MATH
2 MARKET

Machine Learning-based segmentation of individual Fibers in Micro-CT Scans with GeoDict

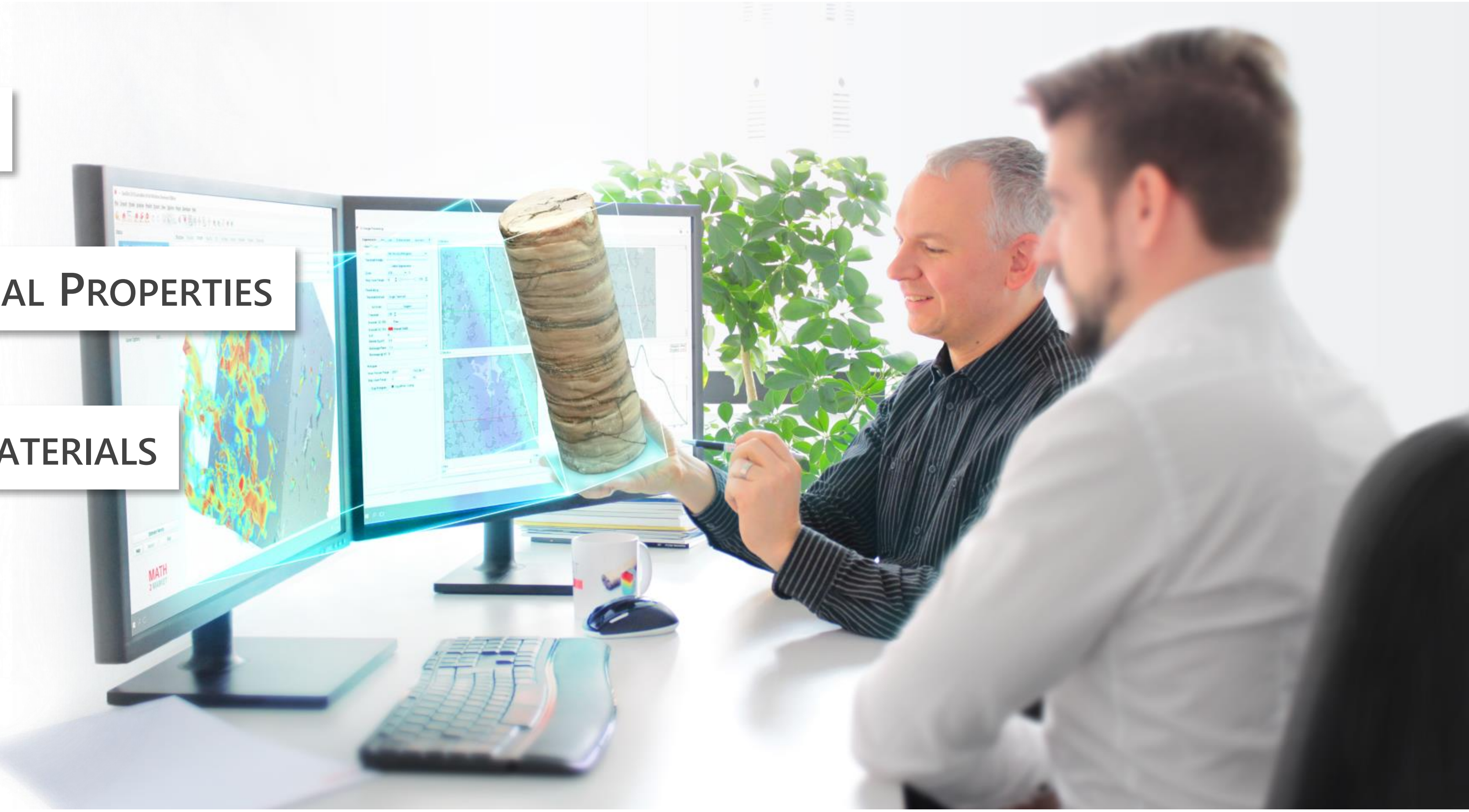
Bruker microCT User Meeting 2018

Andreas Grießer
Dr. Rolf Westerteiger
Dr. Christian Wagner

Core capabilities of GeoDict

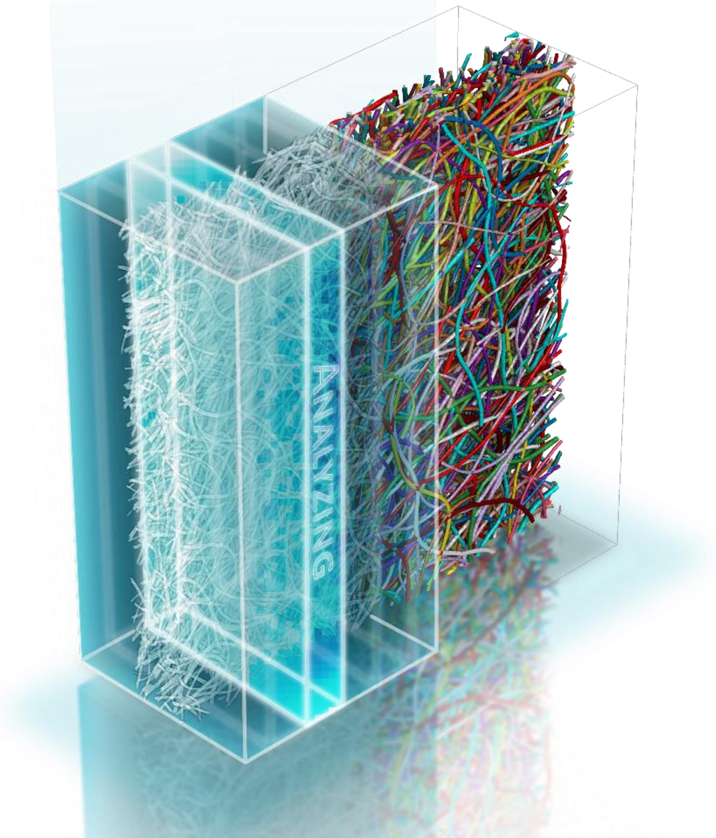
MATH 2 MARKET

- Model & Design Materials
- Analyze & Simulate Material Properties
- Explore the Behavior of Materials
- Develop Novel Materials
- Optimize Processes



Understanding Micro-CT Scans

MATH
2 MARKET

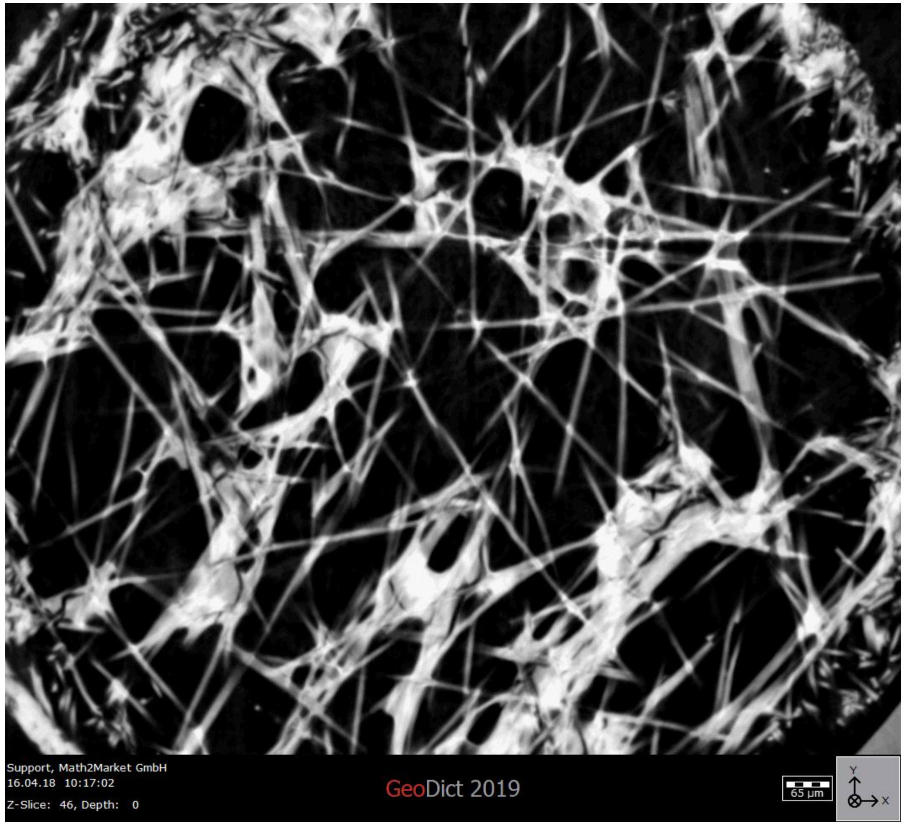


GeoDict for geometric analysis:

