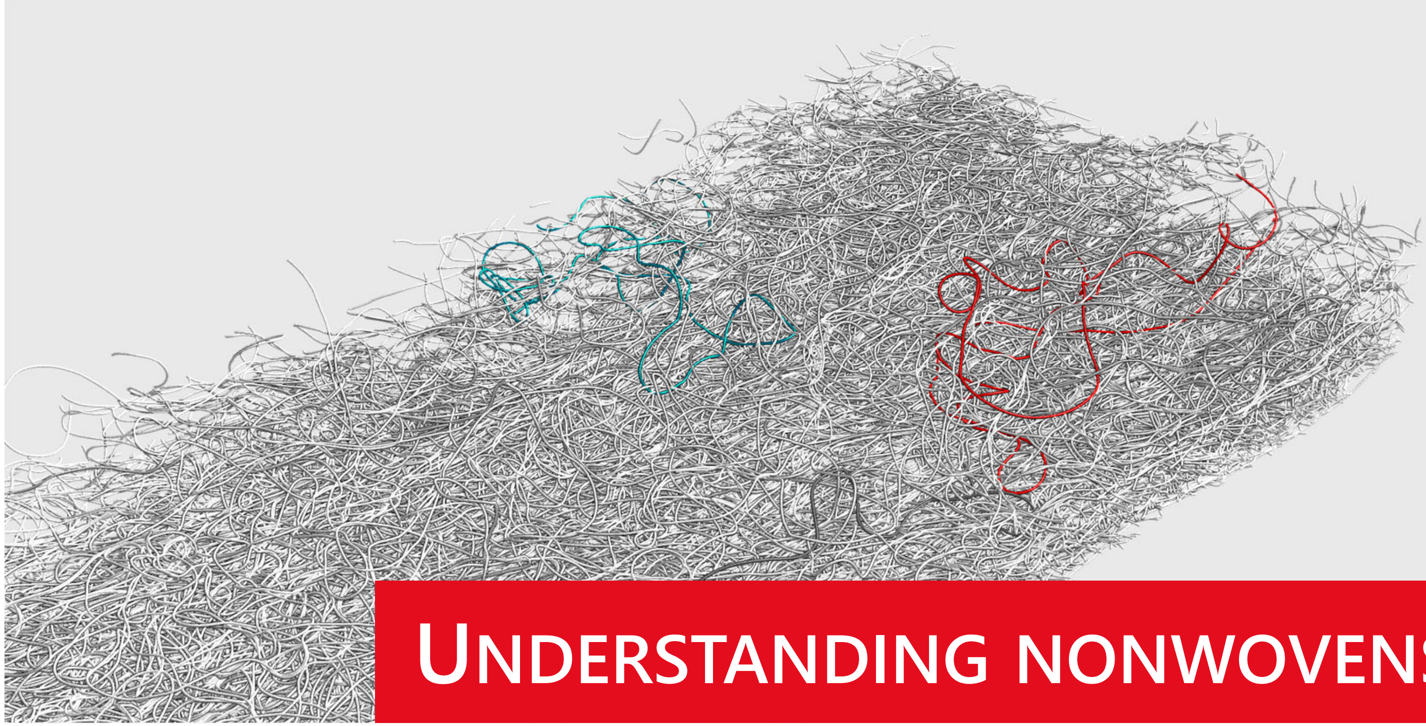

GeoDict
The Digital Material Laboratory

Understanding nonwovens

FiberFind: Machine learning-based segmentation and identification of individual fibers in µCT images of fibrous media

Andreas Grießer, Rolf Westerteiger, Steffen Schwichow, Andreas Wiegmann, Math2Market

Wesley DeBoever, Bruker µCT

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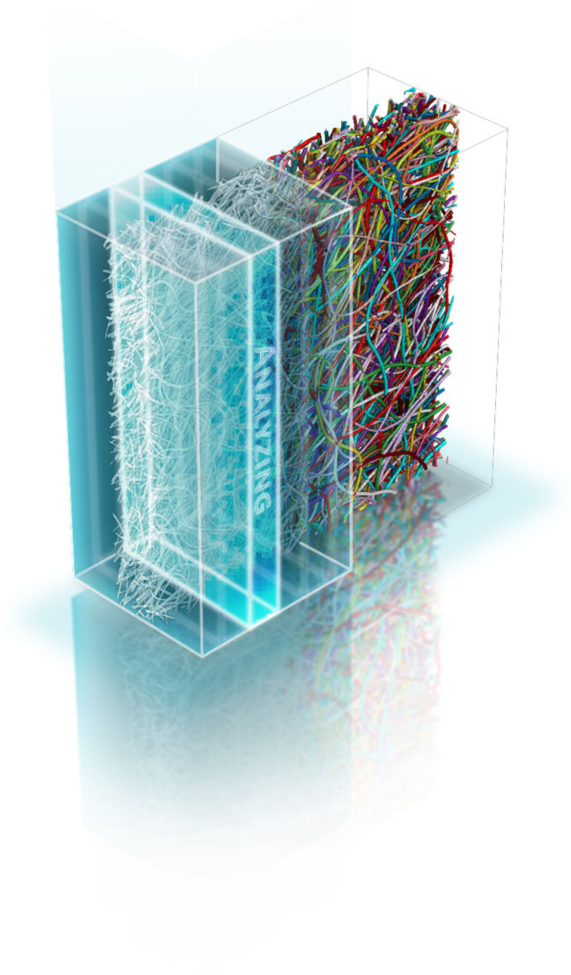
Understanding nonwovens using Machine learning

GeoDict



GeoDict 2018: Existing methods measure

- fiber diameter distribution (**FiberFind**)
- fiber orientation (**FiberFind**)
- pore size distribution (**PoroDict**)

GeoDict 2019: FiberFind-AI with Machine learning

- individual fiber geometry (**FiberFind-AI**)
- individual fiber lengths
- individual fiber diameters
- individual fiber orientation
- statistics of the above better than in 2018

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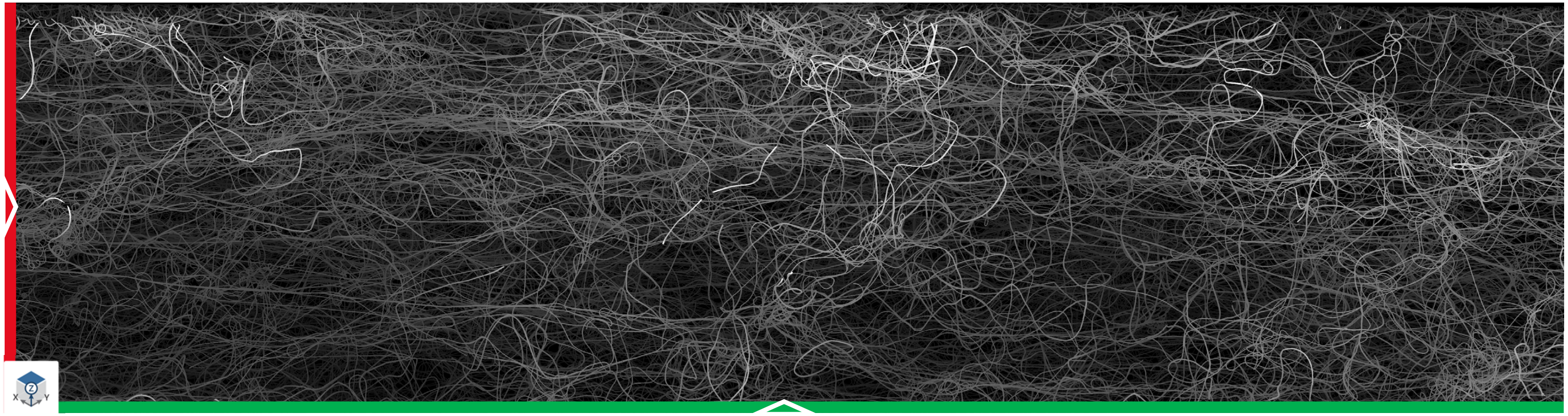
Overview of Sample Structures

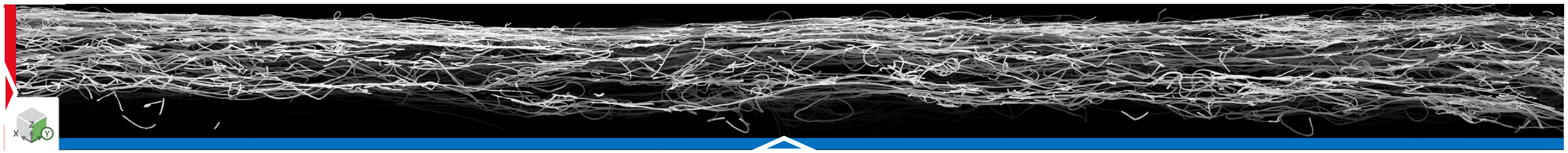
- Aim: Quantify differences in nonwoven samples

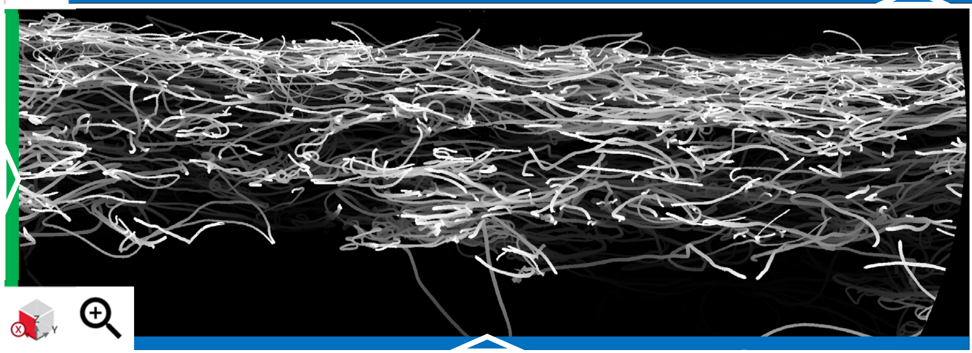
Sample Name	Resolution	Physical dimensions	Voxel dimensions
A	2.4µm	43.9 x 11.6 x 4.1 mm^3	18,310 x 4,816 x 1,704
B	2.7µm	42.2 x 10.9 x 4.8 mm^3	15,619 x 4,032 x 1,796

- Scanned by Bruker microCT on SkyScan 1272
- Analyzed by Math2Market using GeoDict

Sample A – 2D view



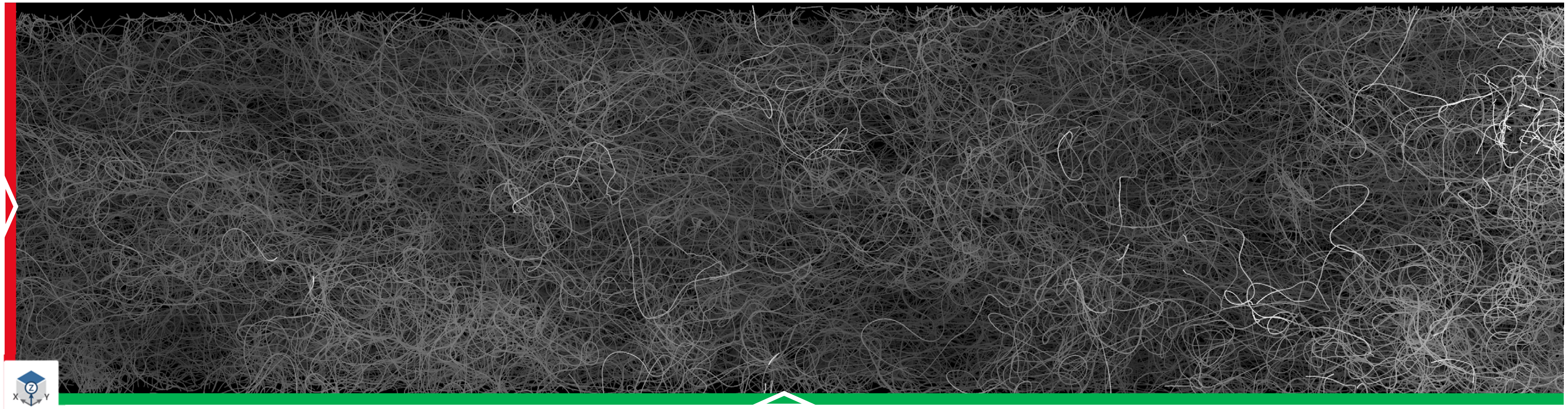




Reso-lution	Physical dimensions	Voxel dimensions
2.4µm	43.9 x 11.6 x 4.1 mm^3	18,310 x 4,816 x 1,704

SAMPLE B – 2D VIEW

GEODICT



Resolution	Physical dimensions	Voxel dimensions
2.7µm	42.2 x 10.9 x 4.8 mm^3	15,619 x 4,032 x 1,796

