Identification of Fibers and Binder from micro-CT Scans using Machine Learning

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MATH2MARKET OVERVIEW

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GeoDict (The Digital Material Laboratory)	2011	GER	38	150+
Product	Spun Off	Location	Employees	Customers

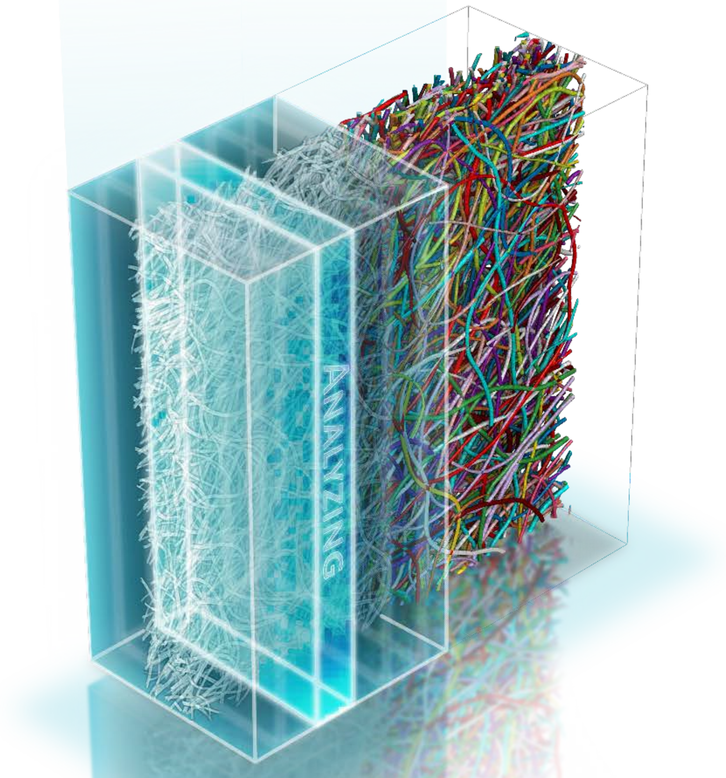
2001 Fraunhofer

Started

Core capabilities of GeoDict

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

Understanding Micro-CT Scans using GeoDict



Existing methods measure:

- Fiber diameter distribution
- Fiber orientation
- Pore size distribution
- …

New machine learning based approach:

- Any geometric analysis to obtain measurements for complex micro structures
- For example: Identify binder & fibers from segmented gray-value image

Gas Diffusion Layer in a Fuel Cell

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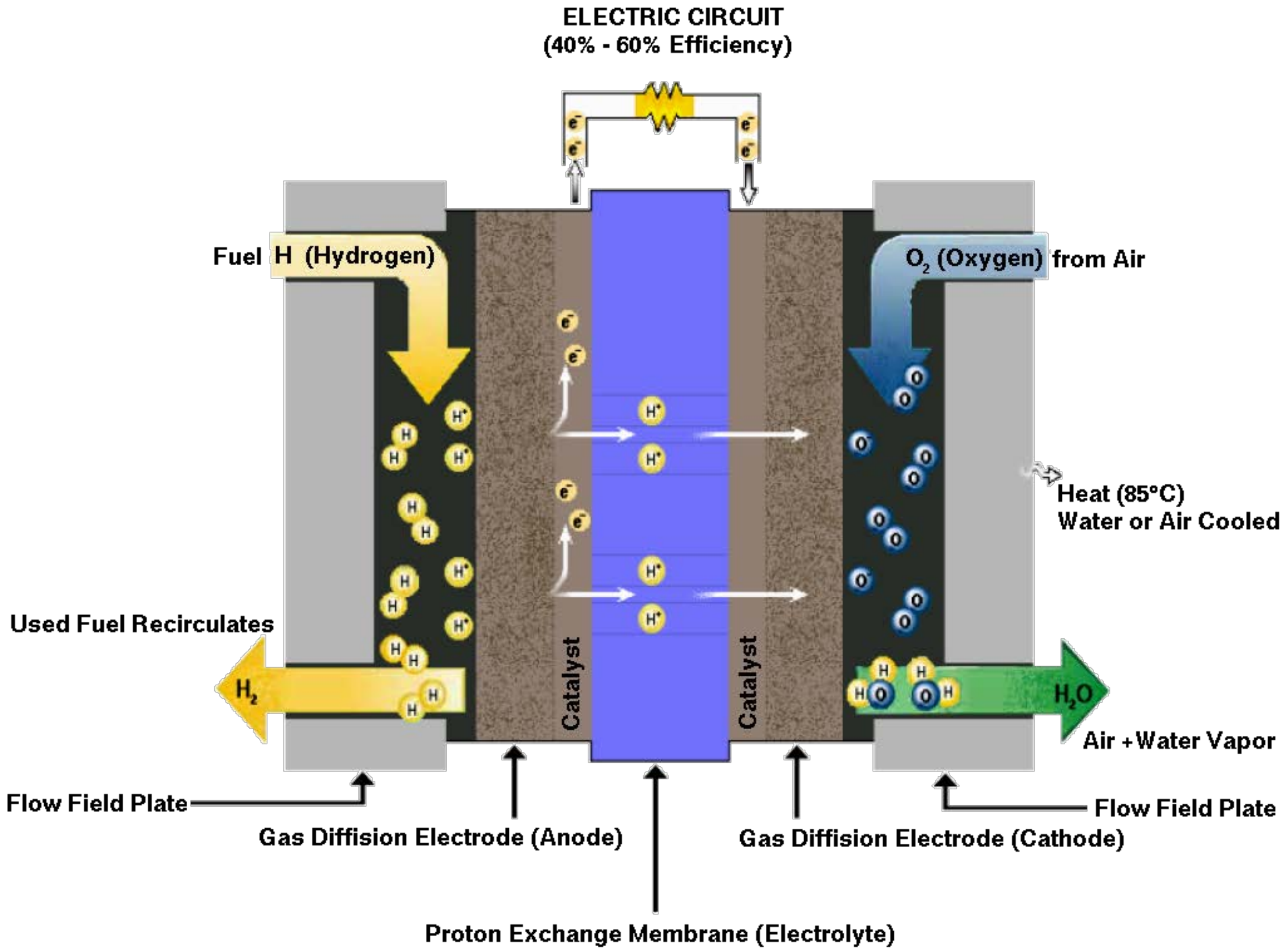
- Gas Diffusion Layer is situated between Fuel/Oxygen input and Catalyst layer
- Must be permeable
- Must conduct heat and electricity
- Must mechanically support the membrane and electrode assembly