- Existing methods measure
  - Fiber diameter distribution
  - Fiber orientation
  - Pore size distribution
  - …
- New machine learning based approach:
  - Any geometric analysis to obtain more measurements out of complex micro structures
  - For example: Identify individual fibers from segmented gray-value image

THE TASK: SEPARATE BINDER FROM FIBERS

MATH
2 MARKET



µCT-scan:
Ca. 1.4mm x 1.2mm x 80µm
1.3µm voxel resolution

Gas diffusion layer Toray Paper TGP-H-030 is used in fuel cells

Fibers and binder have the same attenuation

- and thus cannot be simply thresholded
- but they have different physical properties and must be distinguished for processing

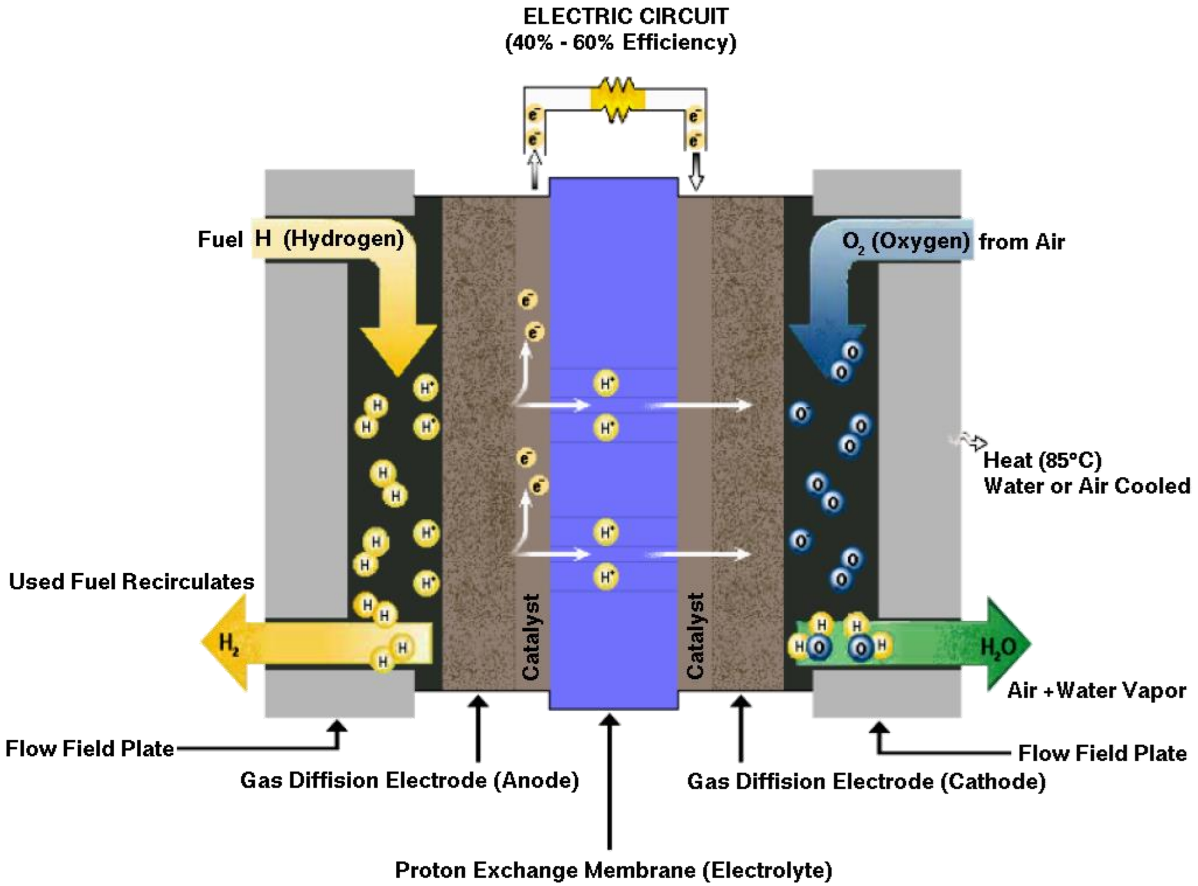
We separate binder and individual fibers

- and run electrical / thermal conductivity on anisotropic carbon fibers
- with contact resistance where fibers touch

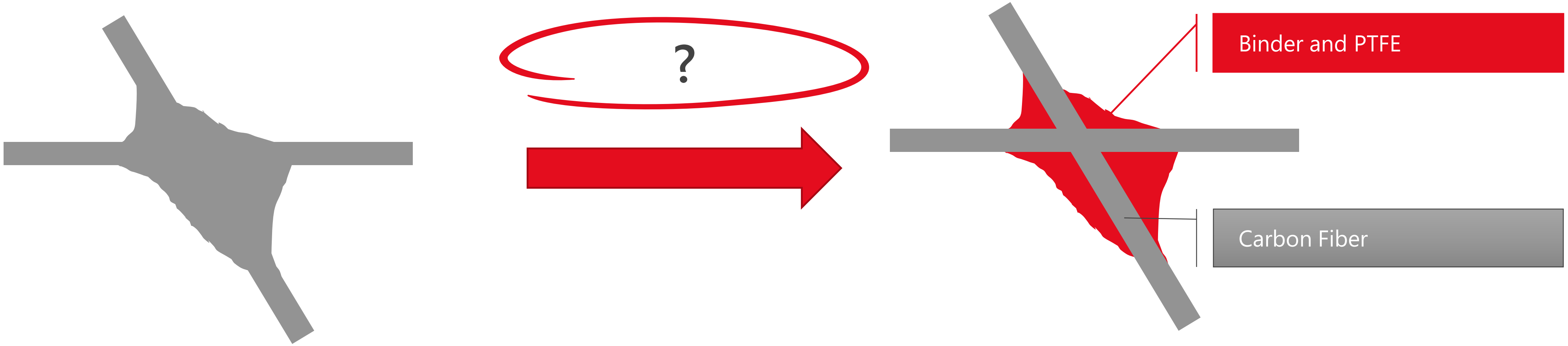
Gas Diffusion Layer in a Fuel Cell

MATH 2 MARKET

- Gas Diffusion Layer is situated between Fuel/Oxygen input and Catalyst layer
- Must be permeable
- Must conduct heat and electricity
- Must mechanically support the membrane and electrode assembly



