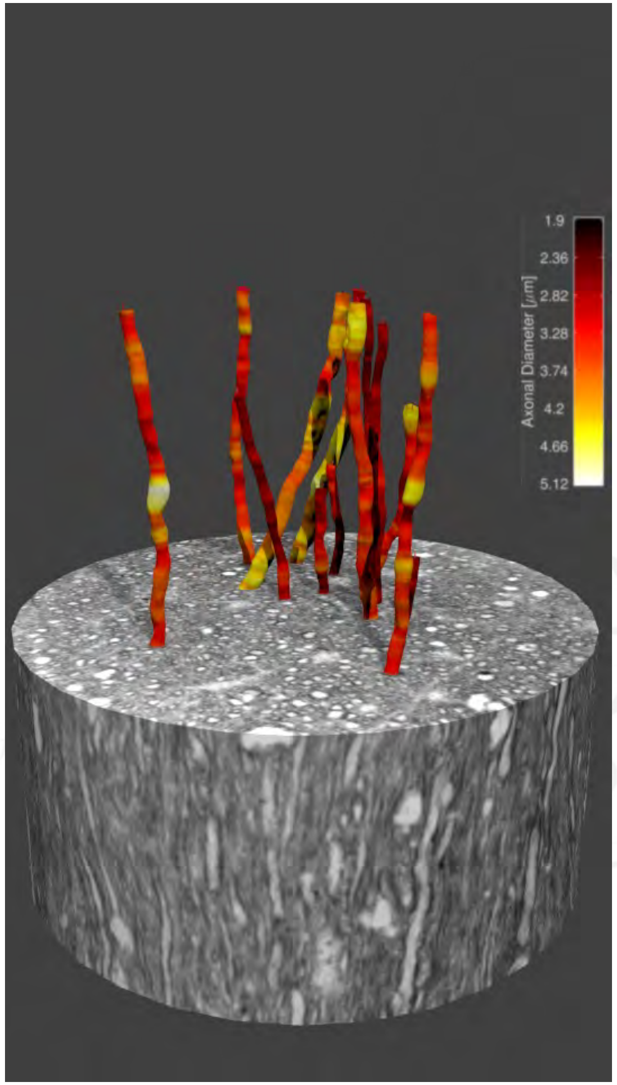
# Nerve tracking, volumetric results




We can investigate distribution of axonal diameter.

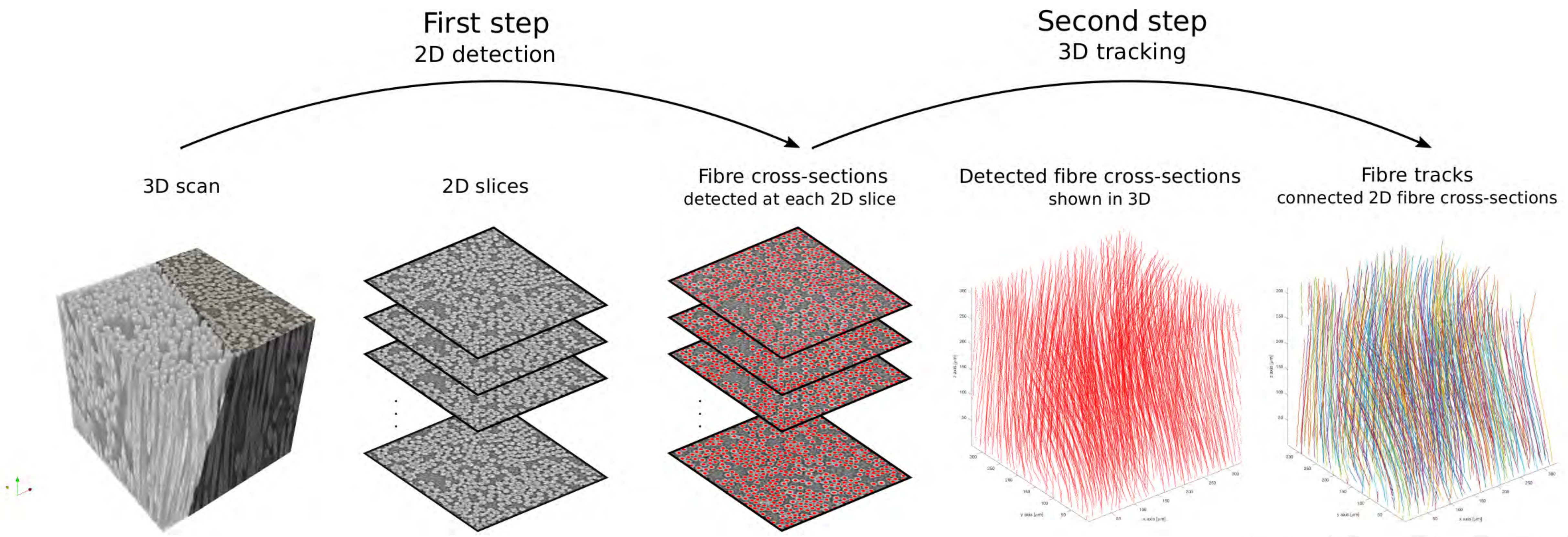
# Similar analysis using deformable models