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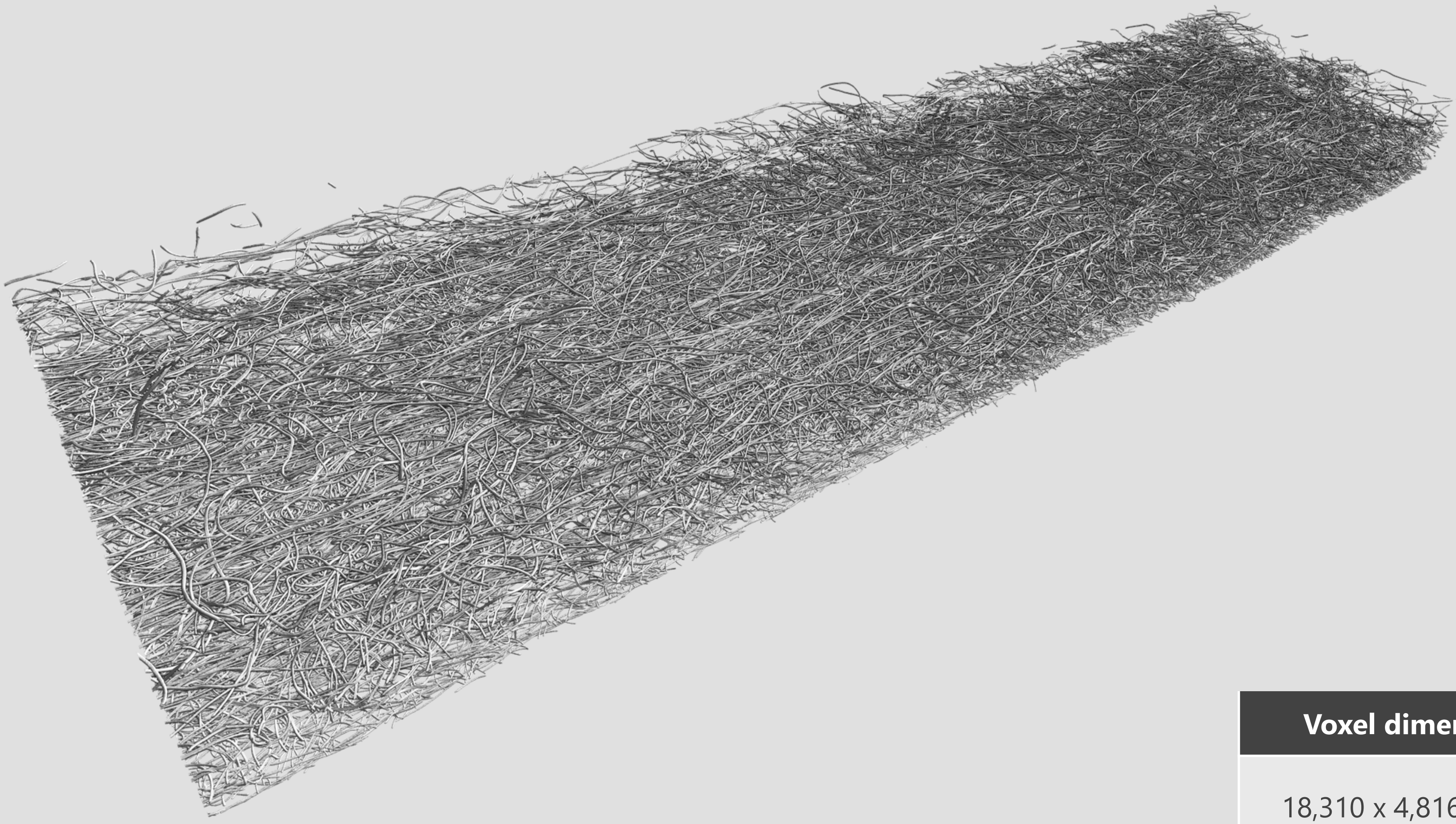
Sample A – 3D view

GeoDict



Voxel dimensions
18,310 x 4,816 x 1,704

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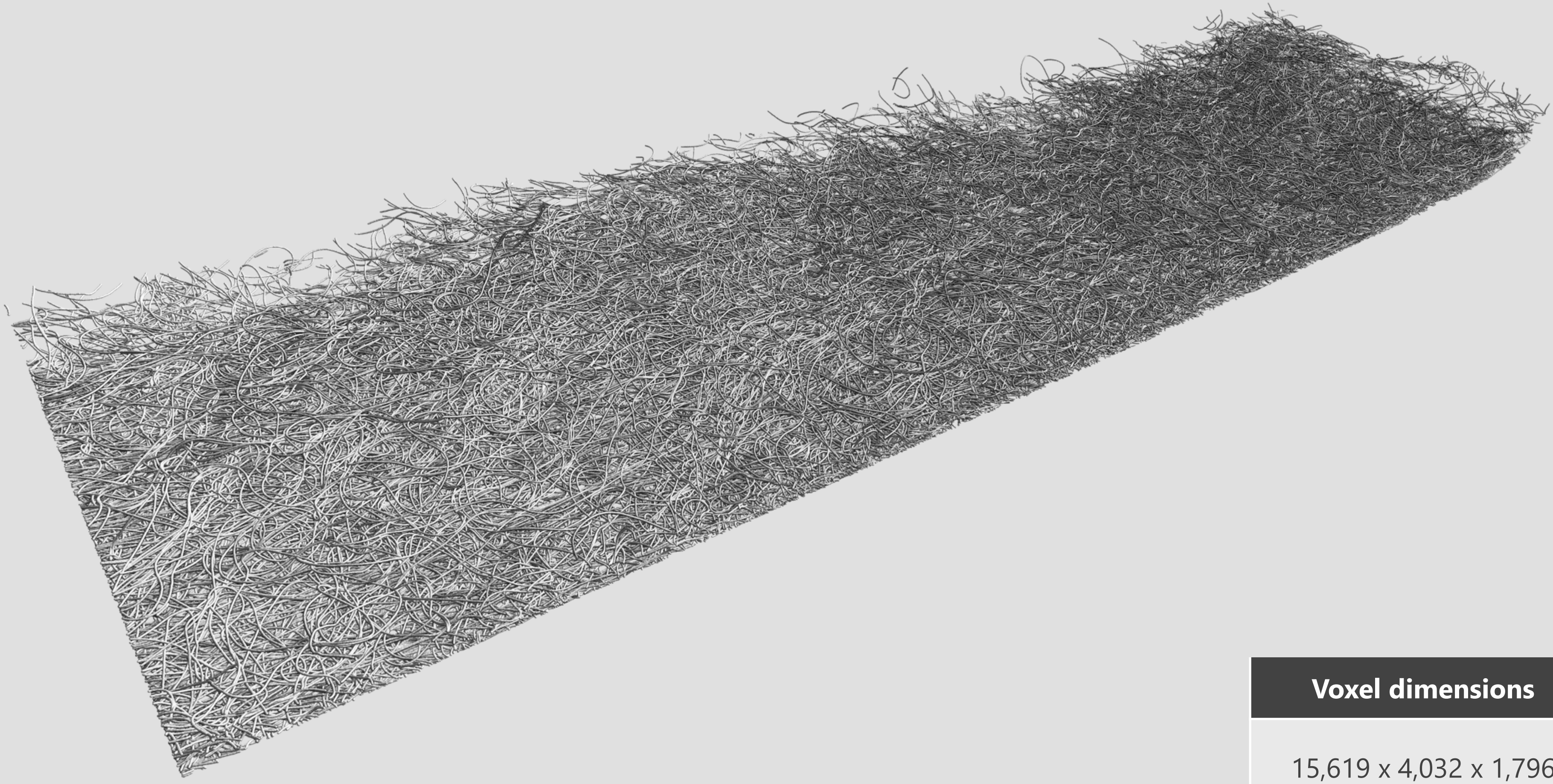
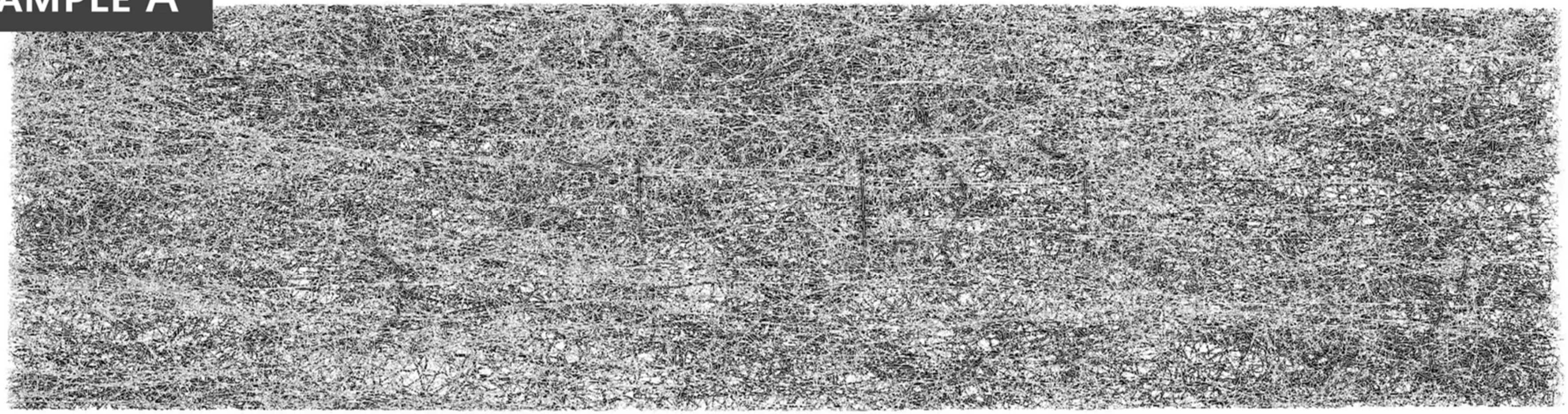
Sample B – 3D view

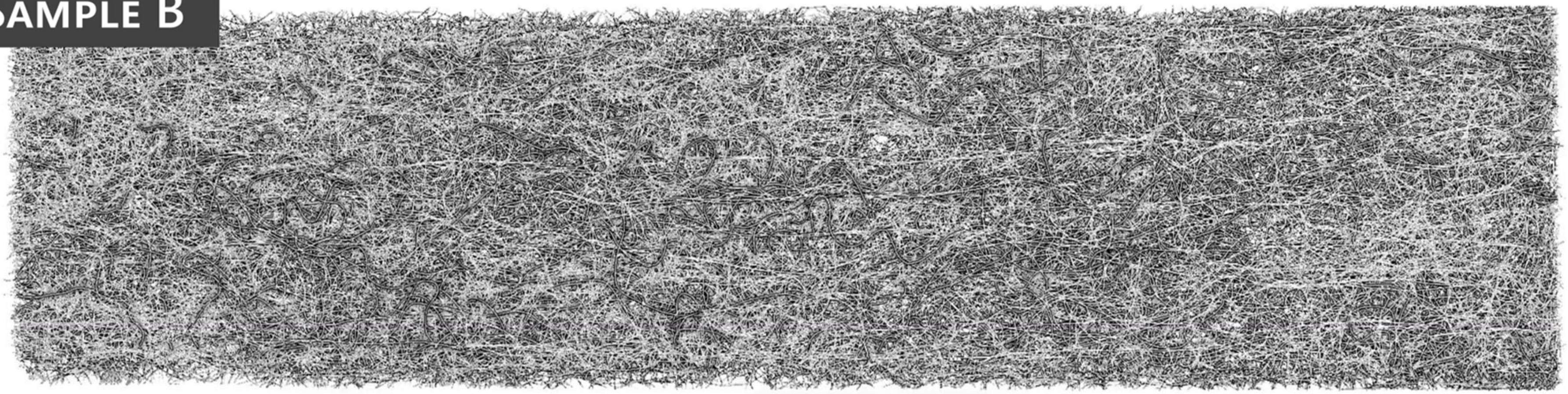


Voxel dimensions
15,619 x 4,032 x 1,796

Sample A



Sample B



How the technology works

GeoDict

1. Generate synthetic GeoDict models that look similar to the real material to be analyzed.
2. Models contain full information: Exact geometry for each fiber is known.
3. Train Neural Network (NN) on synthetic material models.
4. Use Neural Network. Apply trained Neural Network to µCT scan to label centerline of fibers.
5. Postprocess Centerlines into analytic representations.