Binder and Fibers

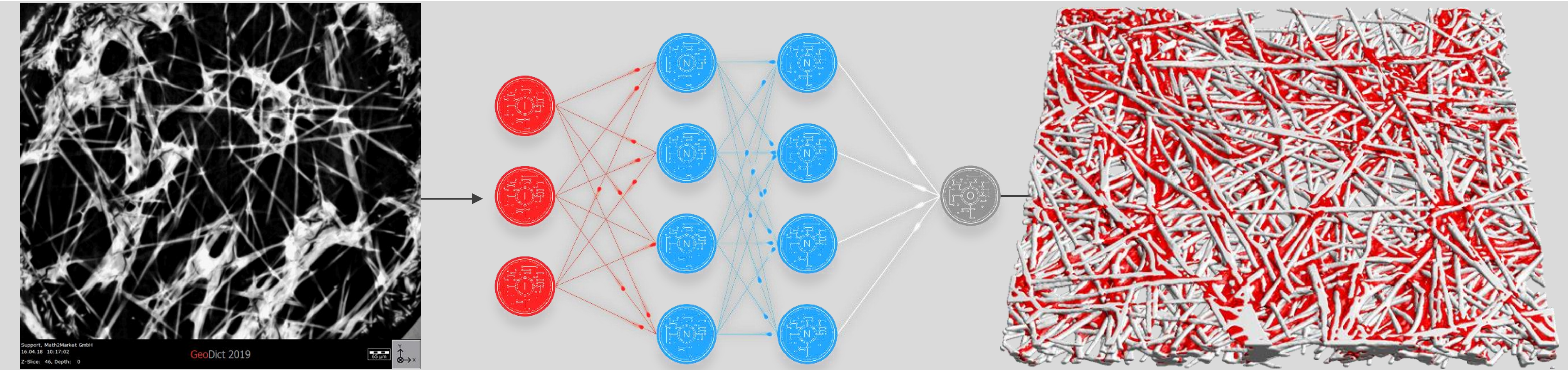


In the original CT Scan binder and fiber can not be seperated

It is necessary to differentiate fibers from binder based on the shape

Identifying binder with Machine Learning

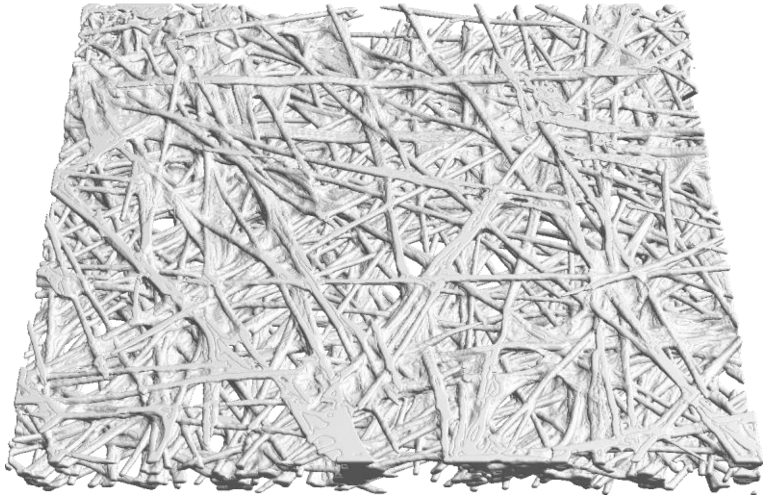
MATH 2 MARKET



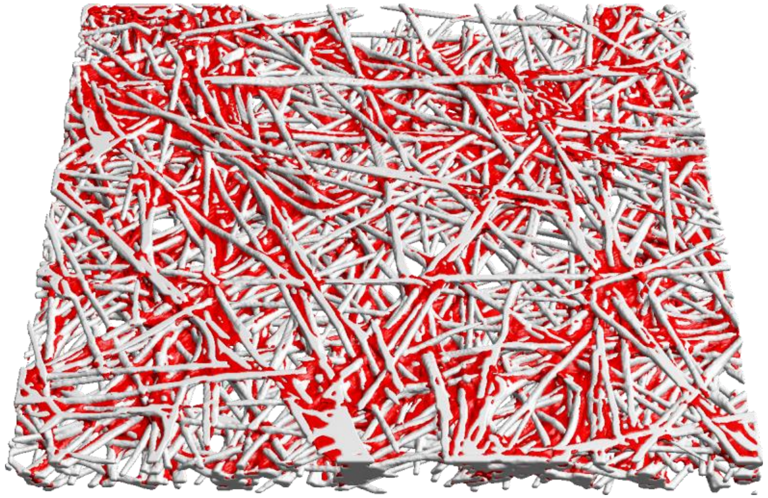
- Neural network: Network of artificial neurons with
  - input original image and output image with labeled binder
- Network learns from training data of input / output pairs
  - to classify each solid voxel as fiber or binder
  - neural networks require huge amounts of training data
- Training data provided by FiberGeo using binder model
- Finally, network is used to identify binder in Synchrotron data

MACHINE LEARNING BASED BINDER IDENTIFICATION

MATH 2 MARKET



Input

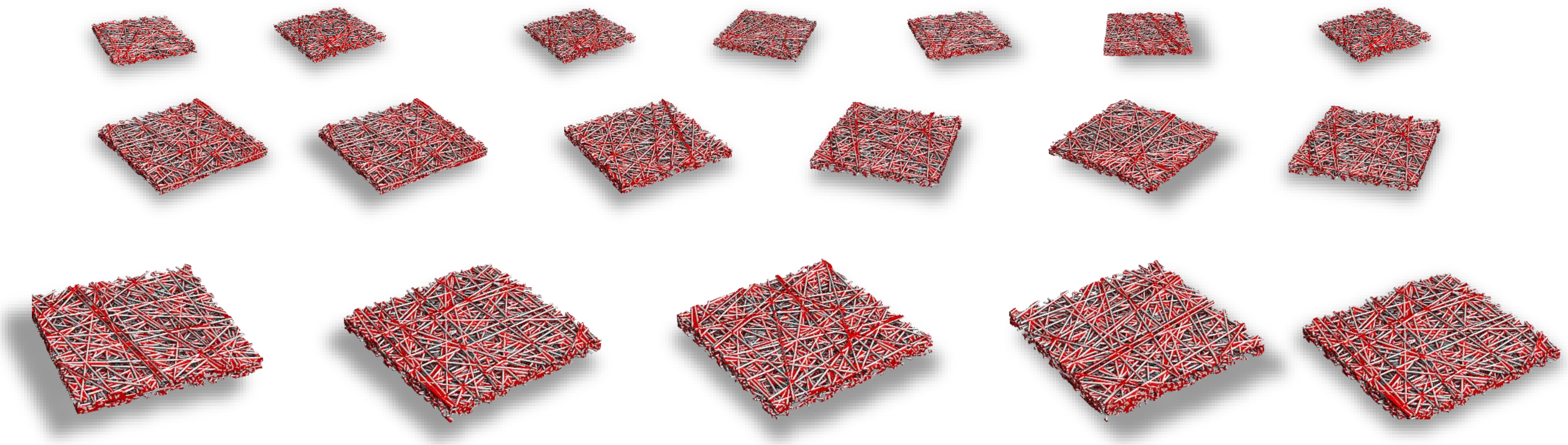


Output

- Input: Segmented micro-CT image of fibers+binder
- Output: Image with identified binder (red)
- Problem:
  - Ground truth to train the network is not easily available
  - Almost impossible to label enough 3D images manually

Generating training data

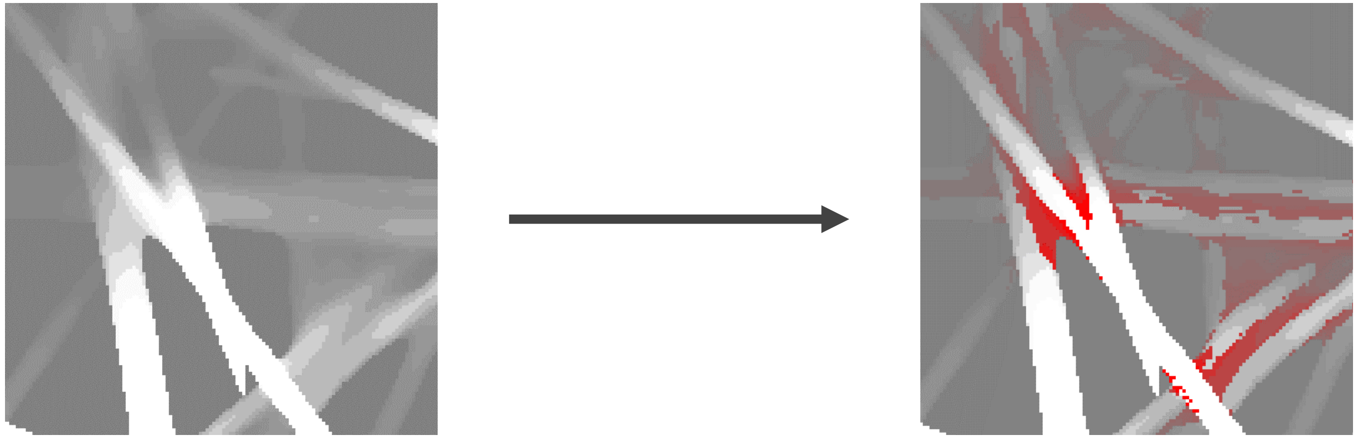
MATH 2 MARKET



- Solution: Use GeoDict's material modelling capabilities to generate training data
  - For training we generated 18 structures (512x512x256 Voxels)
  - Varying porosity and binder volume fraction
  - This corresponds to ~800 million training data points