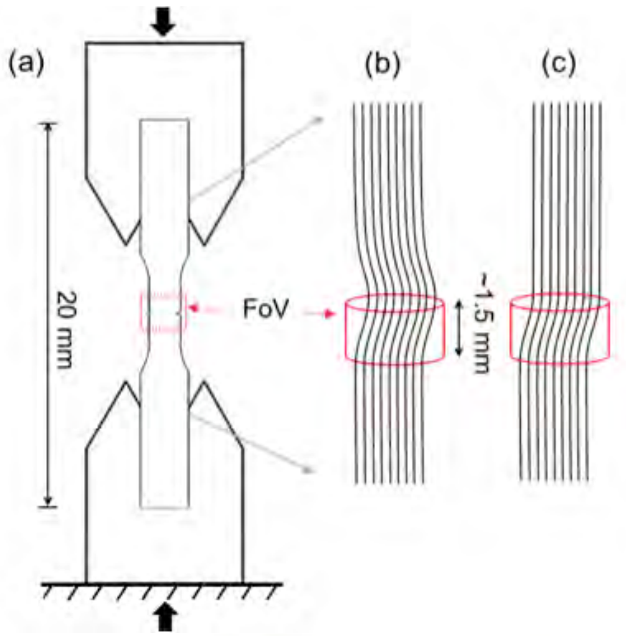


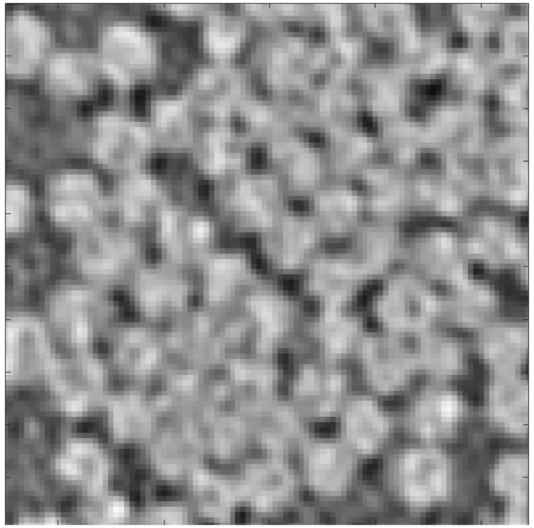


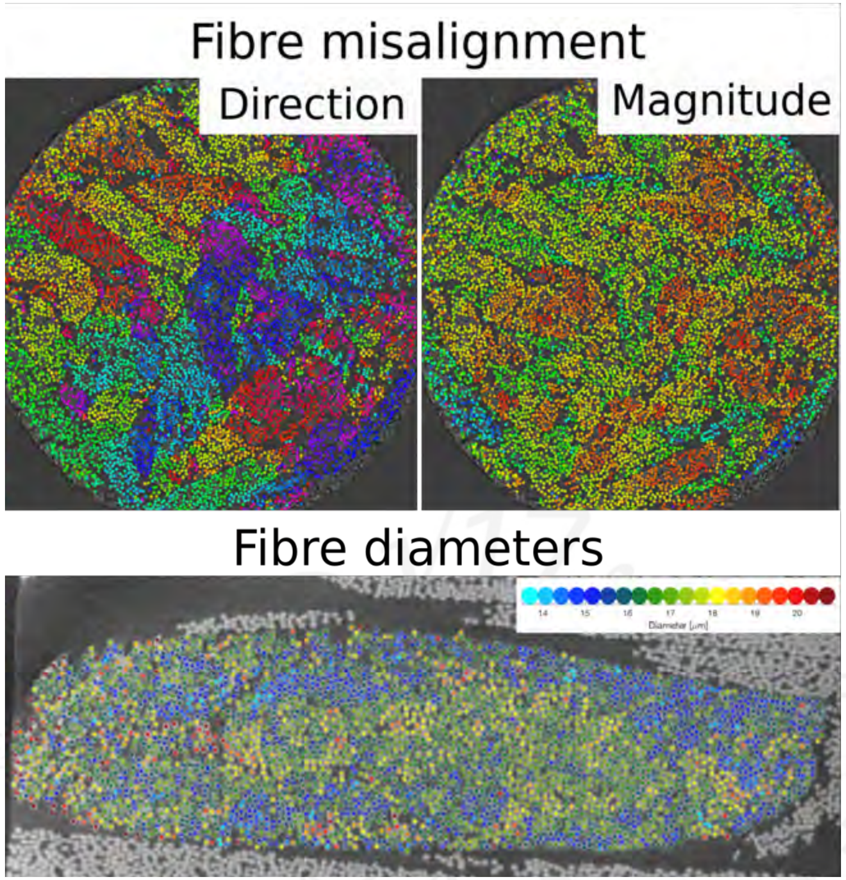
# Composite fiber analysis

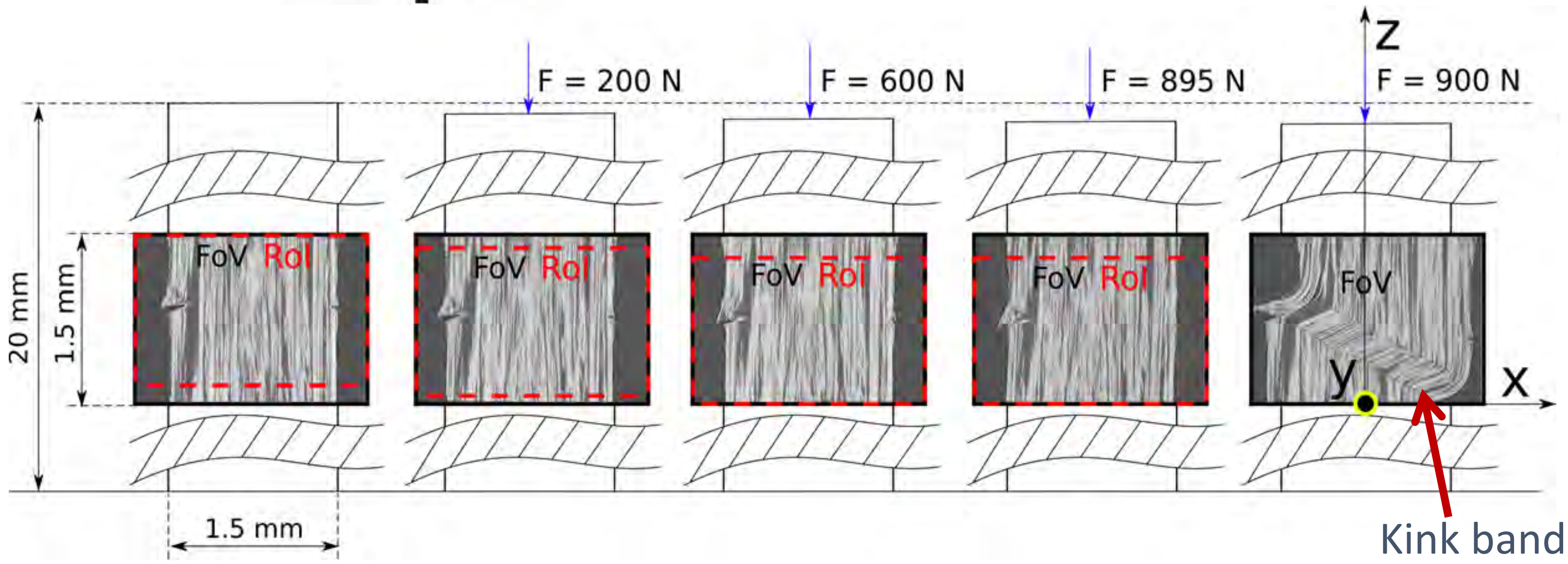


# Composite fiber analysis

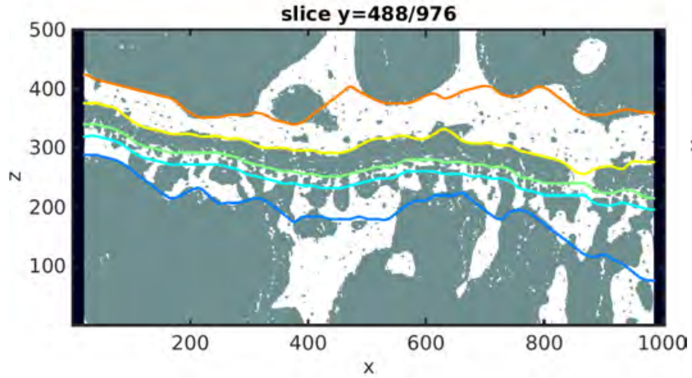


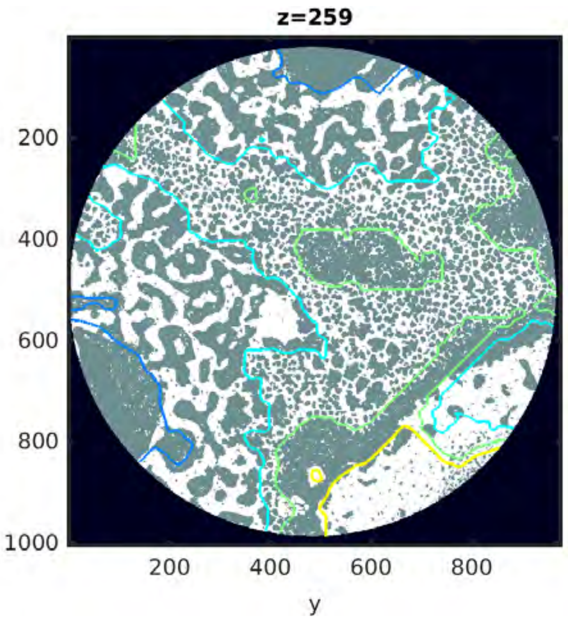





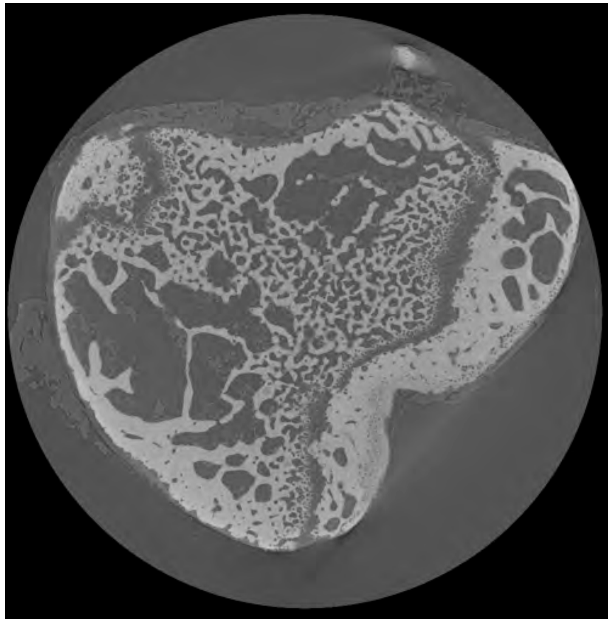



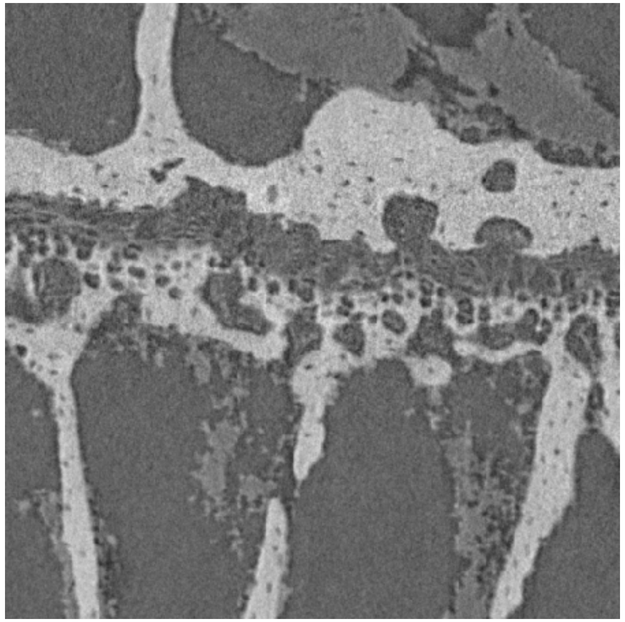
# Bone analysis

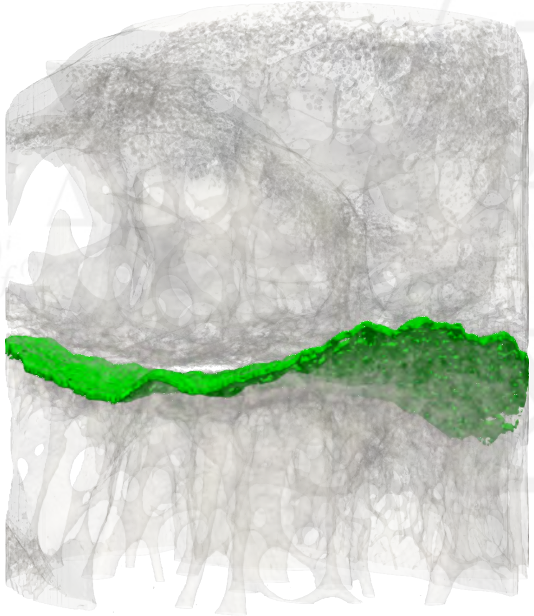