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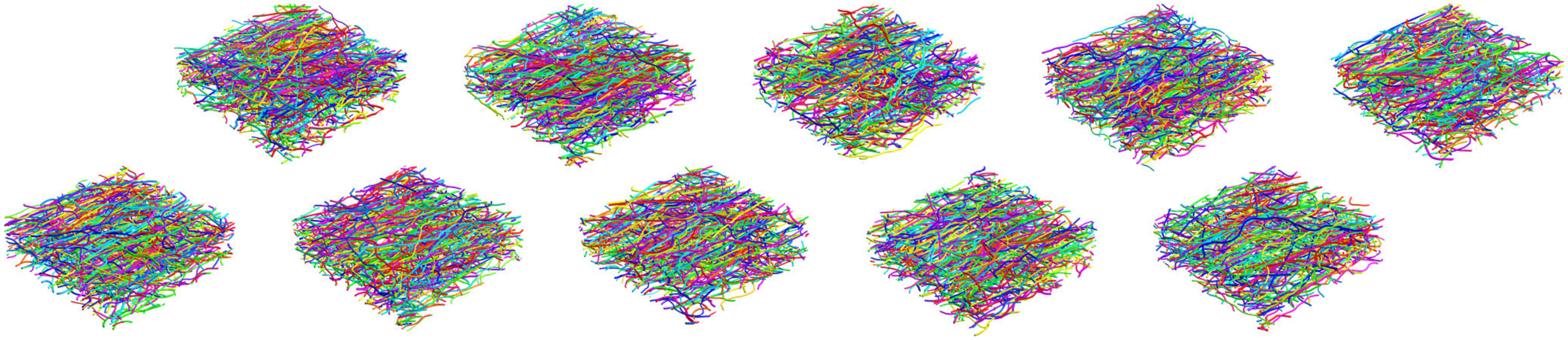
Digital Twins provide ground truth

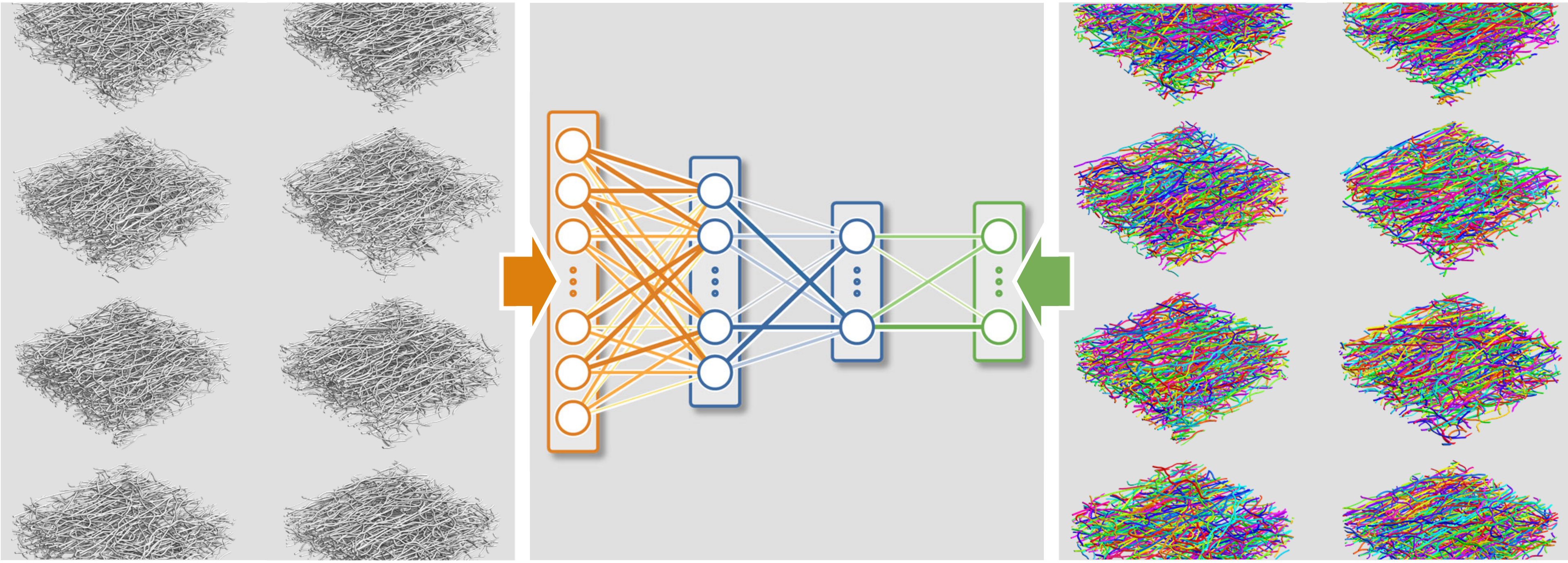


Training Data: Use GeoDict's fiber modelling capabilities:

- Model 10 random digital siblings (512x512x256 Voxels) as training data
- Vary fiber curvature, orientation, length and diameter
- Corresponds to ~1 billion solid voxels as training data points

Training Phase of NN

GeoDict



Dozens of binarized GeoDict models

Neural Network

Dozens of labeled GeoDict models

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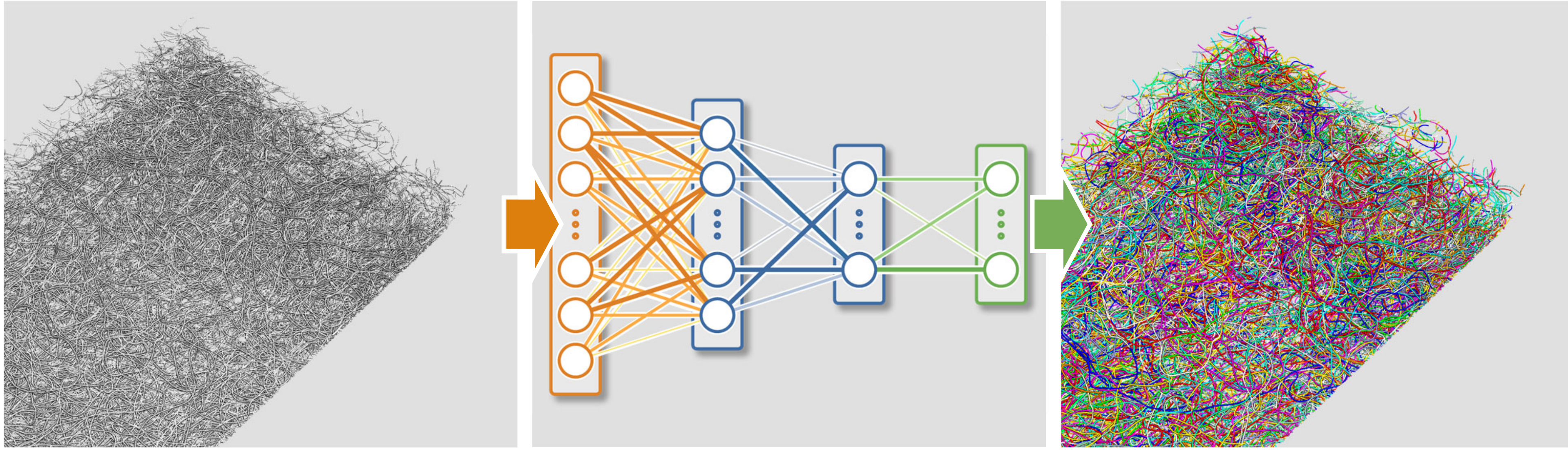
Fiber identification by NN: Summary

GeoDict



Training: NN learns to label centerlines from input and output

- input: GeoDict Model: binary image
- output: GeoDict Model: labeled fibers

Usage: NN predicts centerlines from input

- input: µCT data: binary image
- output: µCT data: labeled fibers

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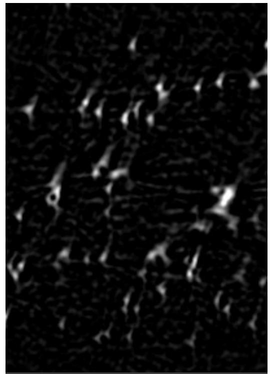
Fiber identification challenges

Sample preparation: Scan 5 cm x 1 cm, 2.4 µm resolution

- 6 µm resolution did not resolve fibers well enough
- Fibers were thinner than expected


Low resolution


Motion blur

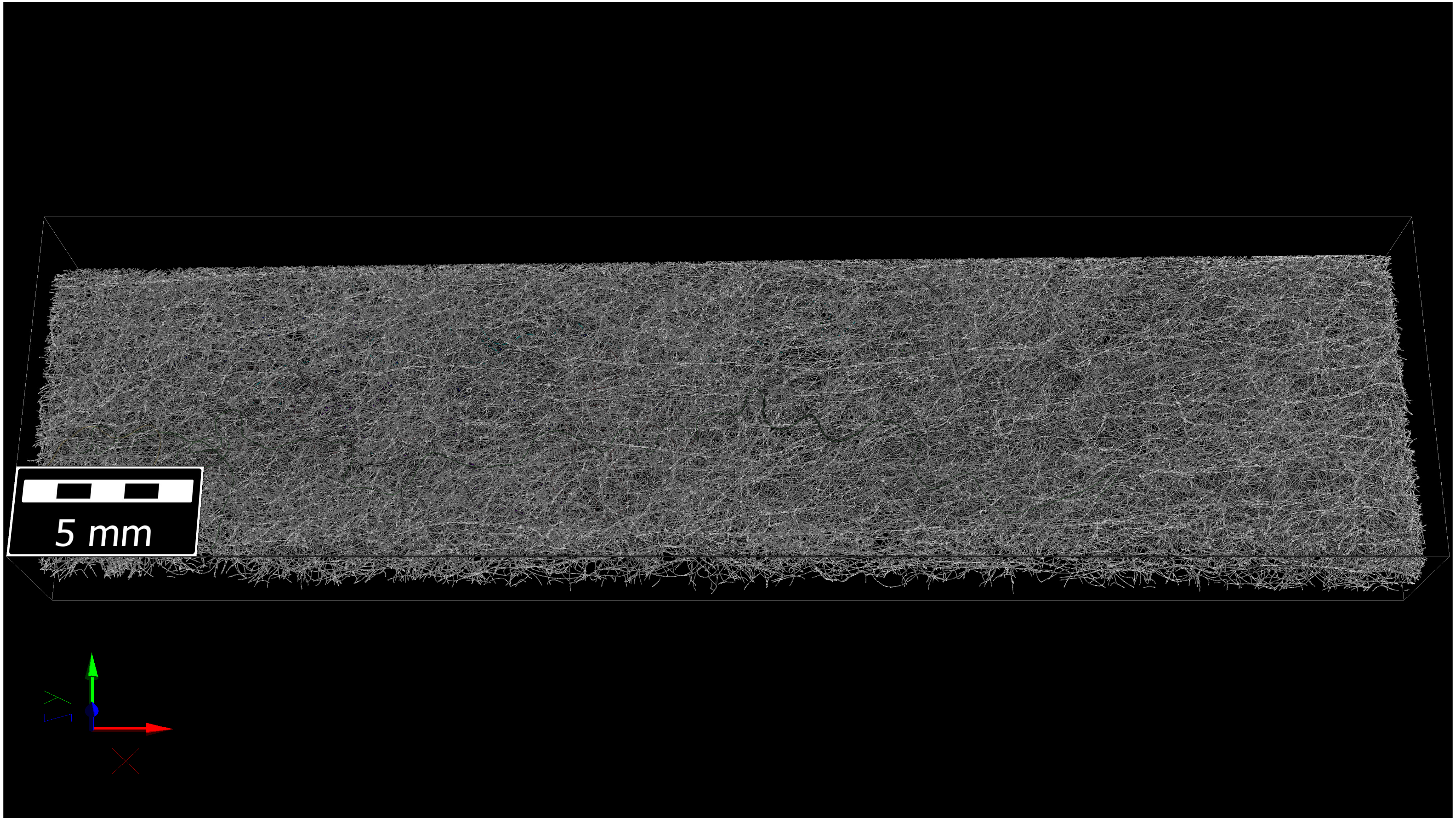
Very large data sets

- Up to 18,310 x 4,816 x 1,704 ~ 150 billion voxels
- Required 1TB memory hardware for full analysis
- Required many optimizations in FiberFind algorithms