IDENTIFYING BINDER IN A MICRO-CT IMAGE

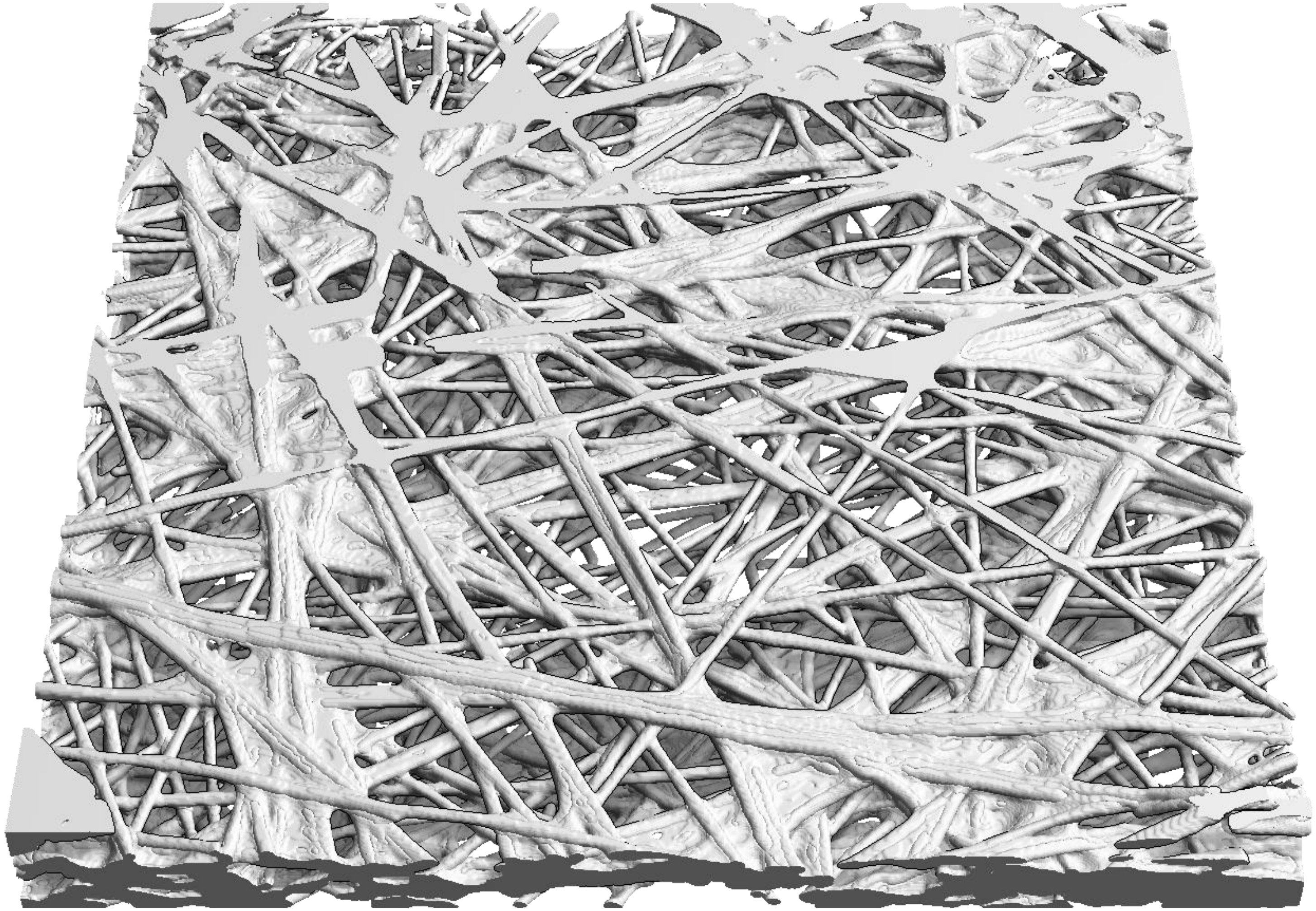
MATH 2 MARKET



- At this point, the network:
  - ...has learned to identify binder in our digital twins
  - ...and use this knowledge to understand real micro CT-scans