The task: Separate Binder from Fibers

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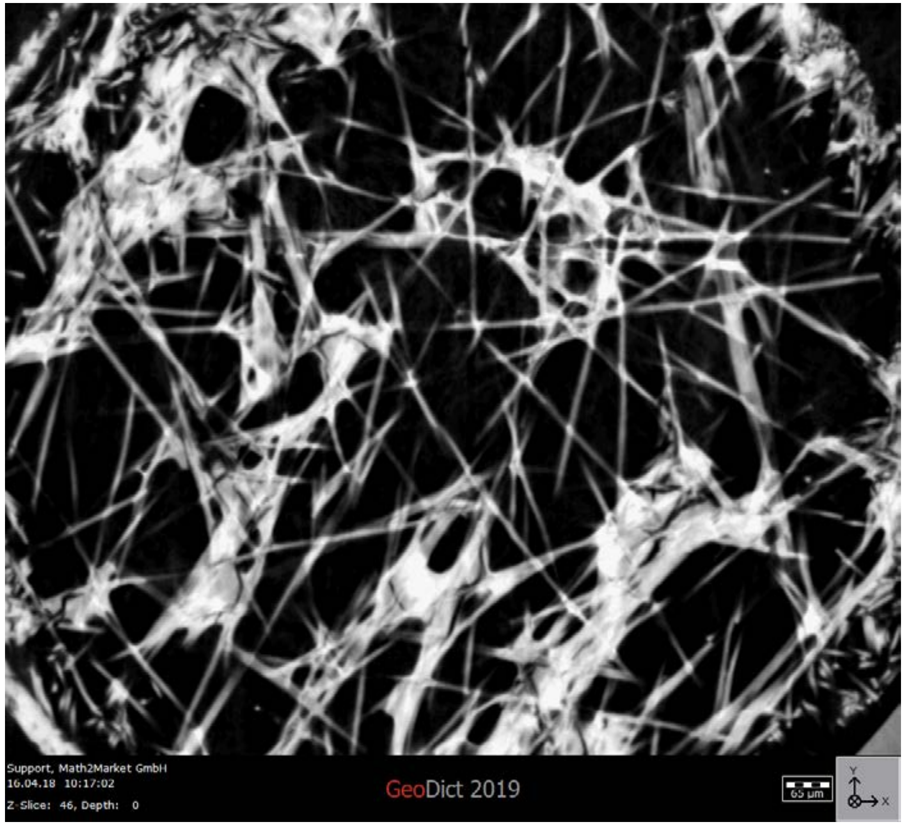


µCT-scan:
Ca. 1.4mm x 1.2mm x 80µm
1.3µm voxel resolution

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

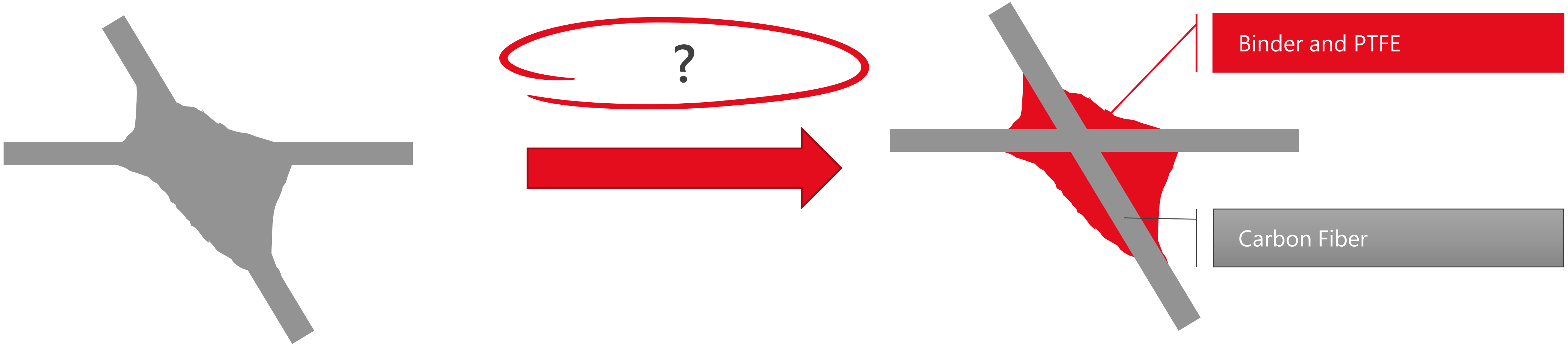
Fibers and binder have same attenuation

- due to different physical properties they must be distinguished for processing
- but simple threshold does not work