Varying fiber diameters and shapes

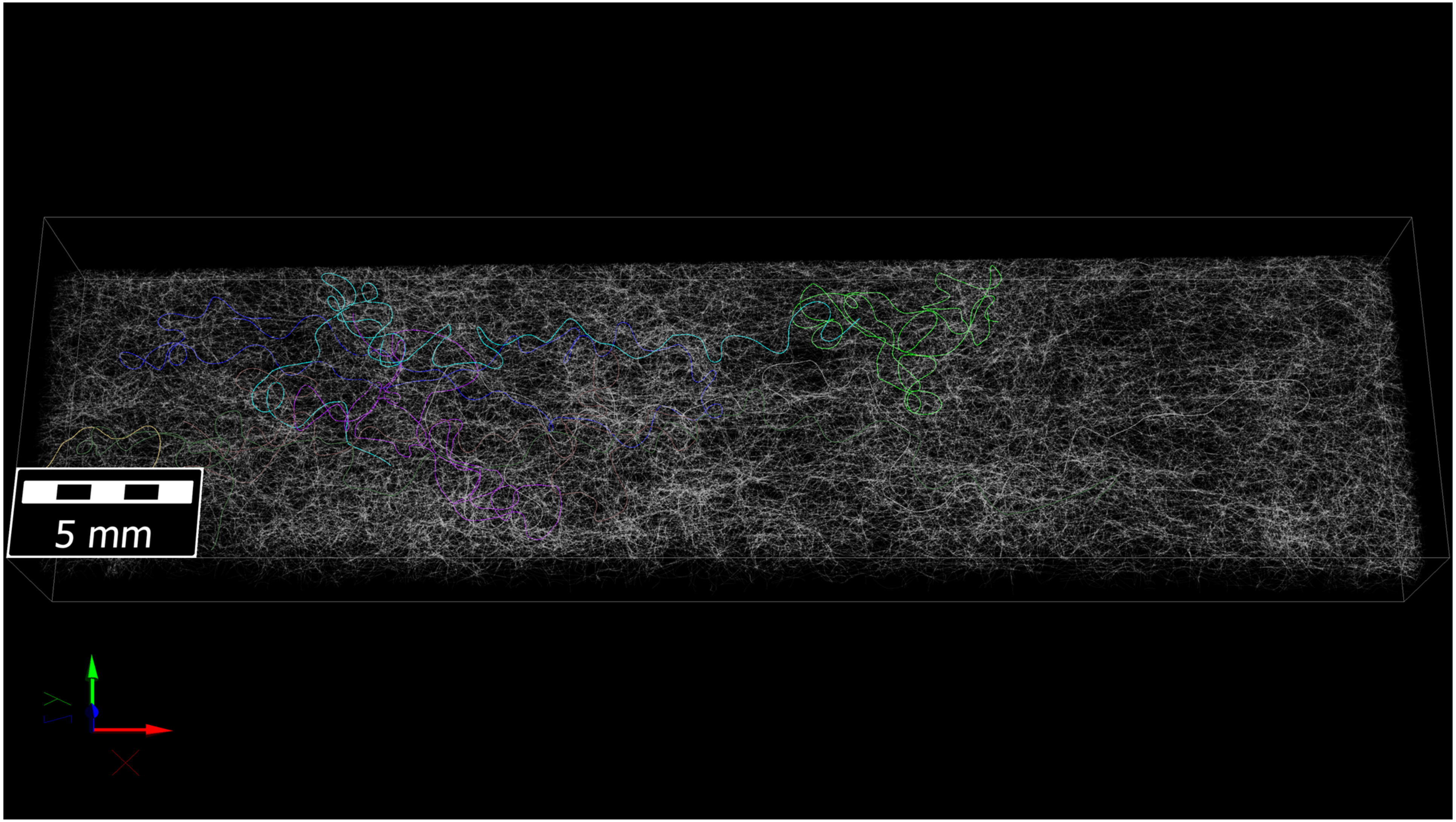
- Round, trilobal, and hollow fibers
- Neural networks (currently) trained only on round fibers

Sample B



SAMPLE B WITH SOME HIGHLIGHTED FIBERS

GEODICT



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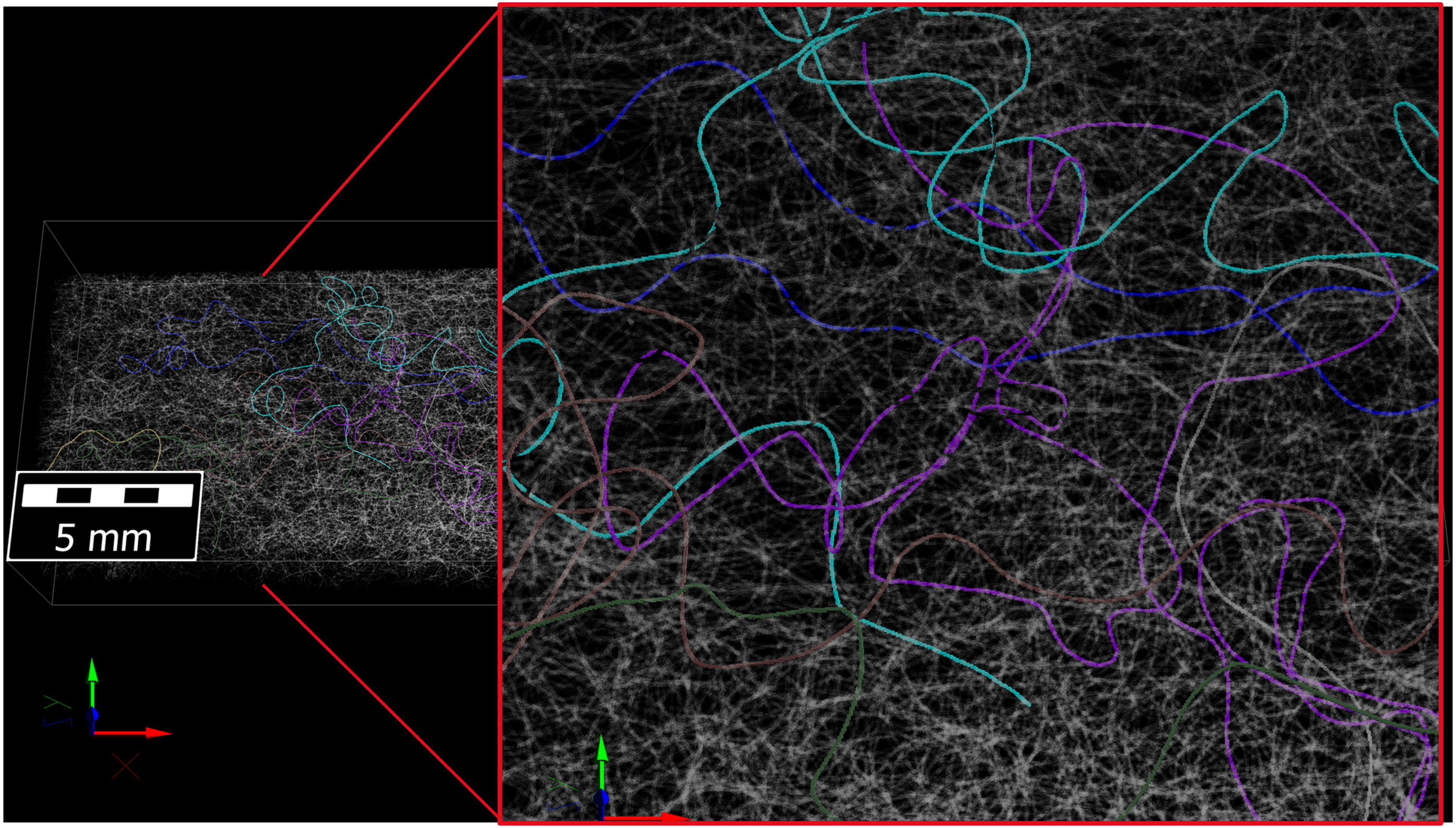
Complete with some highlighted fibers

GeoDict



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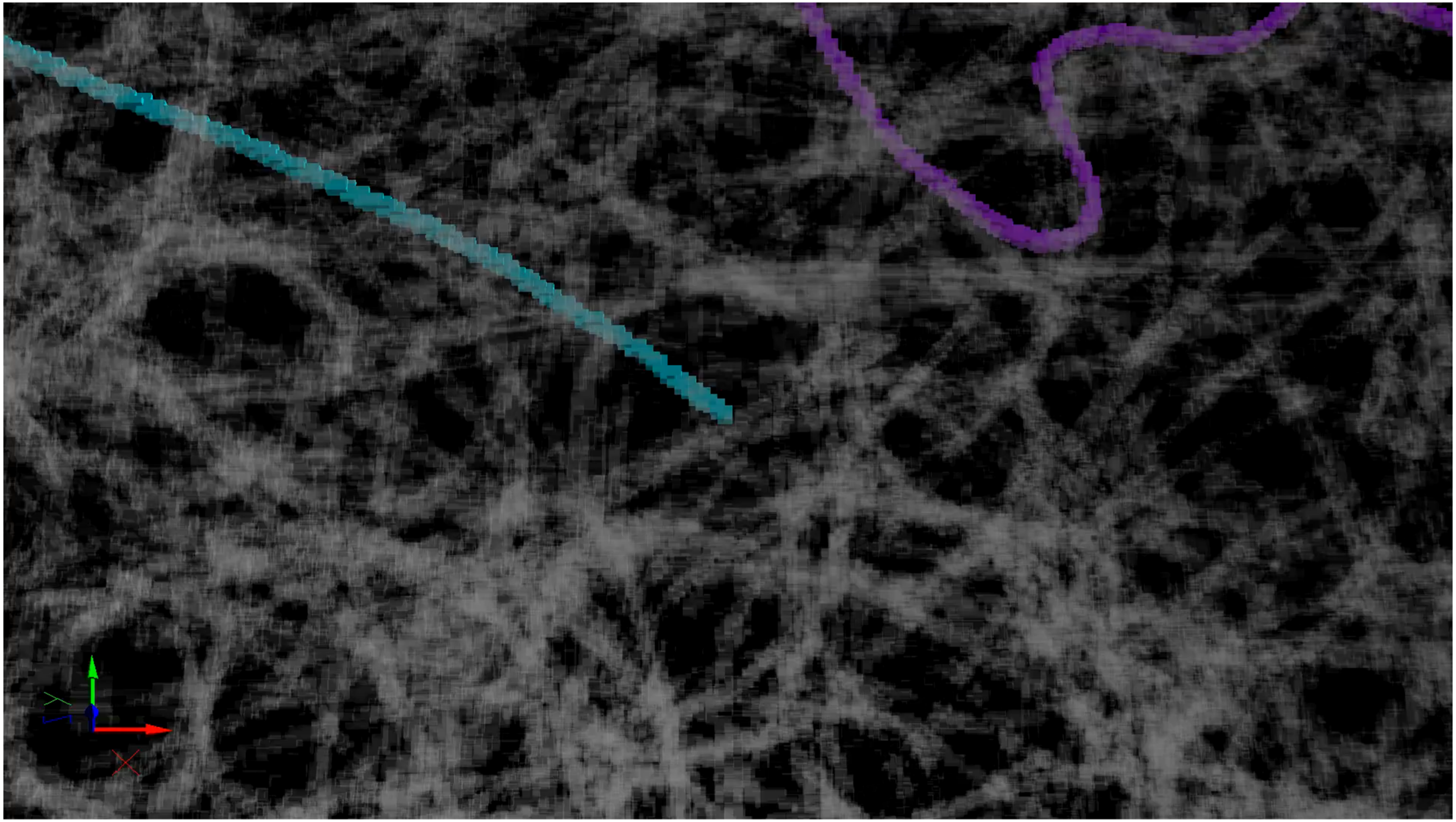
Sample B – Tracking single light-blue fiber