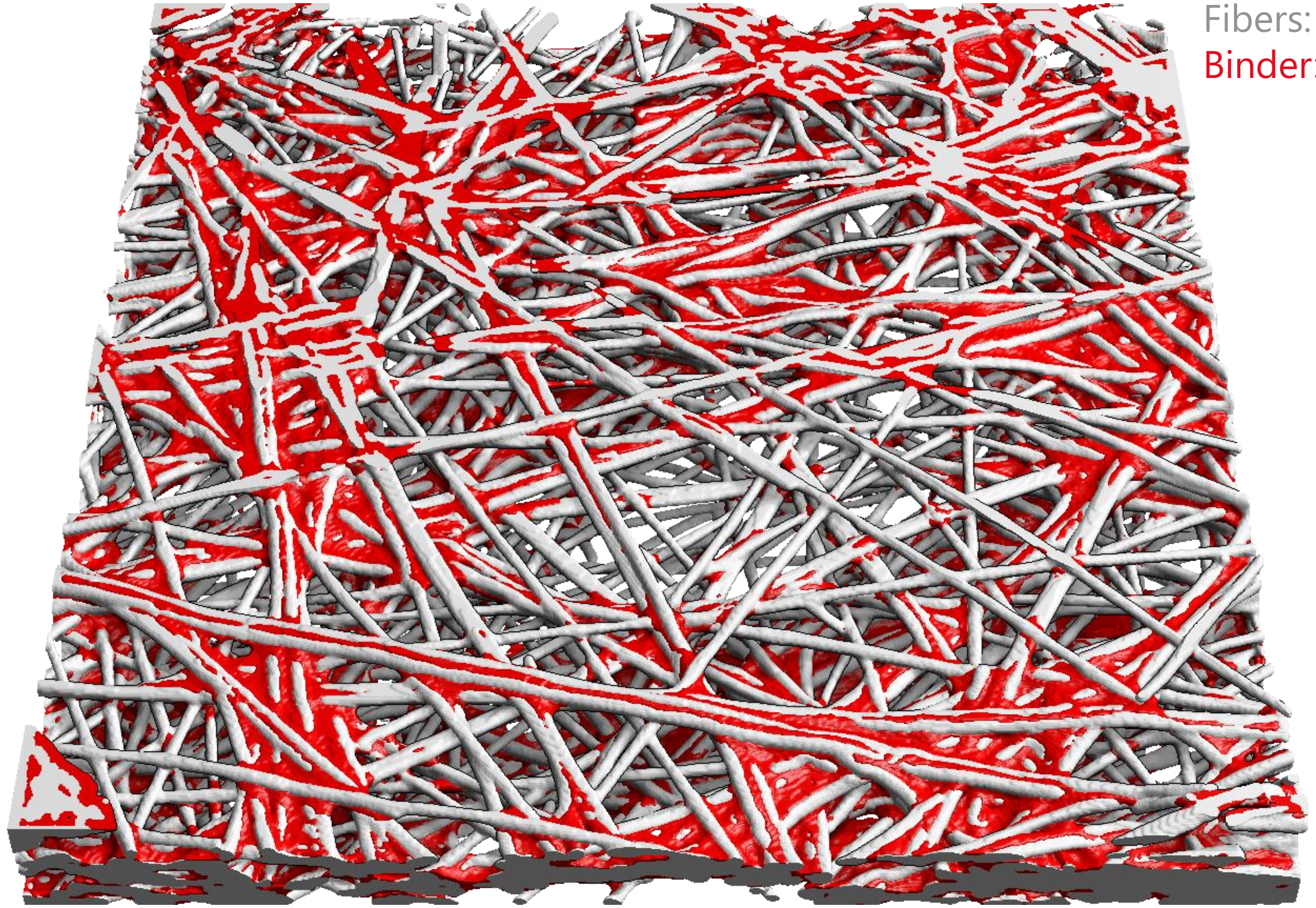
Toray Paper TGP-H-030, 10% Wet Proofing

MATH 2 MARKET



Toray Paper TGP-H-030, 10% Wet Proofing

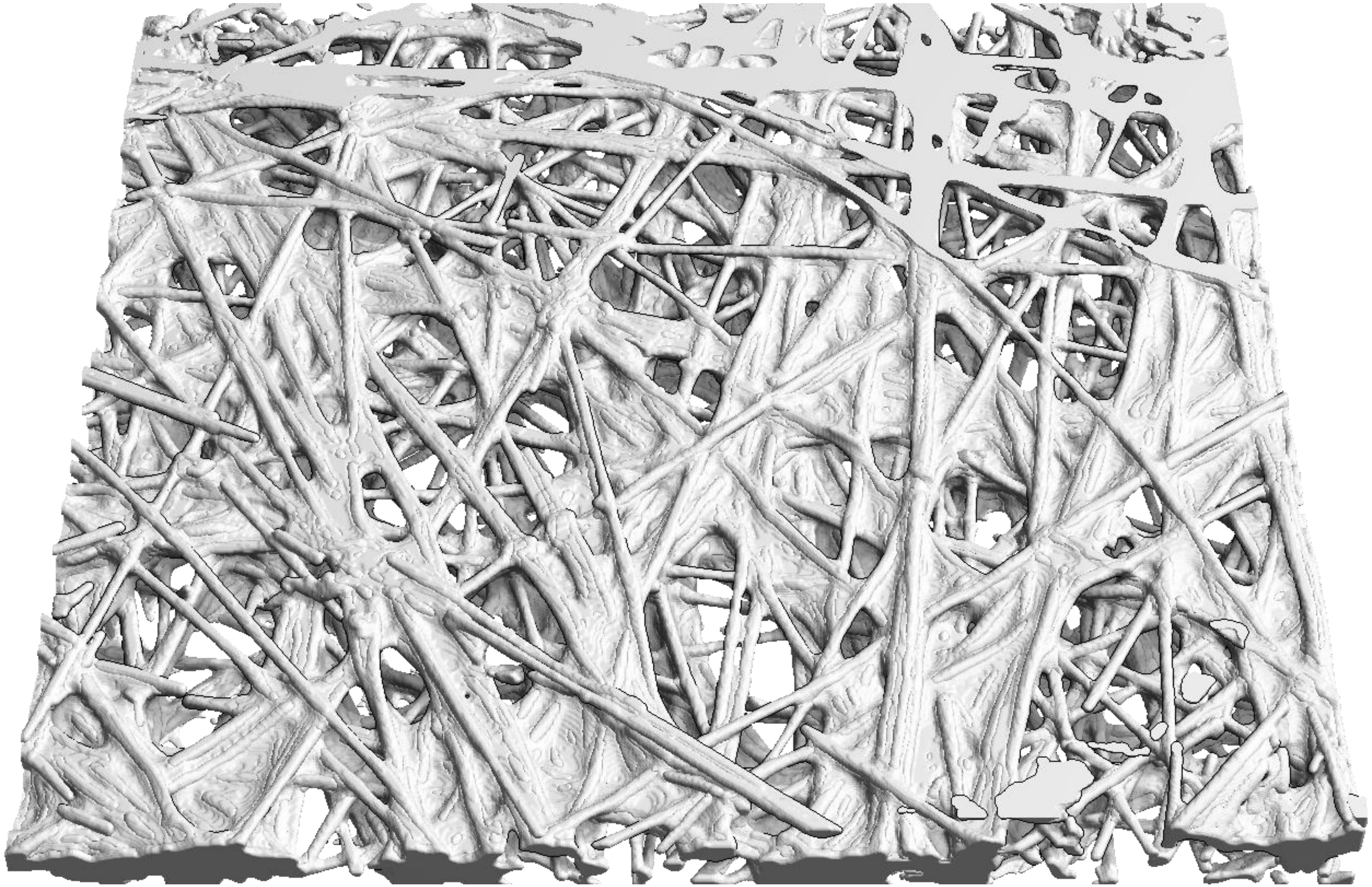
MATH 2 MARKET



Fibers: 16.2%
Binder: 13.2%

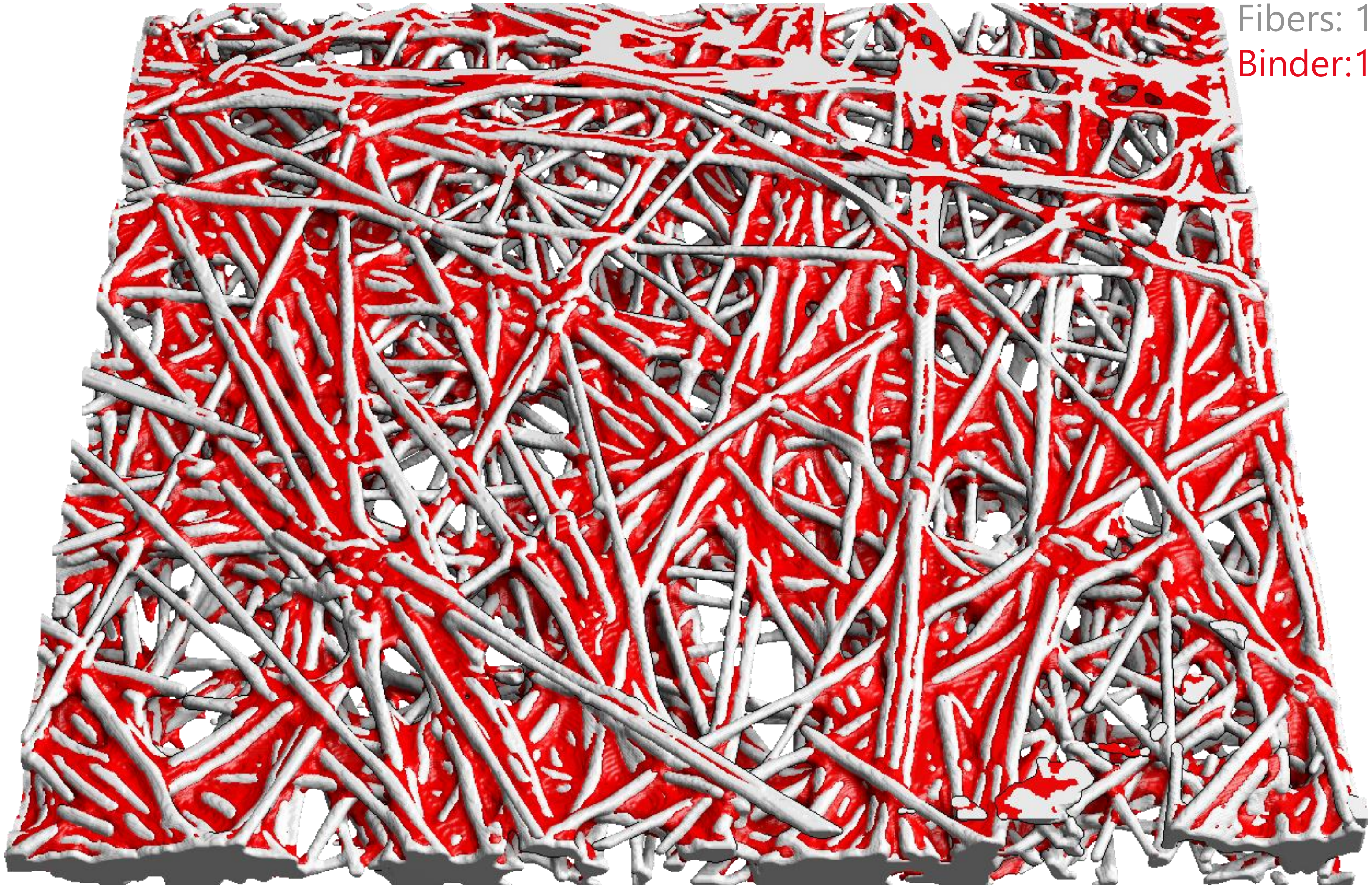
Toray Paper TGP-H-030, 30% Wet Proofing

MATH
2 MARKET



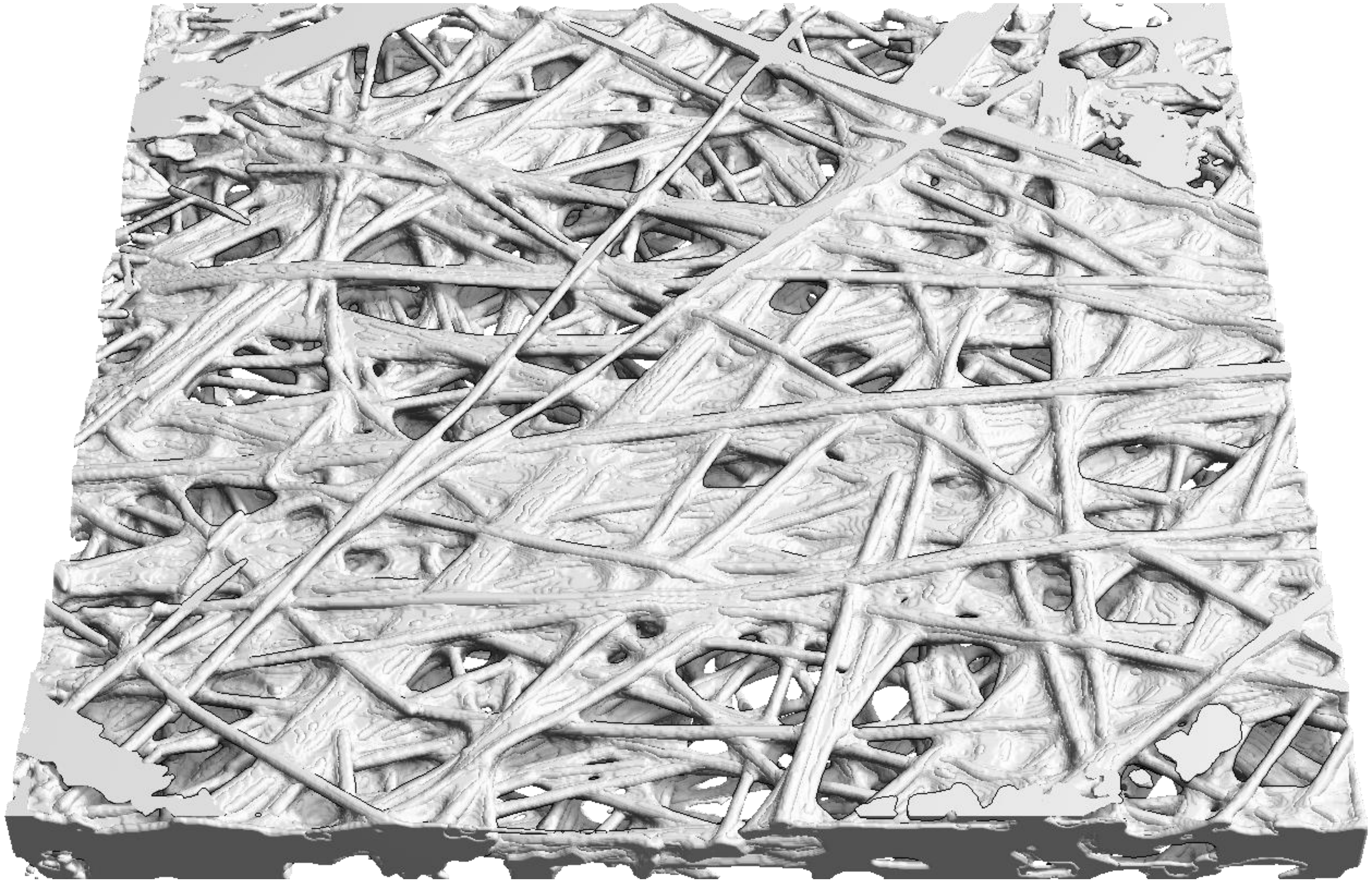