We separate binder and individual fibers

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

Binder and Fibers



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

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

Identifying binder with Machine Learning

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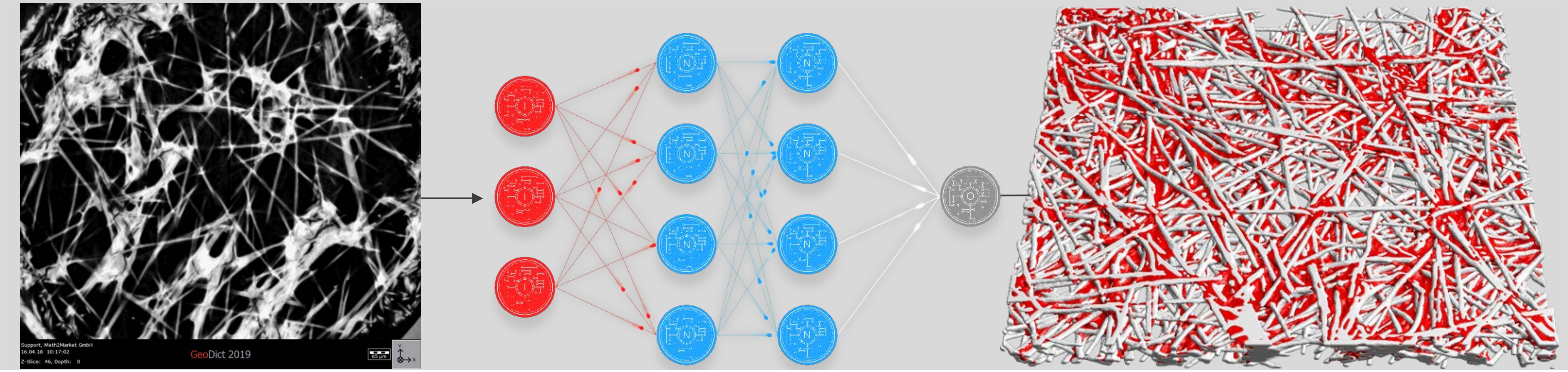

- Neural network: Network of artificial neurons with
  - input original image and output image with labeled binder
- Network learns from training data of input / output pairs
  - to classify each solid voxel as fiber or binder
  - neural networks require huge amounts of training data
- Problem:
  - Ground truth to train the network is not easily available
  - Almost impossible to label enough 3D images manually

GENERATING TRAINING DATA

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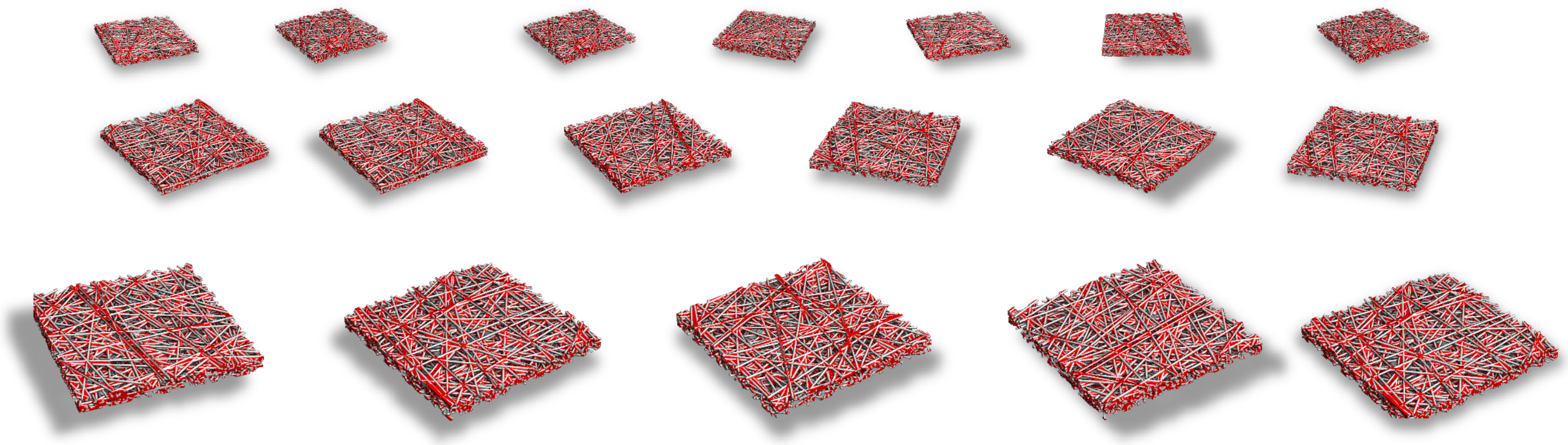
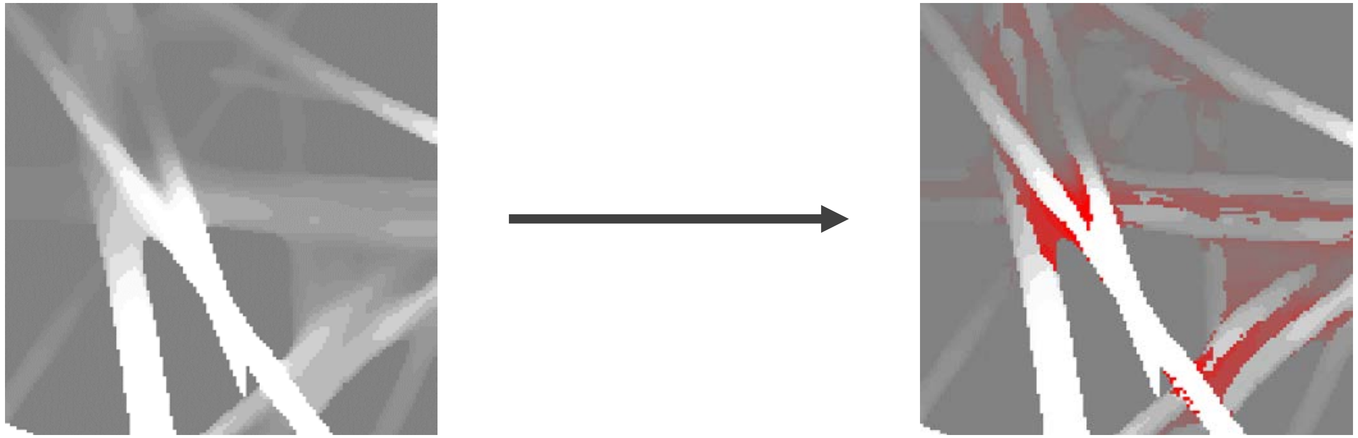