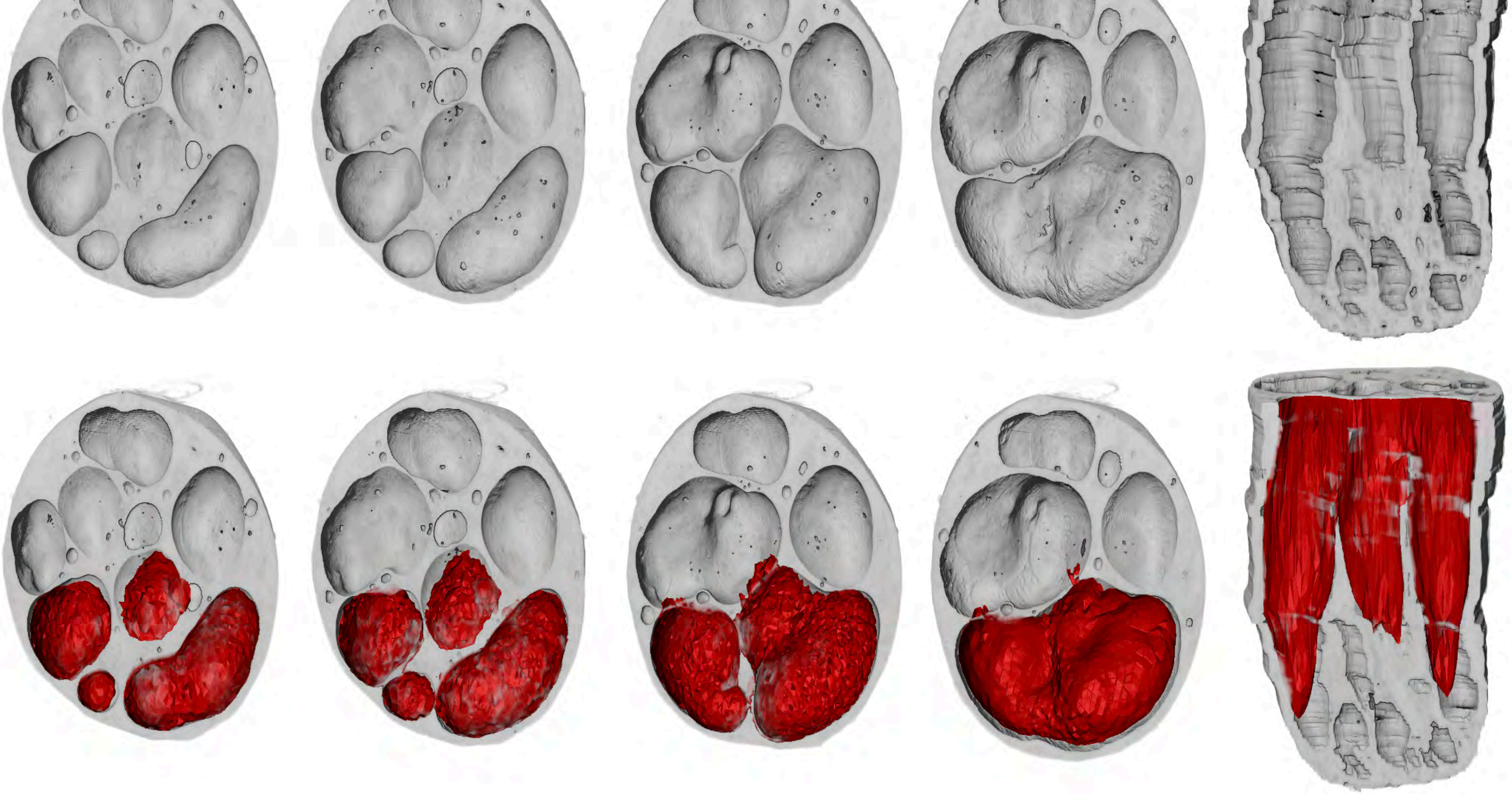

Approach:
Segment textures
Find layers
Quantify structures



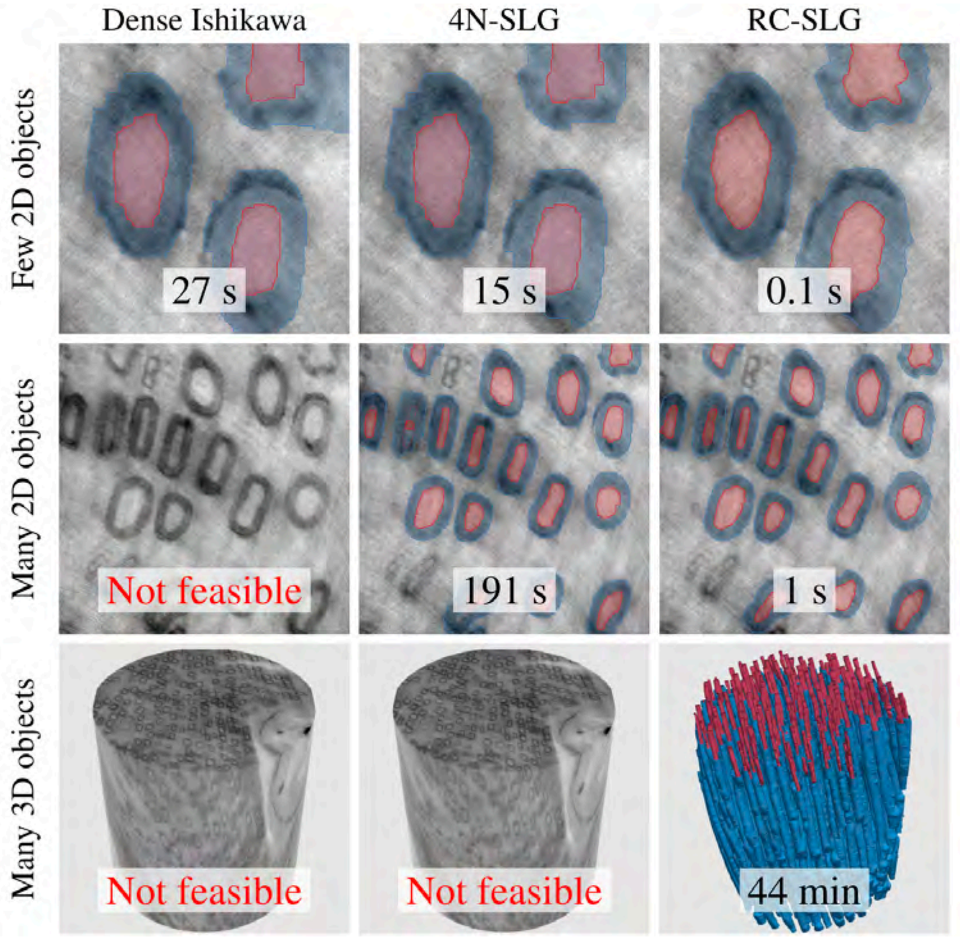


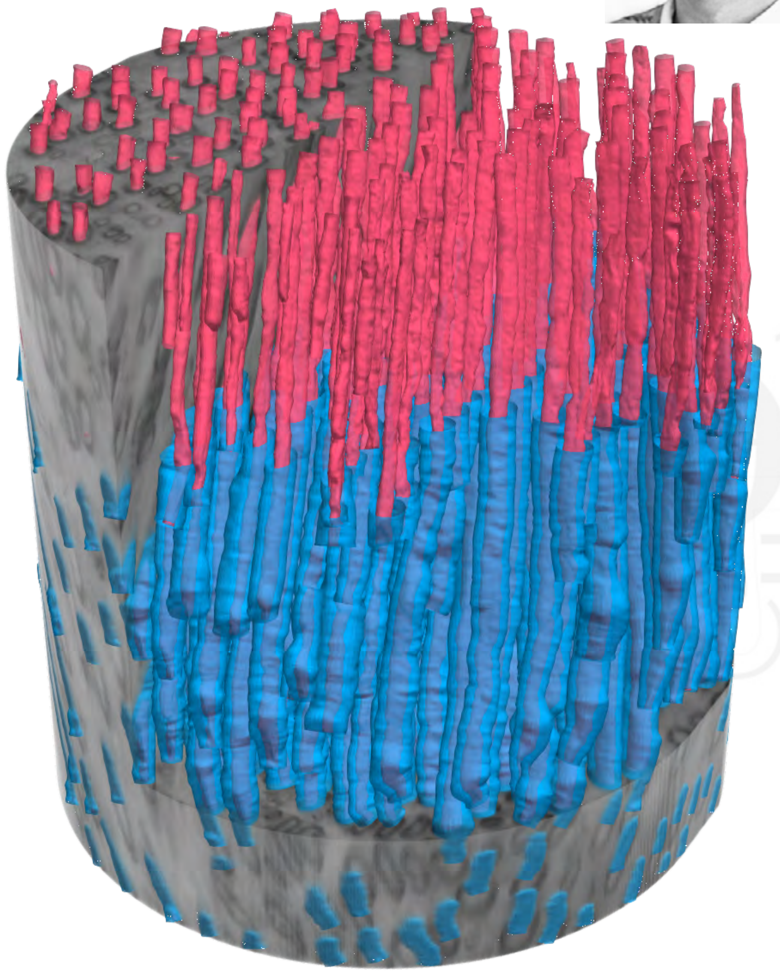




# Sparse Layered Graph for Large-scale Segmentation



The *vision* is to be a **regional science** hub within **image analysis and software** related to **X-ray imaging** in general – the leading one of its kind in Europe