Toray Paper TGP-H-030, 30% Wet Proofing

MATH 2 MARKET



Toray Paper TGP-H-030, 50% Wet Proofing

MATH 2 MARKET



Toray Paper TGP-H-030, 50% Wet Proofing

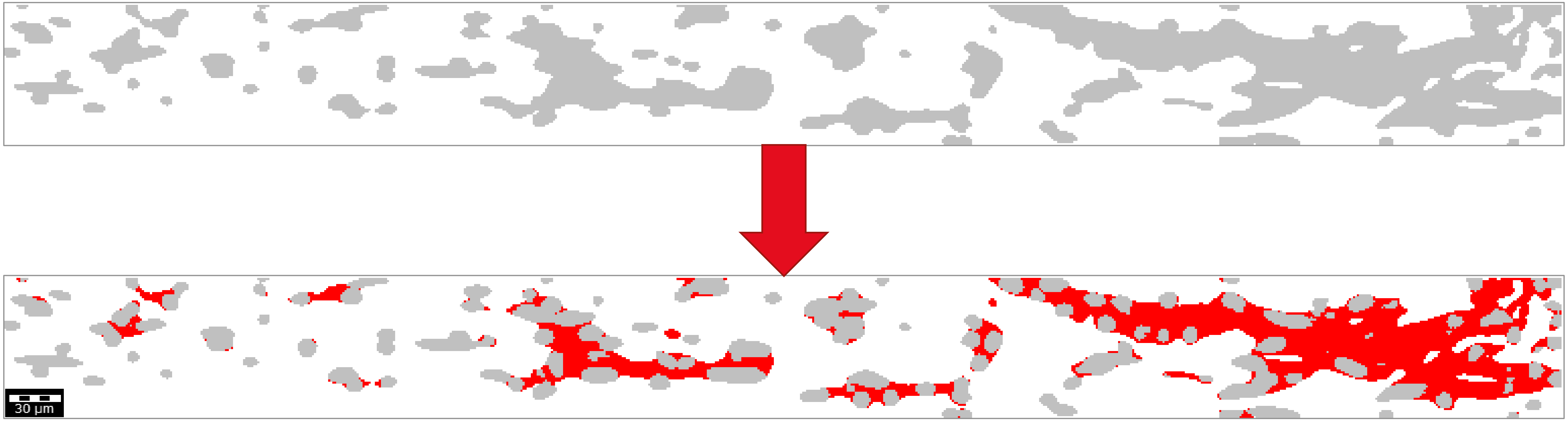
MATH
2 MARKET

Fibers: 17%
Binder: 28%

BINDER IDENTIFICATION IN GAS DIFFUSION LAYER

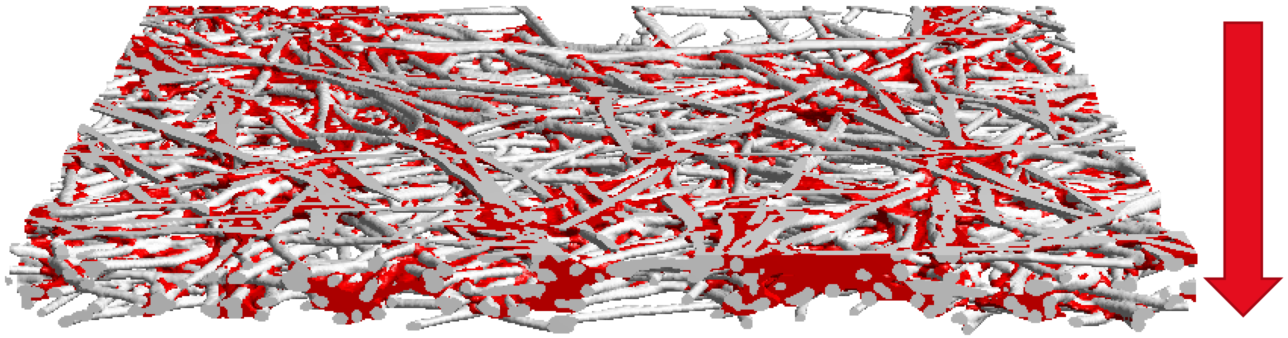
MATH 2 MARKET

Crossection in X-Direction:

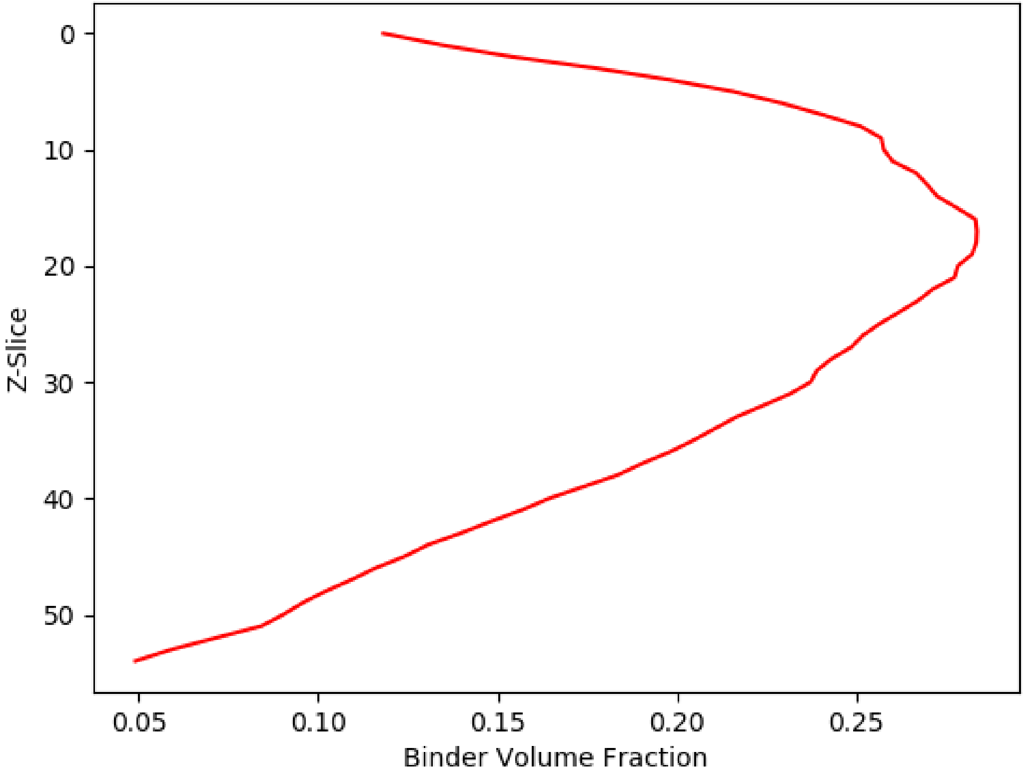


Binder Distribution in Z direction

MATH 2 MARKET



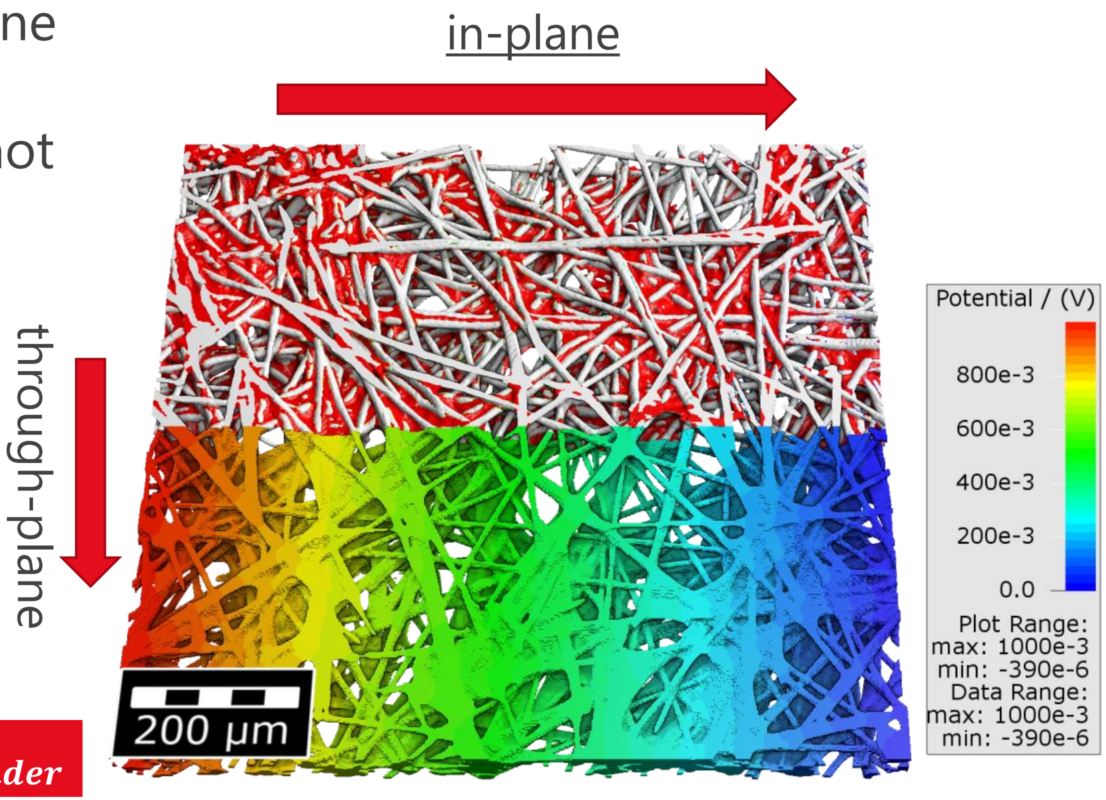
- In Production binder is applied to the top of the fiber and then intrudes into deeper layers
- The expected distribution of binder in the through-plane direction is observable on the right



SIMULATION OF ELECTRICAL CONDUCTIVITY

MATH 2 MARKET

- Past experiments have shown that the ratio of in-plane and through-plane conductivity in experiments and simulations could not be compared because it was not possible to differentiate fibers and binder [1]
  - $r = \frac{\sigma^{eff}_{in-plane}}{\sigma^{eff}_{through-plane}}$
  - We can now run simulations where binder and fibers have different conductivity



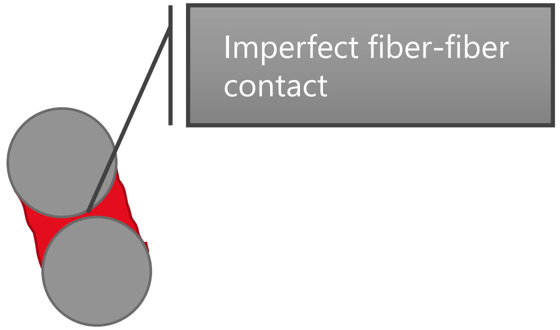
Conductivity	$\sigma_{fiber} = \sigma_{binder}$	$\sigma_{fiber} = 10 * \sigma_{binder}$
r	4.21	5.04

[1] J. Becker et. Al. :Determination of Material Properties of Gas Diffusion Layers: Experiments and Simulations Using Phase Contrast Tomographic Microscopy, Journal of The Electrochemical Society (2009)

IDENTIFY FIBERS

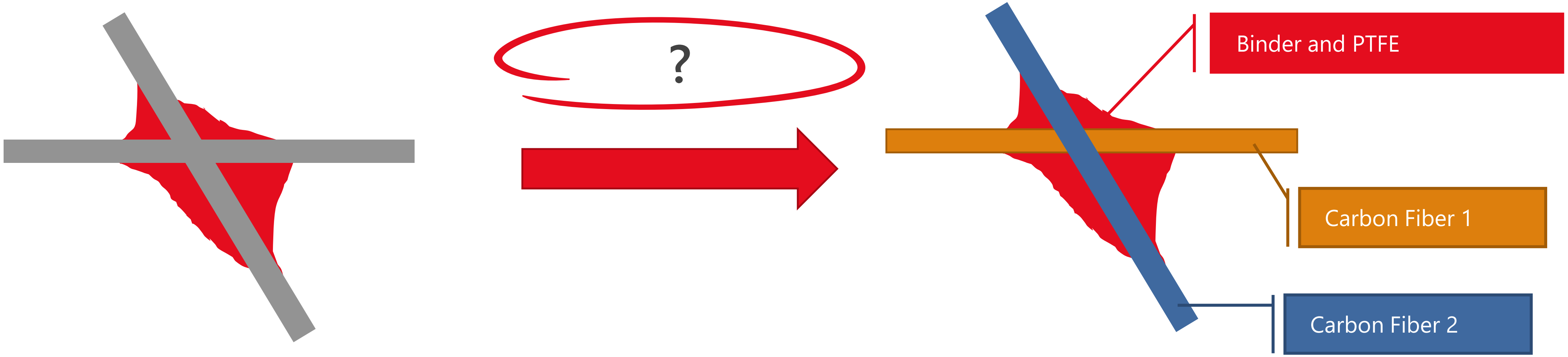
MATH
2 MARKET

- Assigning a different conductivity to the binder increases the ratio of in-plane and through-plane conductivity as expected
- Expected ratio is still not achieved
- Further effects that need to be considered:
  - Anisotropic conductivity of Carbon fibers
  - Contact resistance between fibers due to imperfect contact



➢ Identify individual fibers to assign orientation and distance at contact points correctly

BINDER AND FIBDERS



Segmented binder from fiber using Neural Network trained with model data from GeoDict

Next step segment individual fibers

Identifying individual Fibers

MATH
2 MARKET

- Separating individual fibers allows to get more precise statistics out of micro-CT images
  - Fiber length
  - Fiber curvature
  - Fiber shape