Solution: Use GeoDict's material modelling capabilities to generate training data

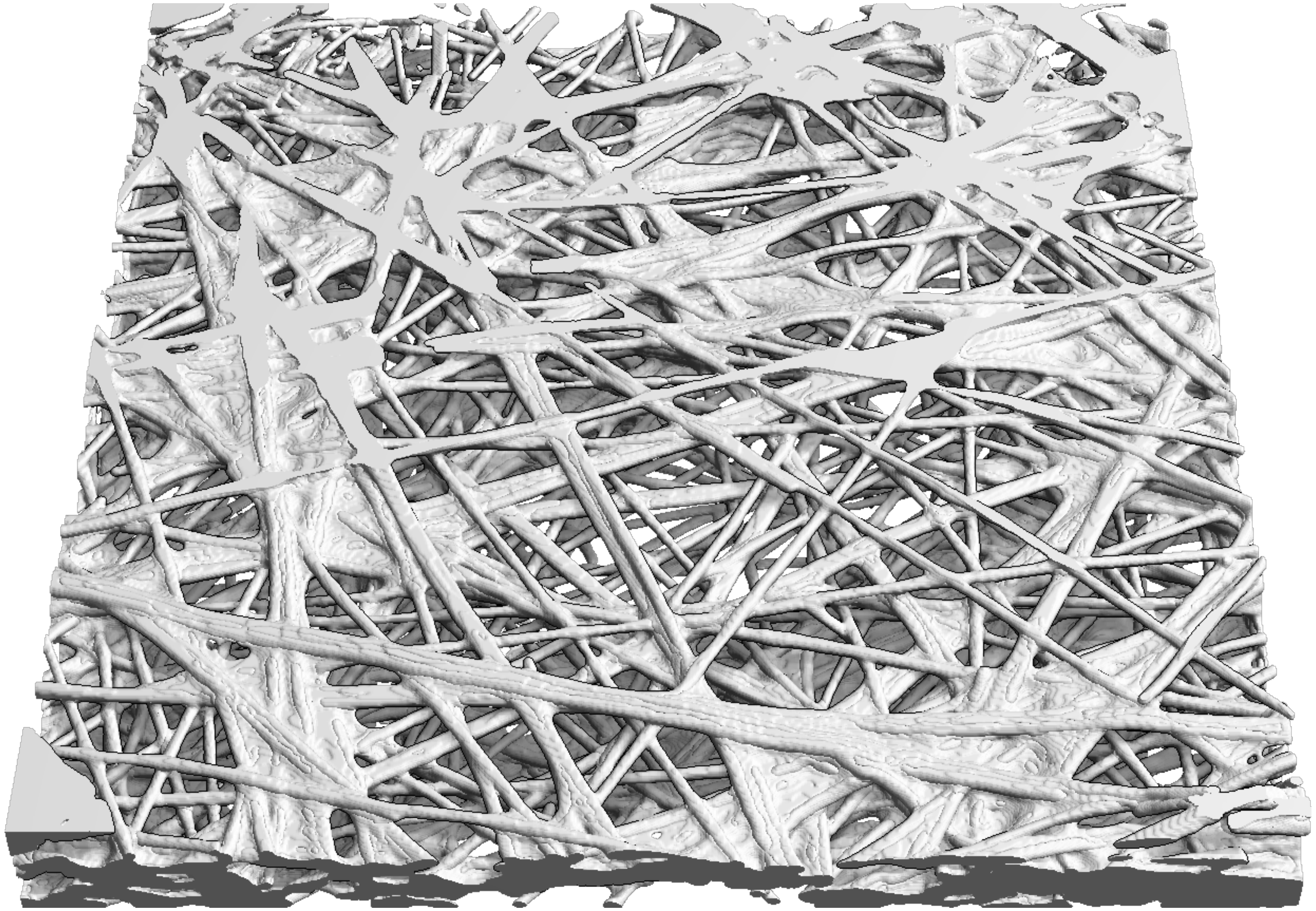
- For training we generated 18 structures (512x512x256 Voxels)
- Varying porosity and binder volume fraction
- This corresponds to ~800 million training data points