GeoDict



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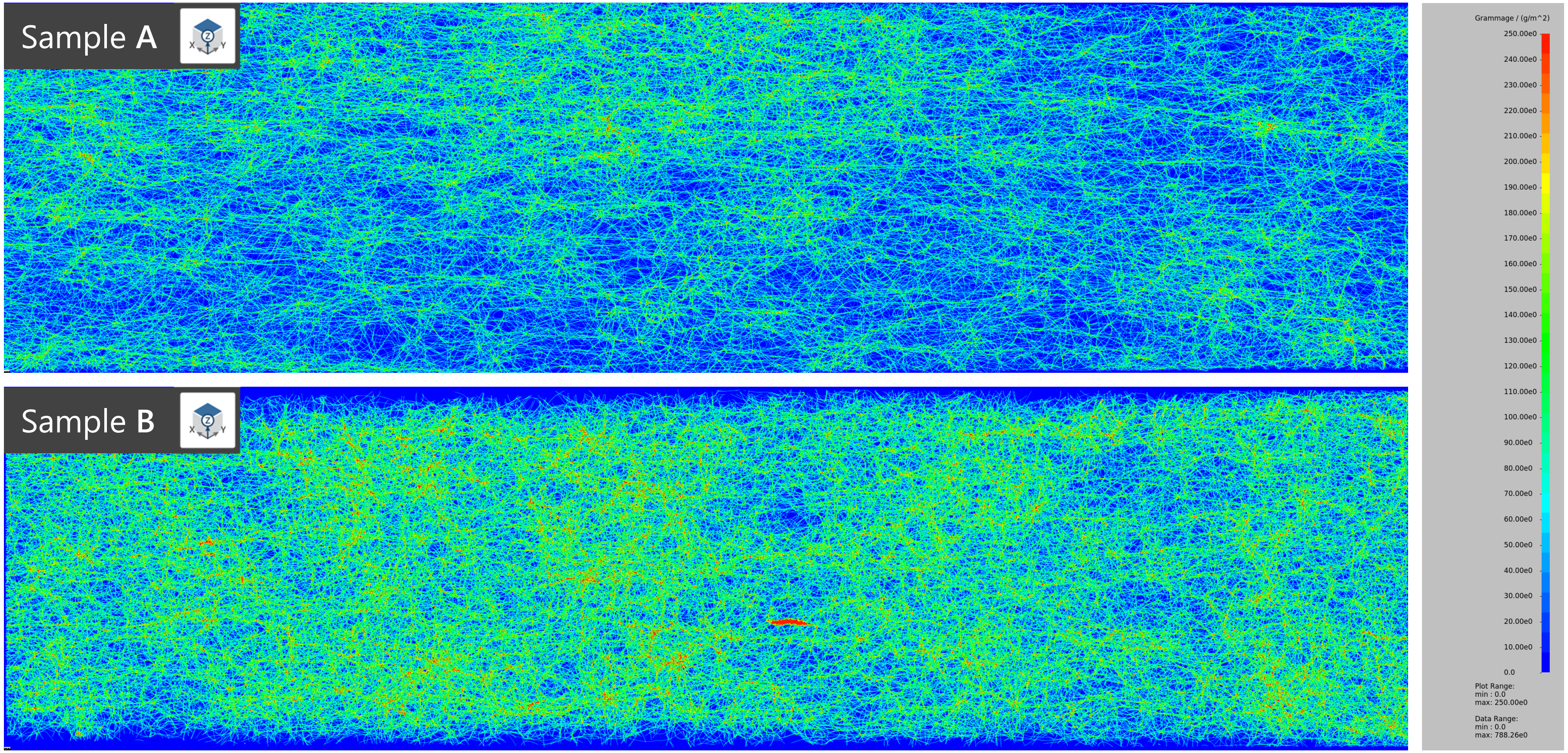
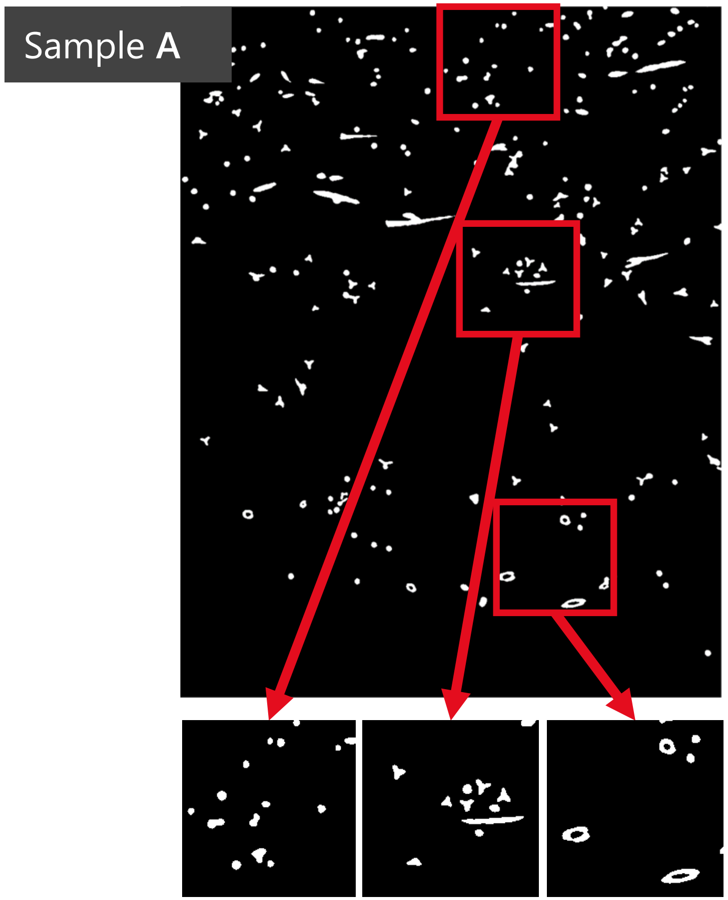
DENSITY MAP (CLOUDINESS)

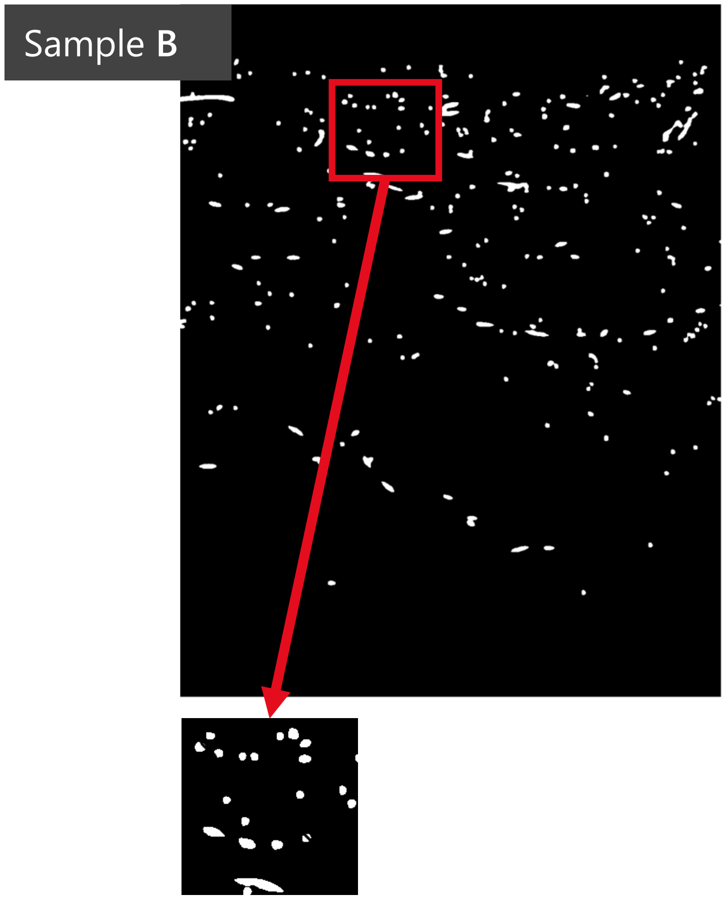


Fiber cross-sections

GeoDict



Round / Trilobal / Hollow



Round

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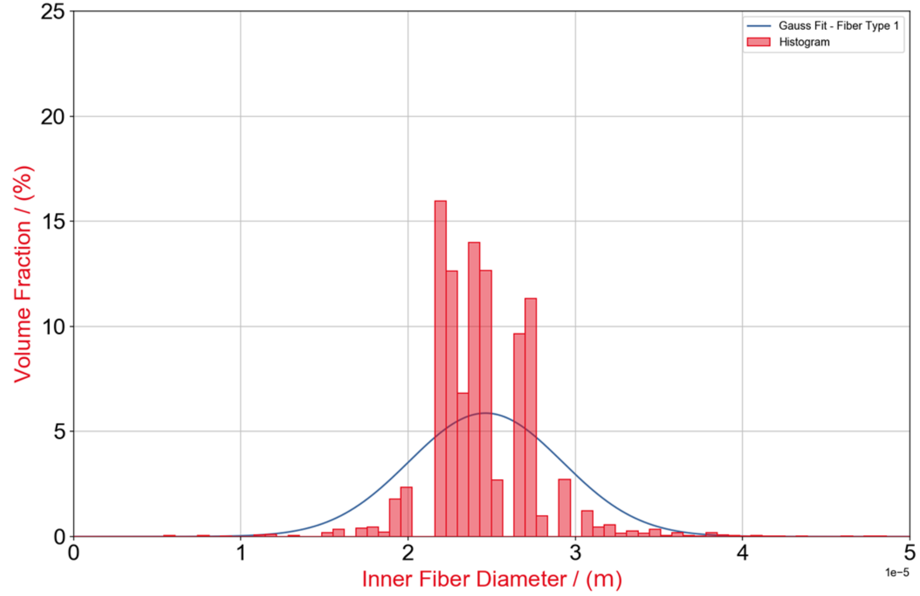
FIBER DIAMETER DISTRIBUTION

GEODICT

Sample A	Sample B	
Not analyzed due to non-circular fiber cross-sections	Average fiber diameter	24.6 µm
	Standard deviation	4.6 µm



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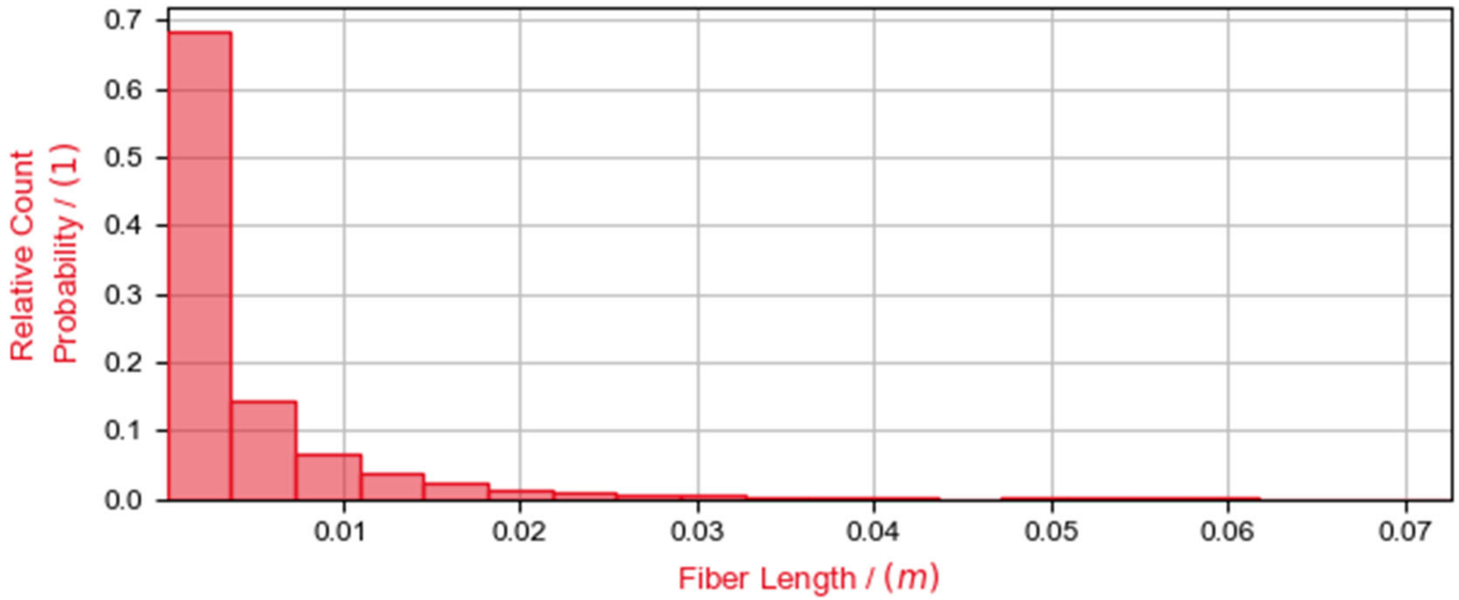
FIBER LENGTH DISTRIBUTION