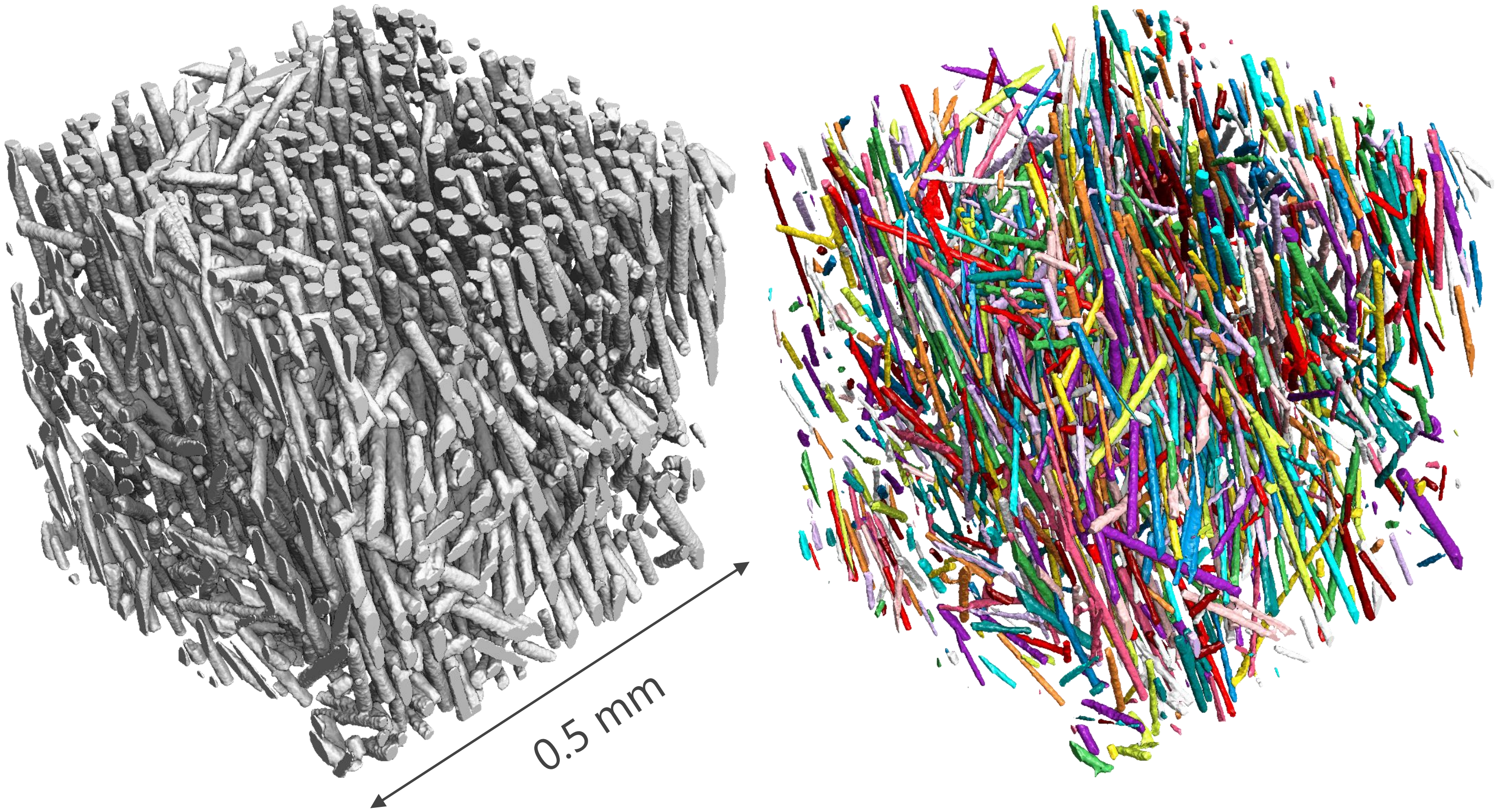
- Separating individual fibers allows to use more advanced models for simulation
  - Contact resistance
  - Isotropic material properties (limited possible without identification)

- By identifying contact voxels and removing them we can split up fibers that are touching each other
- For GeoDict generated fiber structure models information about the contact voxels is available easily

- We deploy the same technic as before and train a Neural Network with the models from GeoDict and then apply the trained Network to the CT-scans

FIBER IDENTIFICATION IN A GFRP

MATH
2 MARKET



- GFRP scan provided by Bruker microCT
- 1000^3 Voxels
- 500nm Resolution

- Removed Fiber Contacts
- Each fiber is labeled by connected component analysis

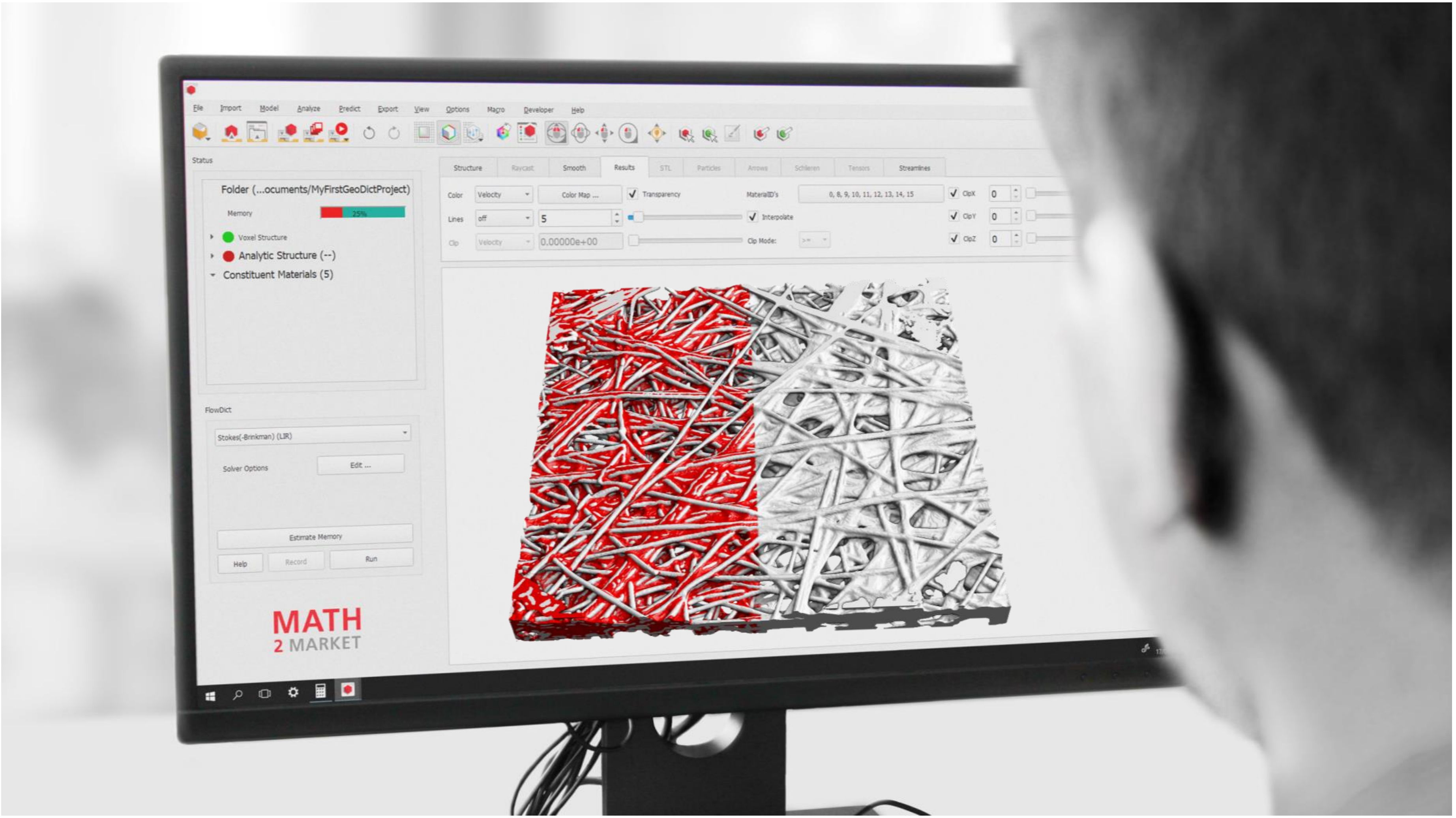
Future Work

- Investigate influence of isotropic conductivity of carbon fibers on effective conductivity of GDL

- Use fiber identification Tool too the GDL datasets und fit analytic fiber models into CT-Scan to model contact resistance

Thank You!

MATH
2 MARKET



Questions?

Contact:

Andreas Grießer:
andreas.griesser@math2market.de

Dr. Christian Wagner:
christian.wagner@math2market.de