IDENTIFYING BINDER IN A MICRO-CT IMAGE



- 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



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

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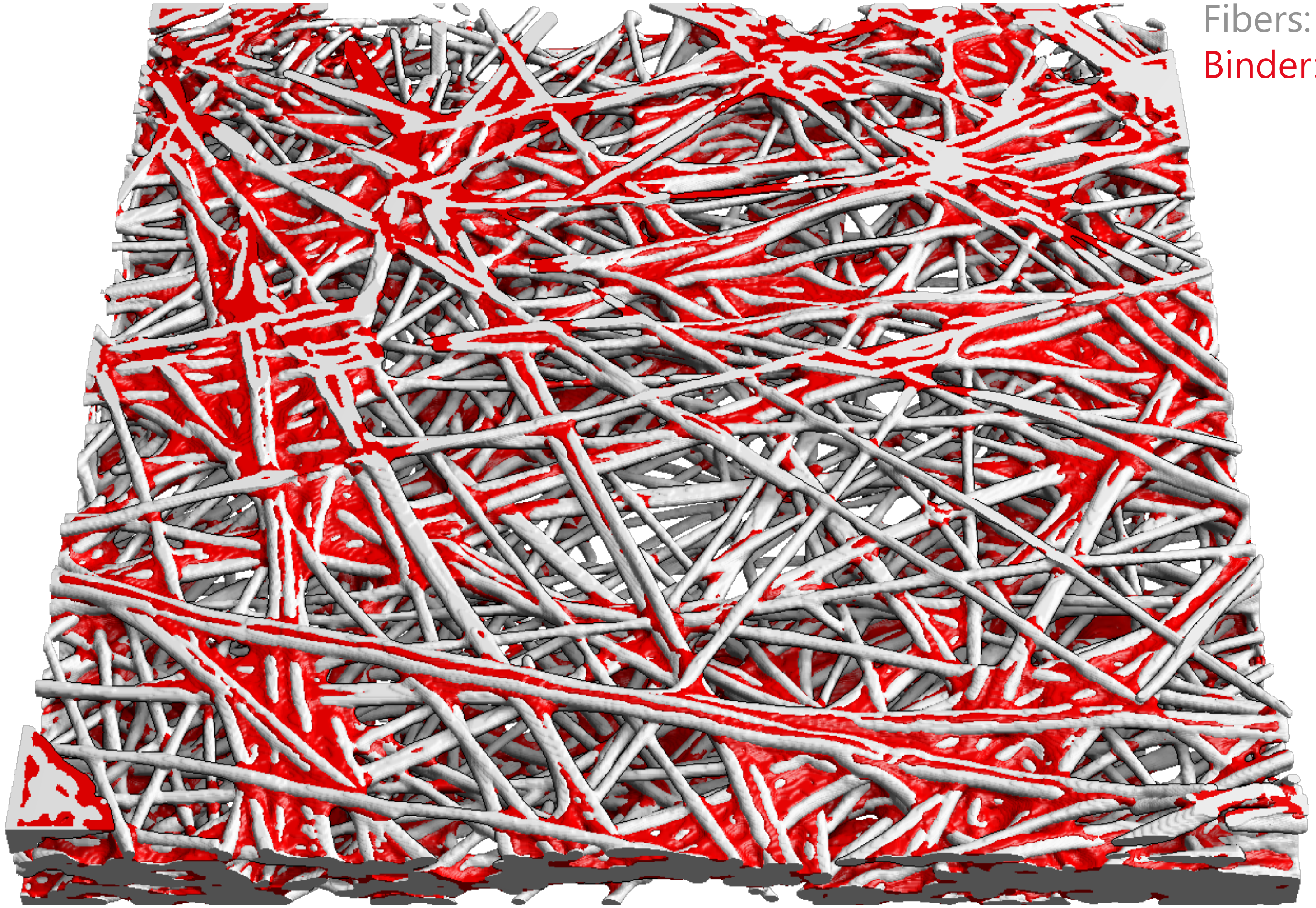