GEODICT

Sample B	
Average Fiber Length	4.4 mm



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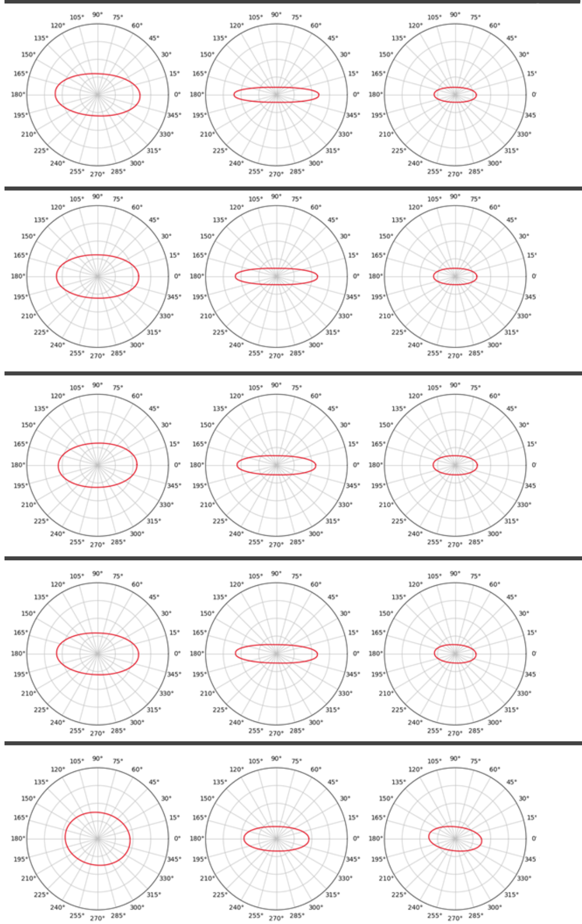
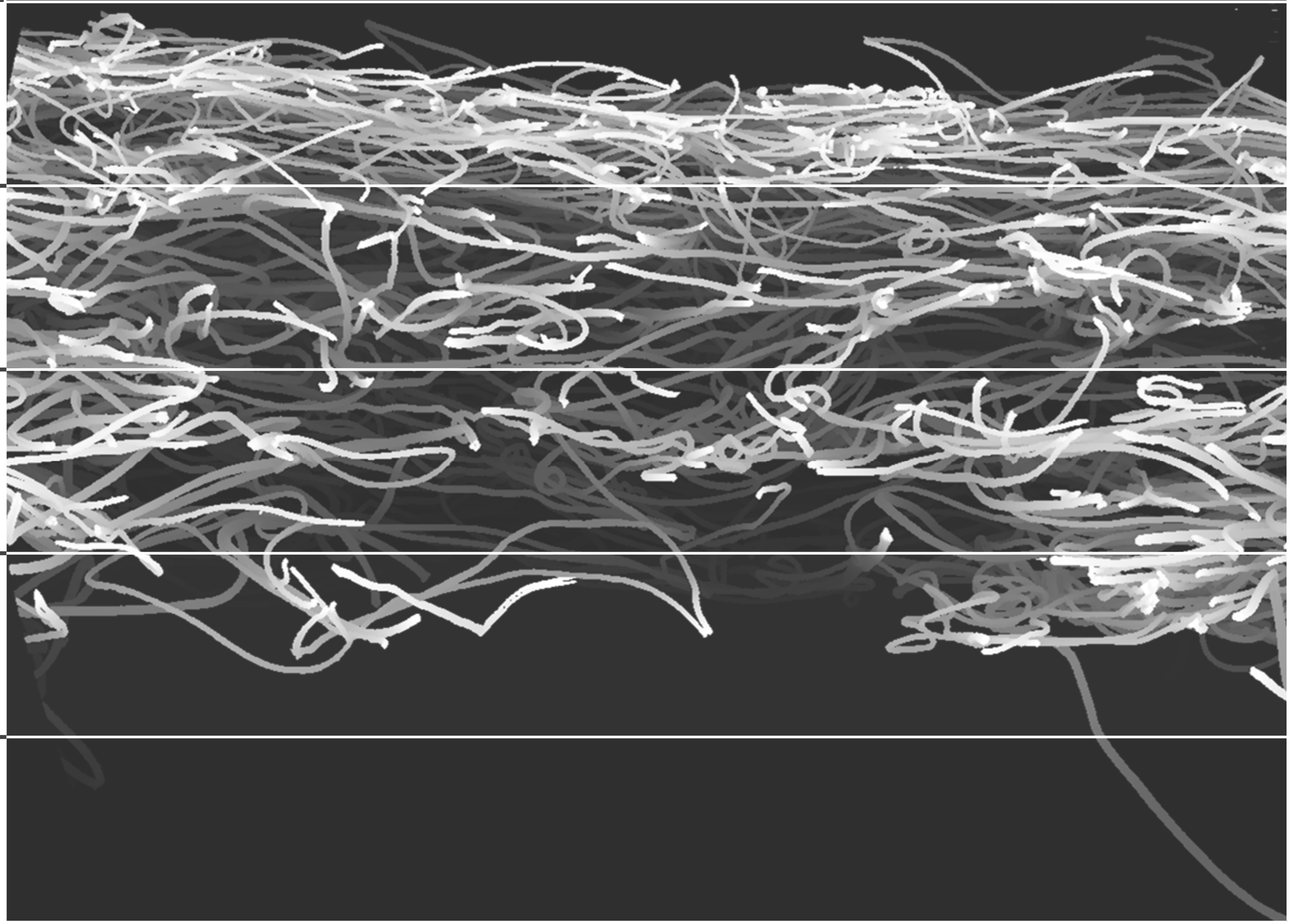
Fiber orientations – sample A

GeoDict

XY	XZ	YZ	View of a section of the surface in the direction of the X axis.





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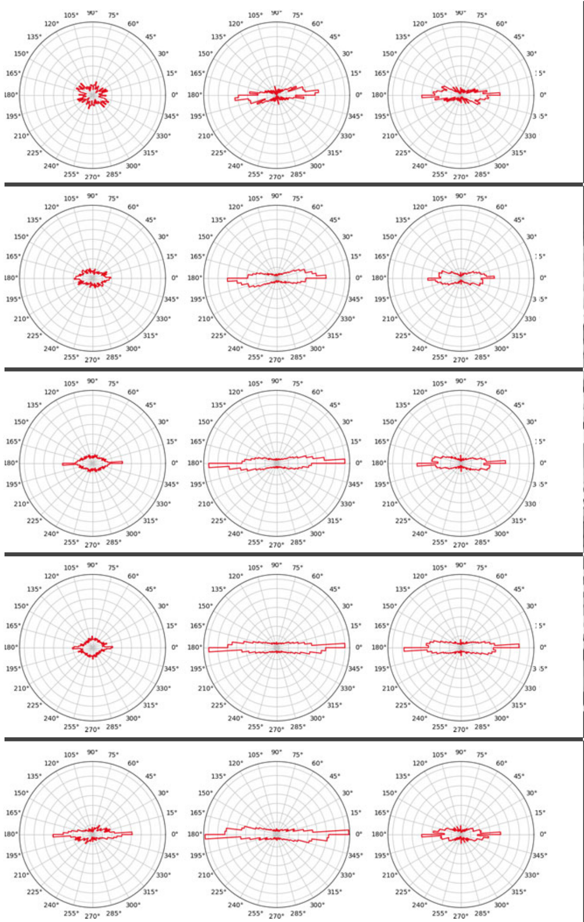
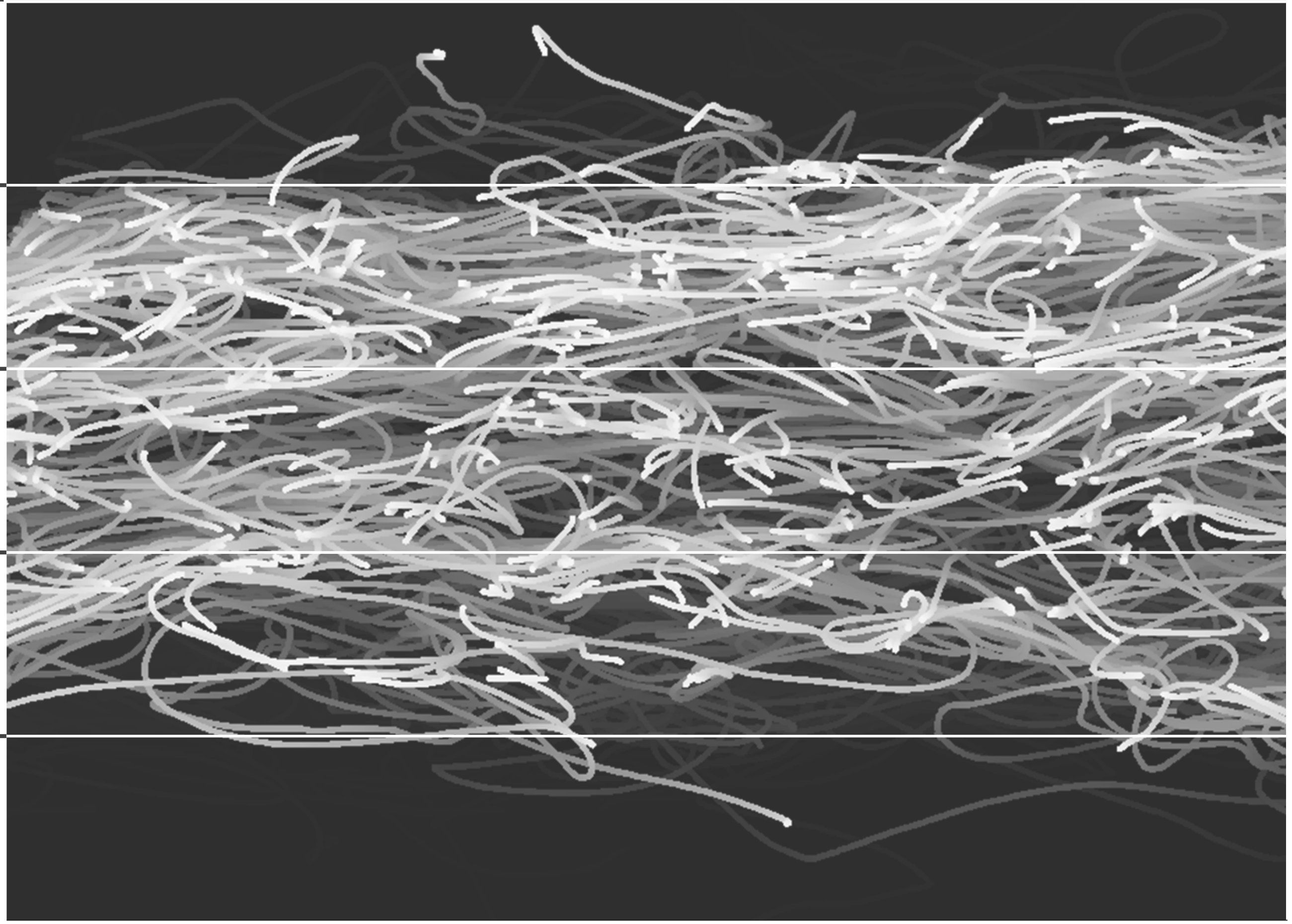
FIBER ORIENTATIONS – SAMPLE B

GEODICT

XY	XZ	YZ	View of a section of the surface in the direction of the X axis.





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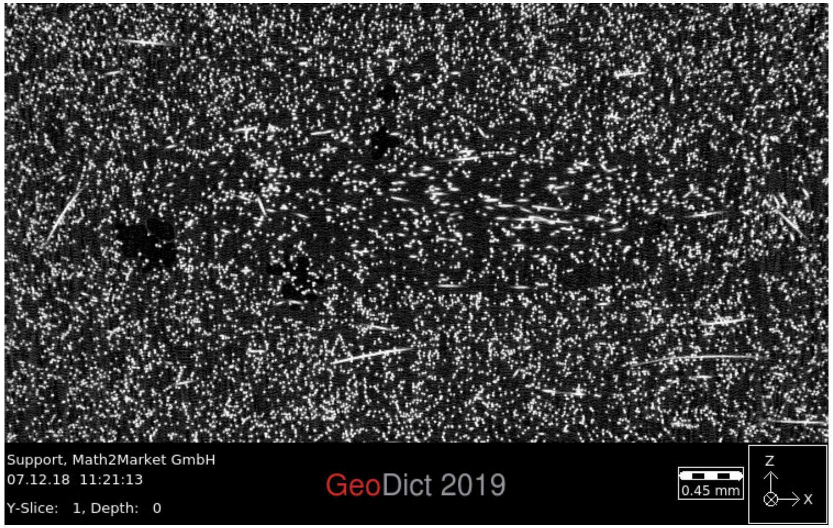
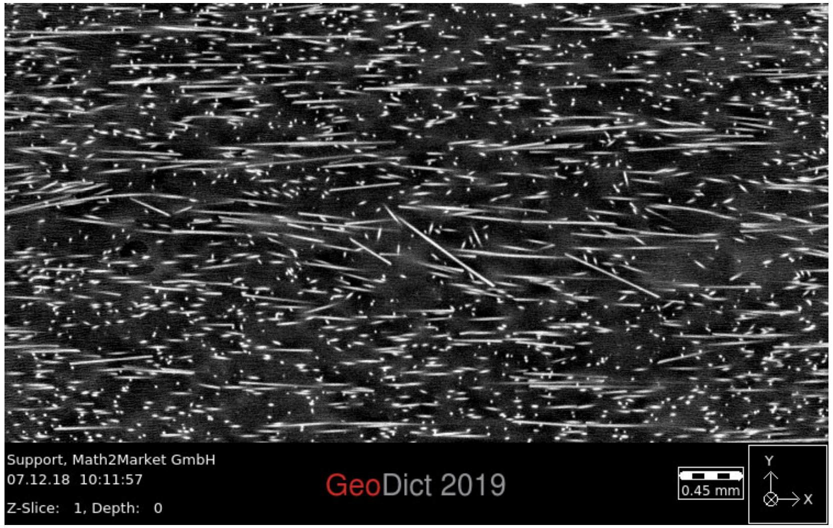
GFRP SAMPLE

GEODICT





(Long)-Glass Fiber Reinforced Polymer (GFRP):

- Glass weight percentage 30%
- Polypropylene Matrix
- Fiber length of 4-6 mm
- Fiber diameter 15-30 µm

GFRP are used in various applications, e.g.