## Mission

- Support beamlines at MAX IV
- Support local imaging facilities
- Ensure that image analysis is not that bottleneck in imaging

## Basis

- Duration for 10 years – establish an international lead on image analysis
- Start-up phase of 3.5 years – funding from RegionH
- Headed by DTU Compute and (to be) located in the 3D Imaging Center and co-located at KU, LU and MAX IV

QIM

## Collaboration with scientists

- We are ready to start collaborations with scientists using 3D imaging
- We are building up the repository of tools
  - Based on case studies
  - Driven by user needs
  - Aim that users perform analysis
- Users are experts in the material
- Various levels of experience
- User guided analysis
- Advanced tools for analysis


[qim.compute.dtu.dk](qim.compute.dtu.dk)

# QIM: Status

QIM homepage

- http://qim.dk/
- Under construction
- Sharing of analysis tools and resources
- Information about use of QIM

Approach

- Open source – no restrictions on use and available for all
- Commercial software (Matlab, Avizo, VGStudio, etc.)
- Pipelines – Jupyter notebooks
- Access to computing facilities – LUNARC
- Access to support – staff
- Focus on structural quantification, visualization and interface to reconstruction and modeling
- Example: https://learnmore1.imm.dtu.dk/hub/login

# Perspective for AI

- Image analysis for 3D tomography – not established like medical image analysis
  - Images are large
  - Image data is non-standard

- AI/machine learning can help with
  - Image segmentation
  - Higher throughput – from experiment to result to result
- Needs
  - Methods that require little training data
  - Visualization of data and results
  - Interaction with data – annotation and correction