Toray Paper TGP-H-030, 30% Wet Proofing

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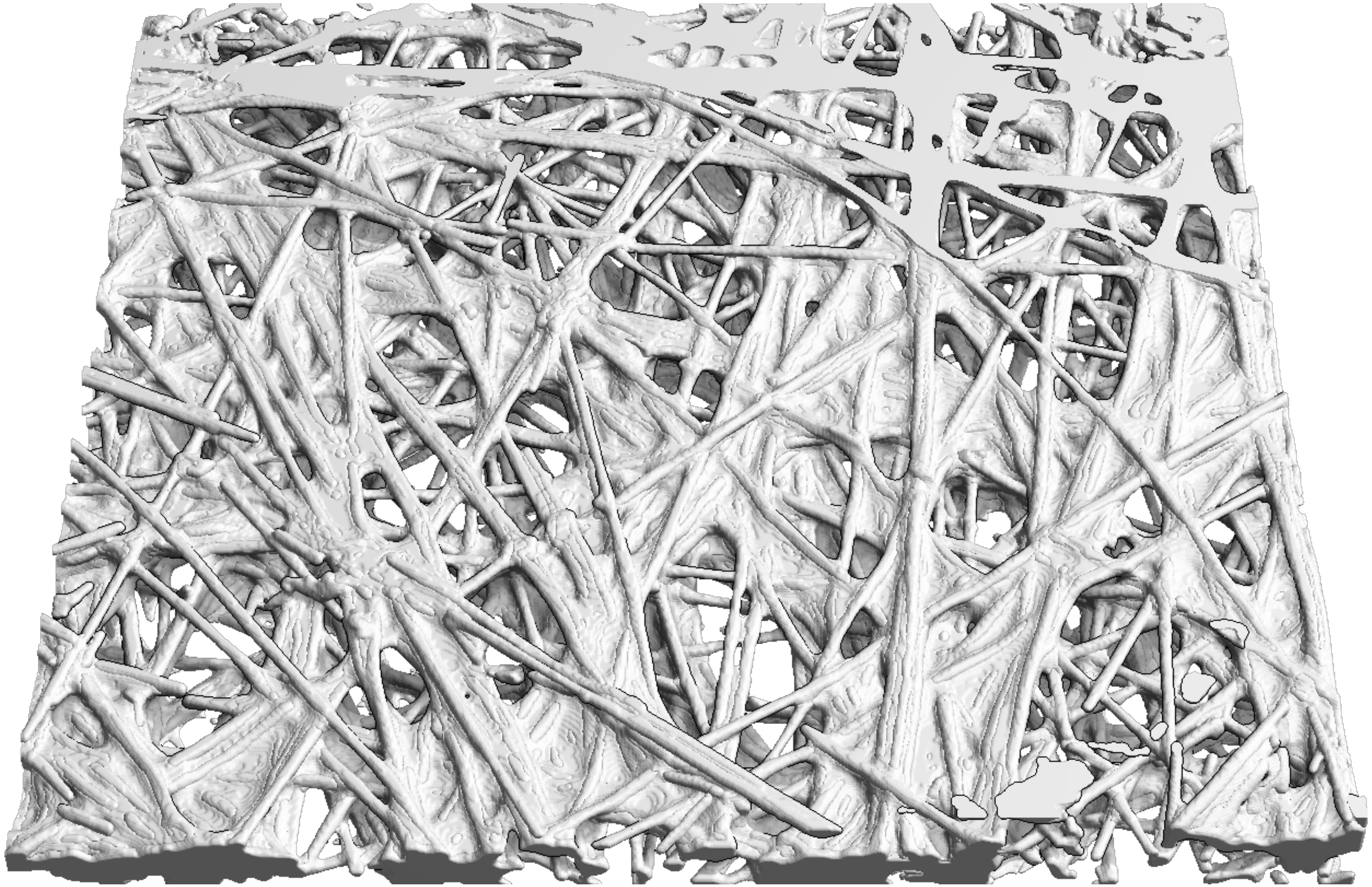
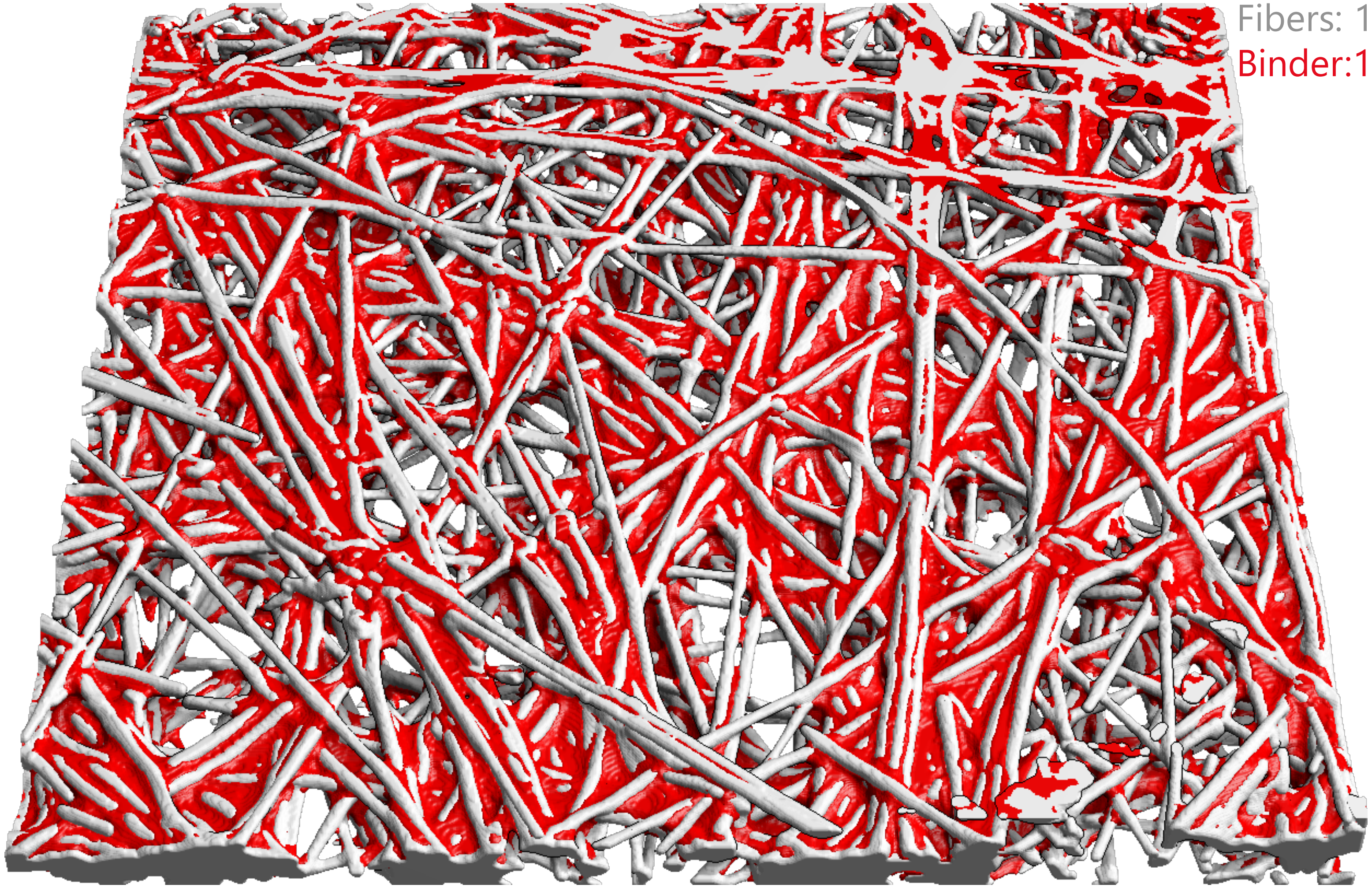