- **Aerospace/automotive body components**
- **Hydrogen tanks**

µCT-scan:
Ca. 6mm x 6mm x 3.2mm
2µm voxel resolution

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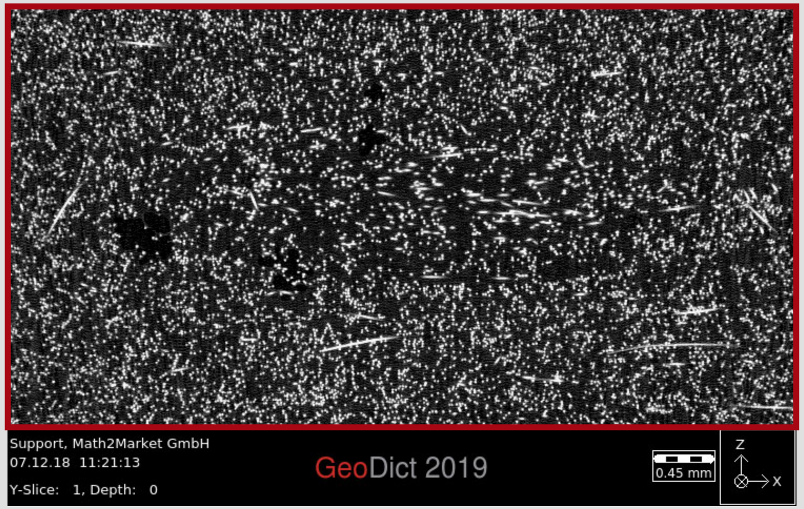
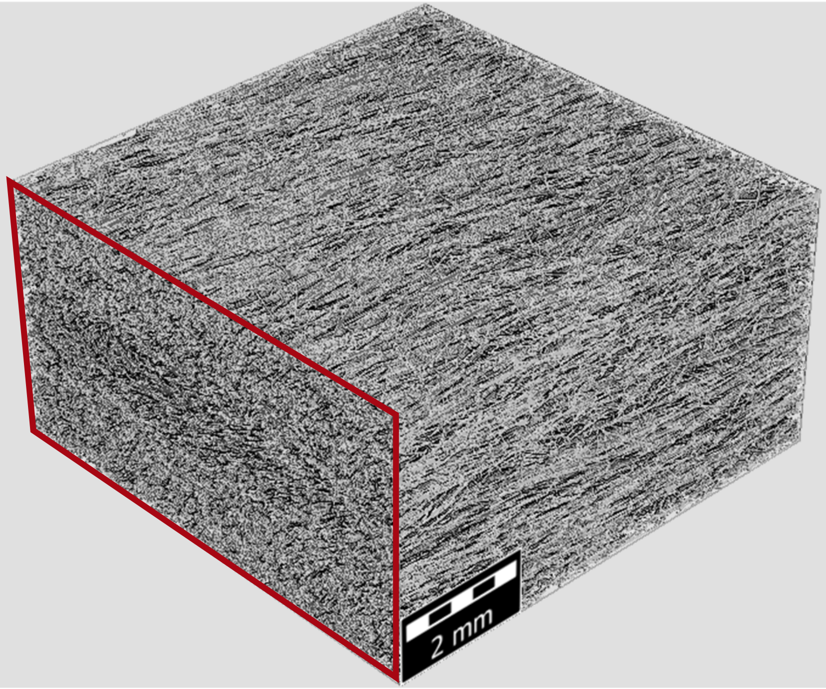
SEGMENTATION



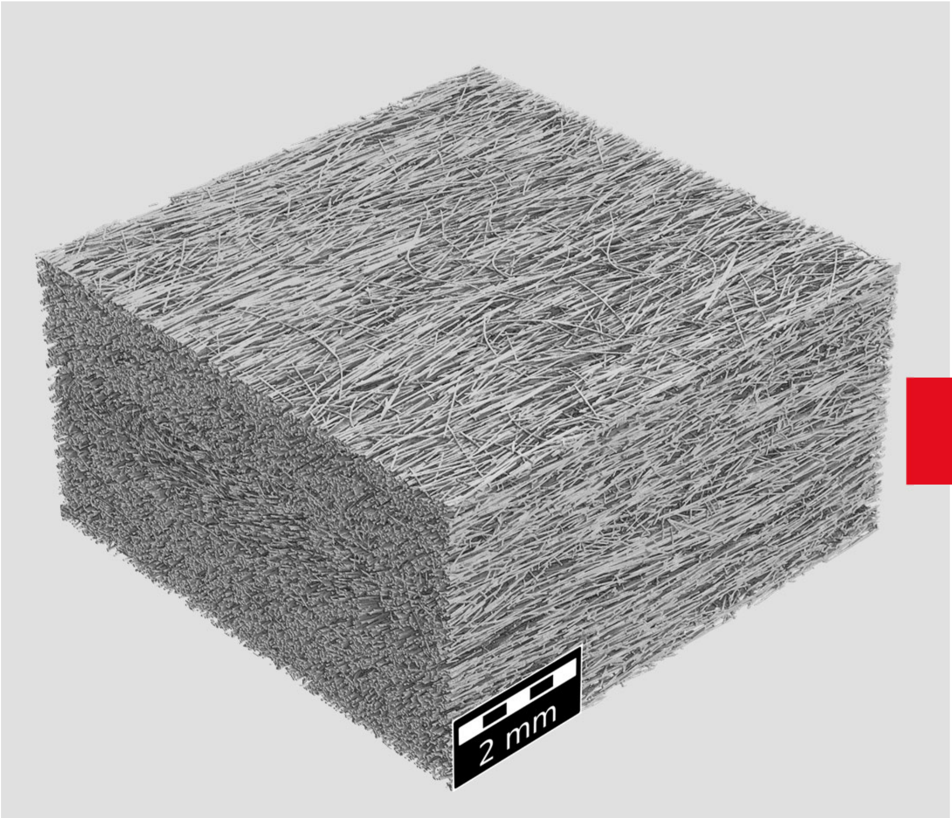


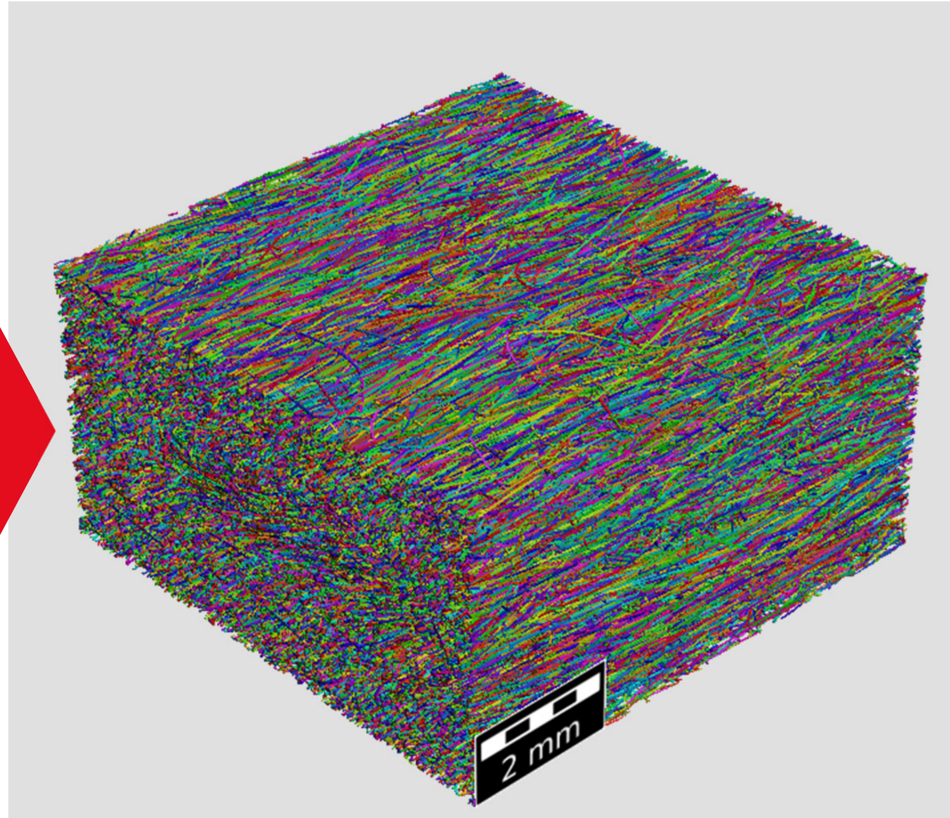
From stack of gray value slices

To 3-D segmented image

IDENTIFIED FIBERS ON WHOLE CT SCAN

GEODICT





Input: Segmented CT scan

Output: Labeled CT scan

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FIBER DIAMETER AND LENGTH ANALYSIS

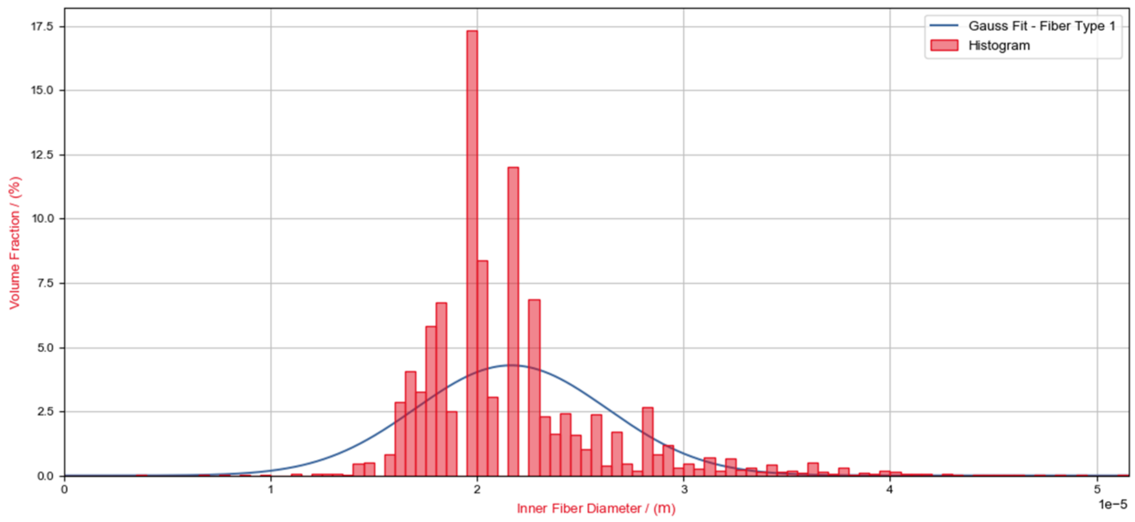
GEODICT

- Fiber diameter distribution

  X-Axis: Diameter

  Y-Axis: Volume Fraction

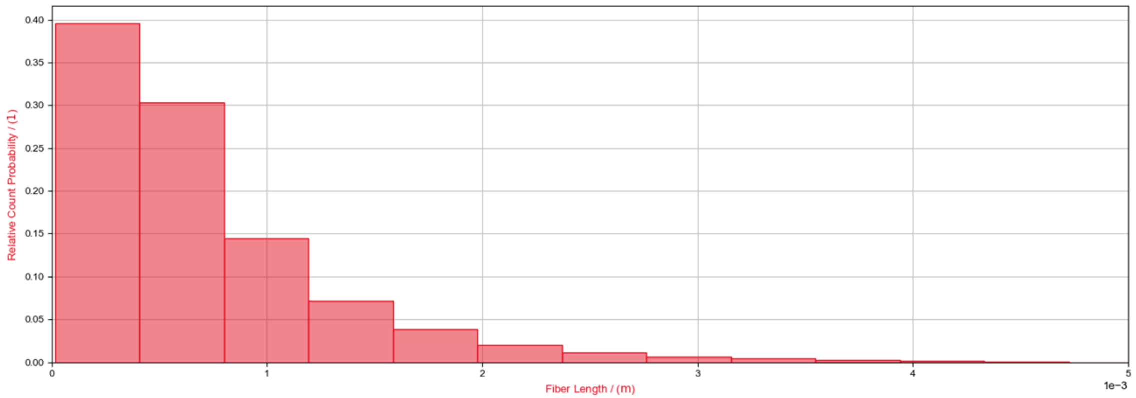
- With Gaussian distribution fit



- Fiber length distribution

  X-Axis: Fiber Length

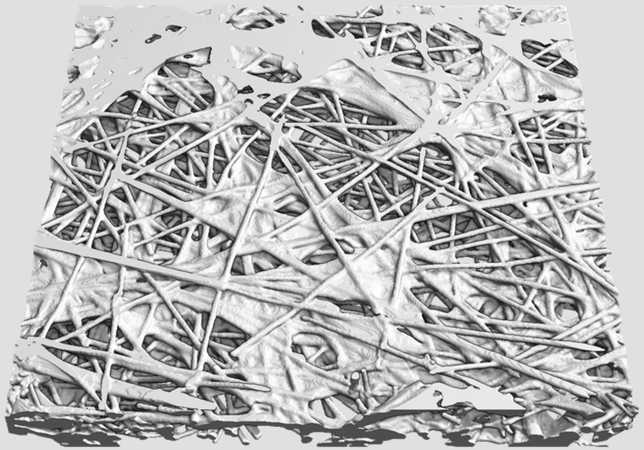
  Y-Axis: Relative Count Probability

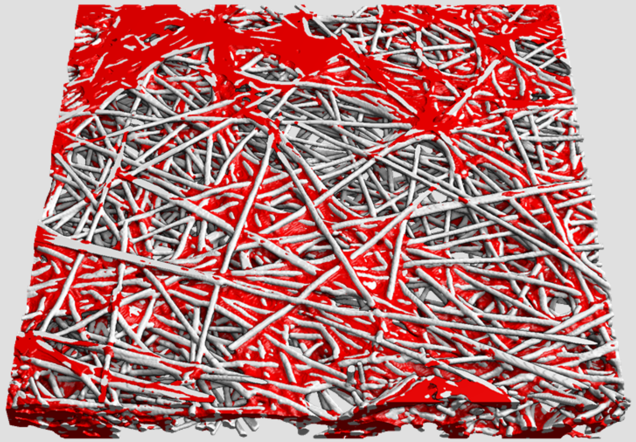


MATH 2 MARKET

Machine learning-based Binder identification (Toray carbon paper)