Toray Paper TGP-H-030, 30% Wet Proofing



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

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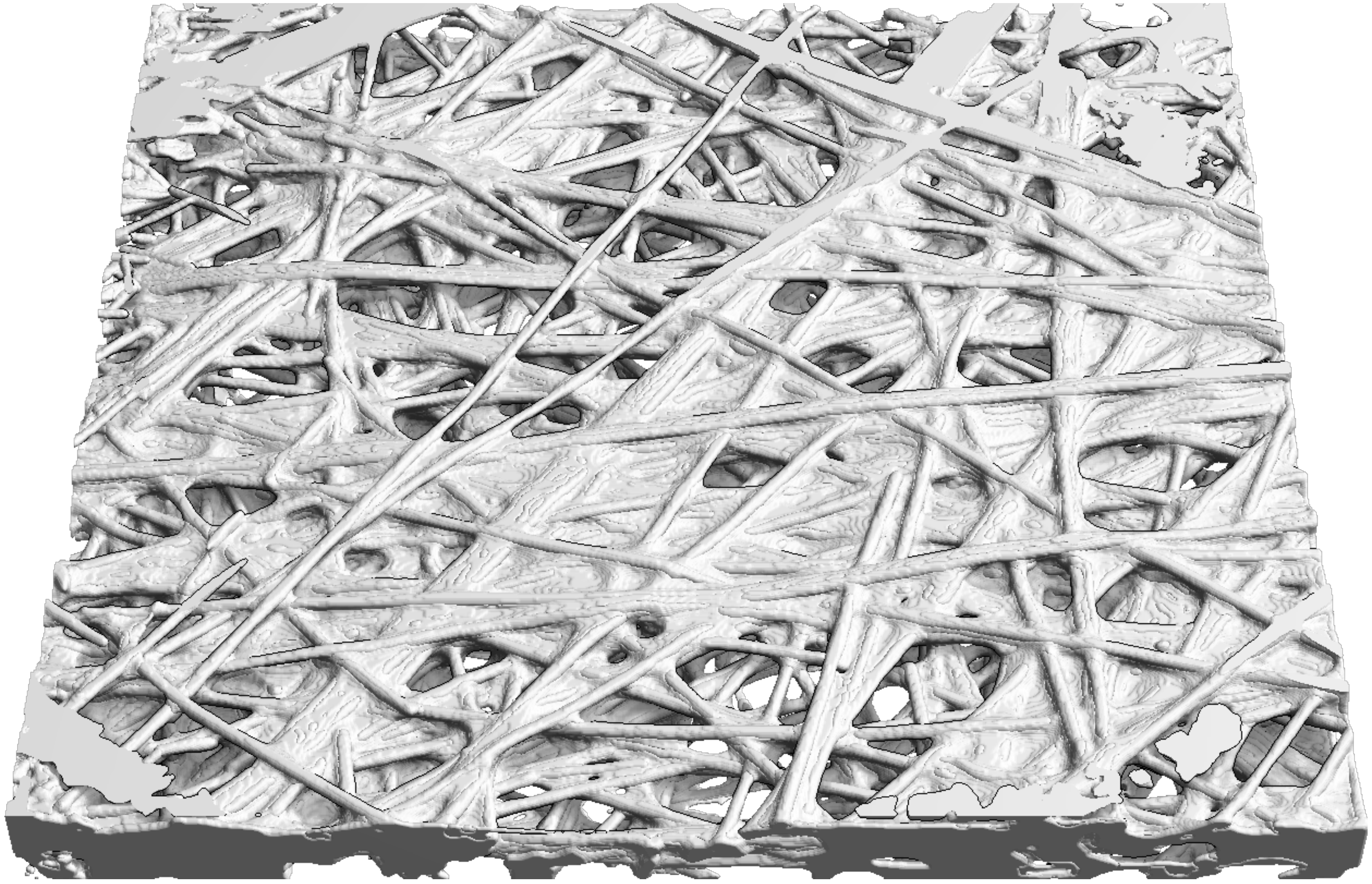

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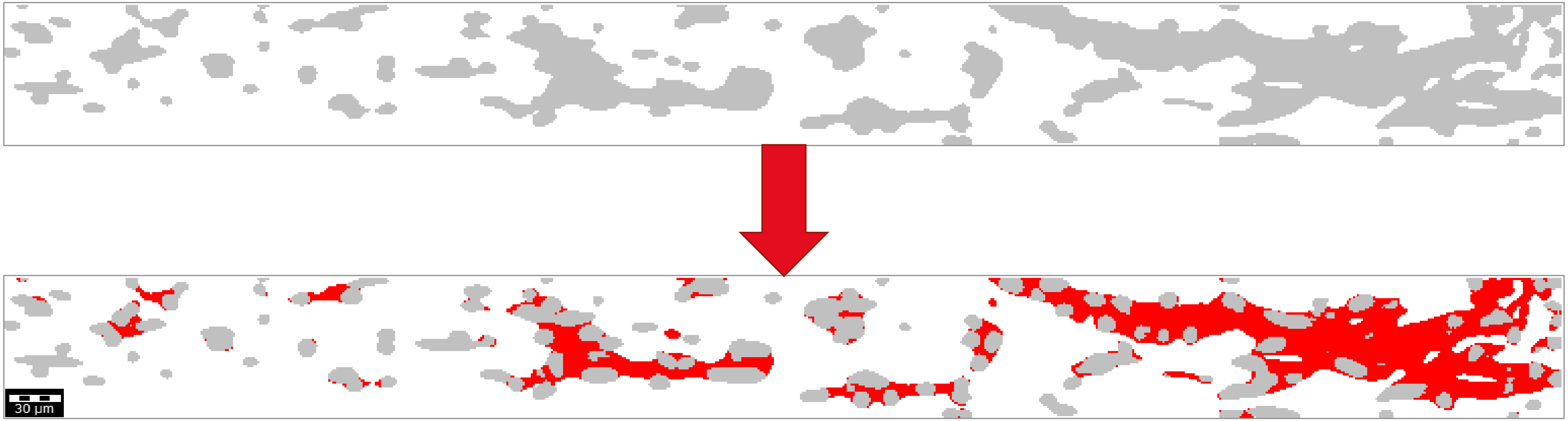
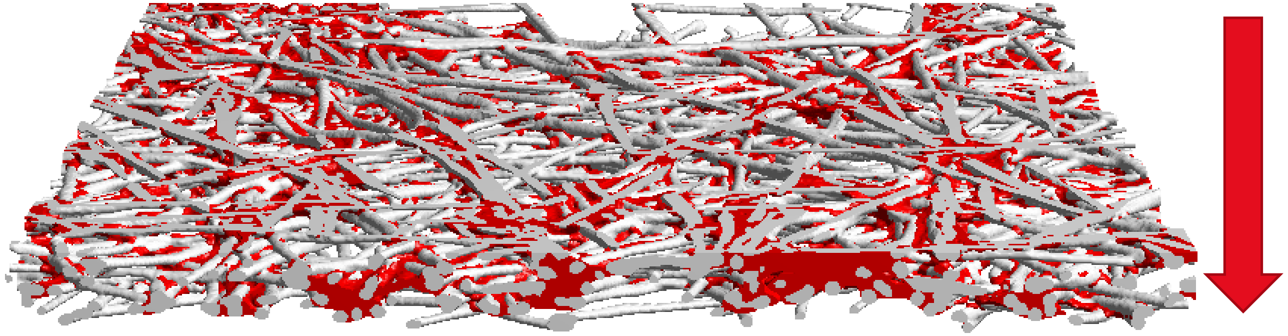
Fibers: 17%
Binder: 28%