GeoDict





INPUT: segmented µCT-Scan of fibers (white) + binder (also white)

OUTPUT: labeled fibers (white) and identified binder (red)

Challenges:

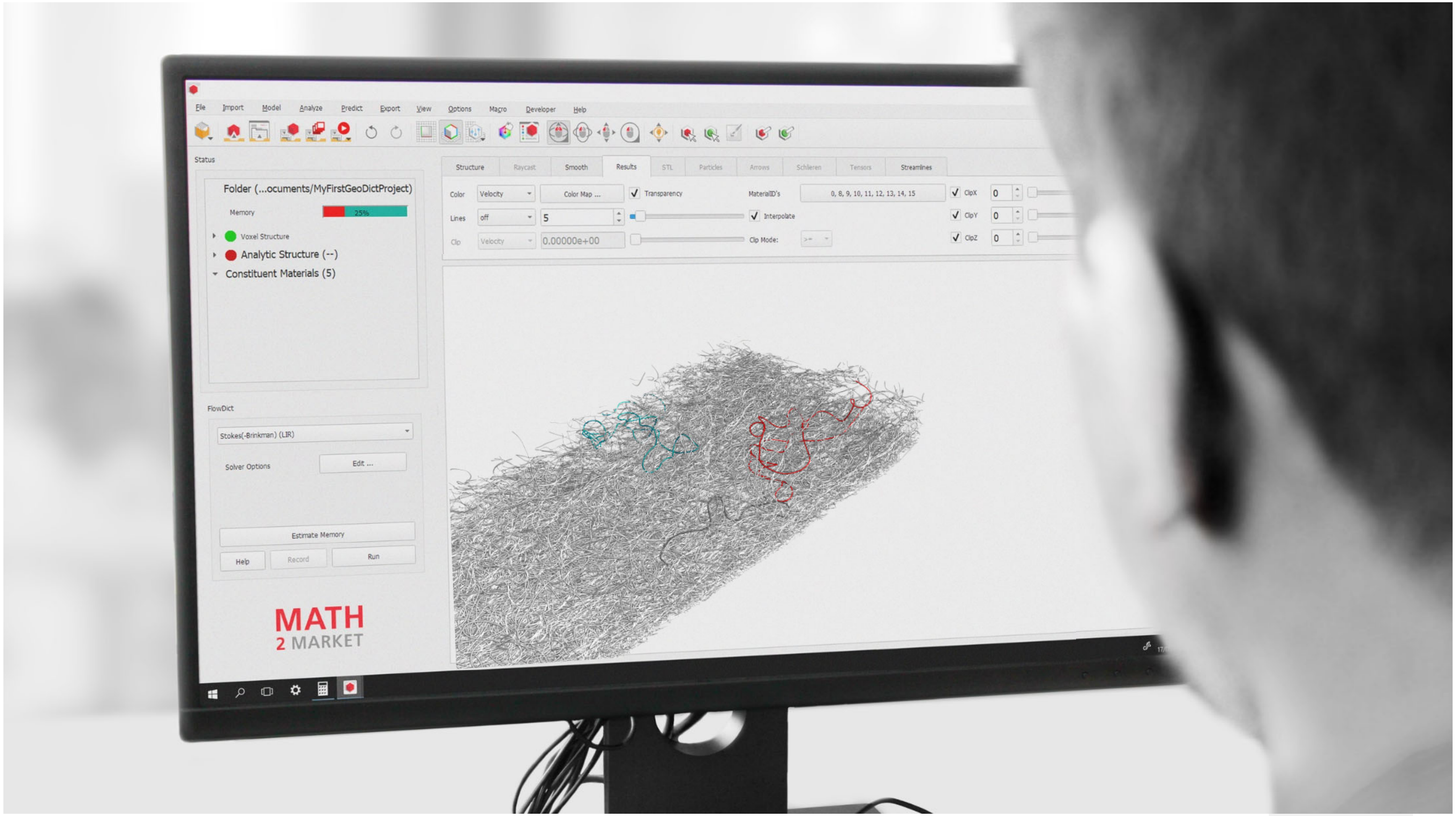
- Ground truth to train the network is not easily available
- Generated training data with GeoDict
- Applied trained network successfully to CT-Scan

Conclusion

- Neural networks trained to segment artificial microstructures generalize to µCT-scans of real materials
- Identification of individual fibers in different types of material types works
  - Allows wide range of statistics on the fibers
- Approach can easily be extended to other materials using the powerful structure generators available in GeoDict
  - Currently looking at applying this for grains
  - We are open for new challenges – see us at our booth!

Thank You!

GeoDict



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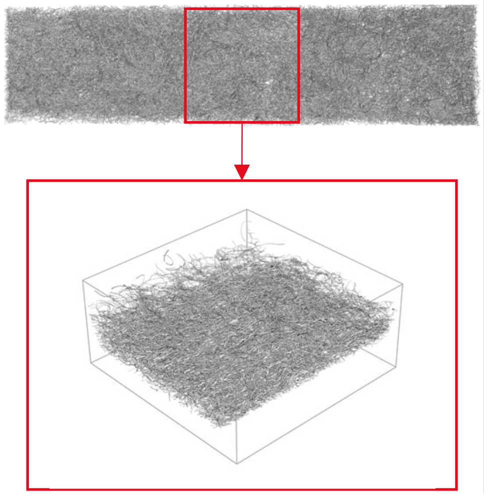
Fiber identification on Sample B

Sample B

FiberFind was used on the complete sample.

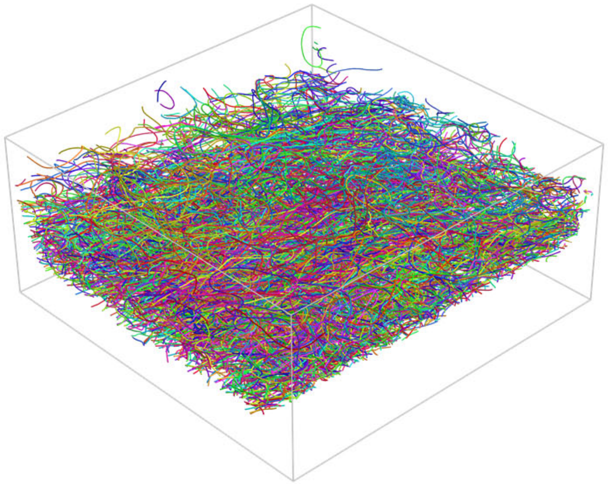
Process is explained on a smaller cutout



Labeling of fibers

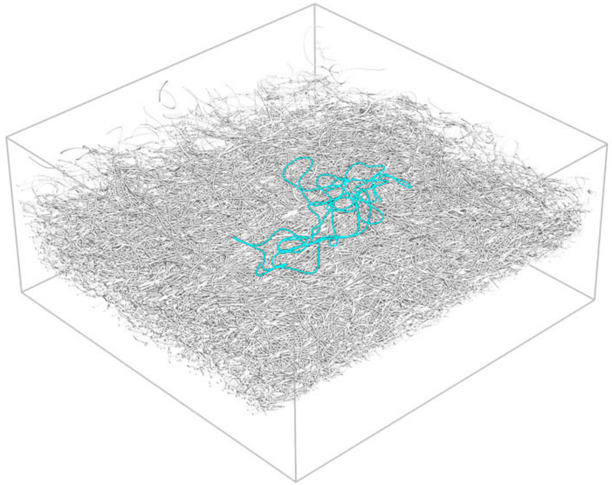
The artificial intelligence separates the solid voxels in the image data into individual fibers.

Each fiber becomes an independent, modifiable object which can be treated independently.



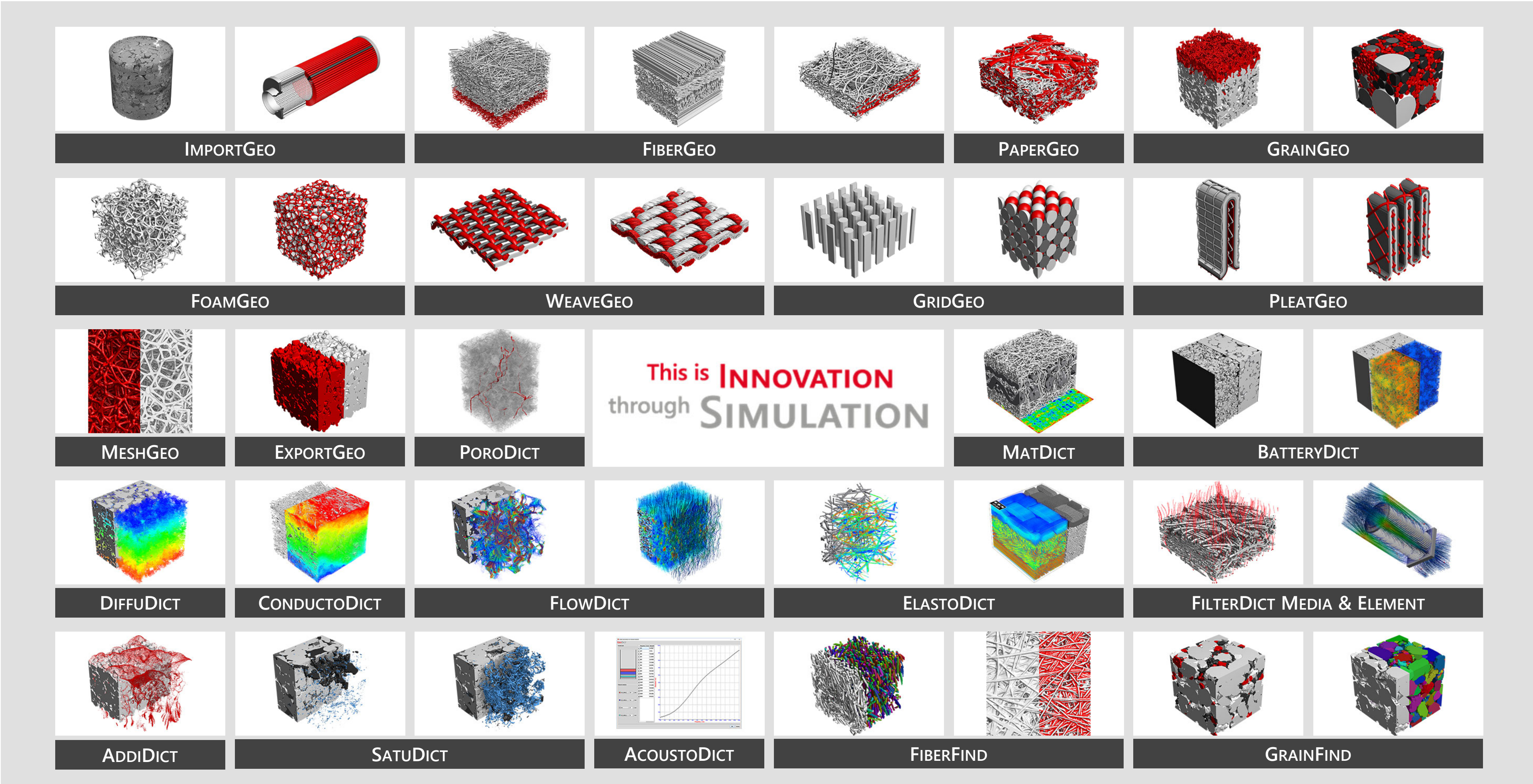
Data becomes information

Geometric information, such as fiber length, fiber segment orientation and fiber diameter, can be read directly from the object.



GeoDict® Module Overview

GeoDict



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