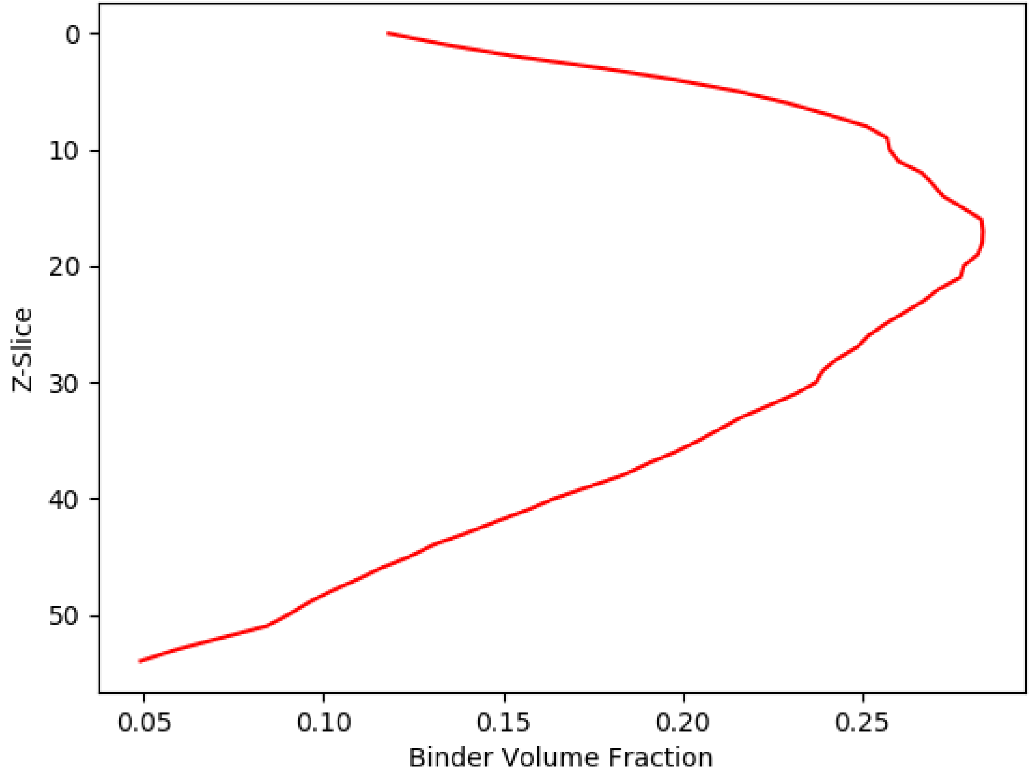
Binder identification in Gas Diffusion Layer

Crossection in X-Direction:



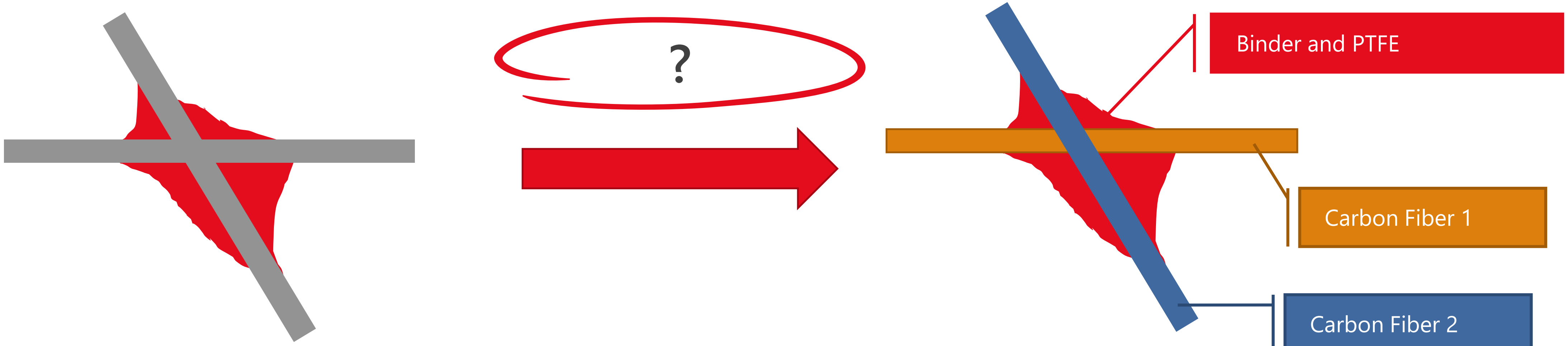
Binder Distribution in Z direction





- 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

Binder and Fibders



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

Next step segment individual fibers

IDENTIFYING INDIVIDUAL FIBERS

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- 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
  - Anisotropic material properties (limited possible without identification)

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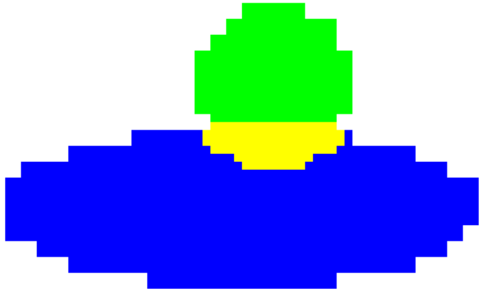
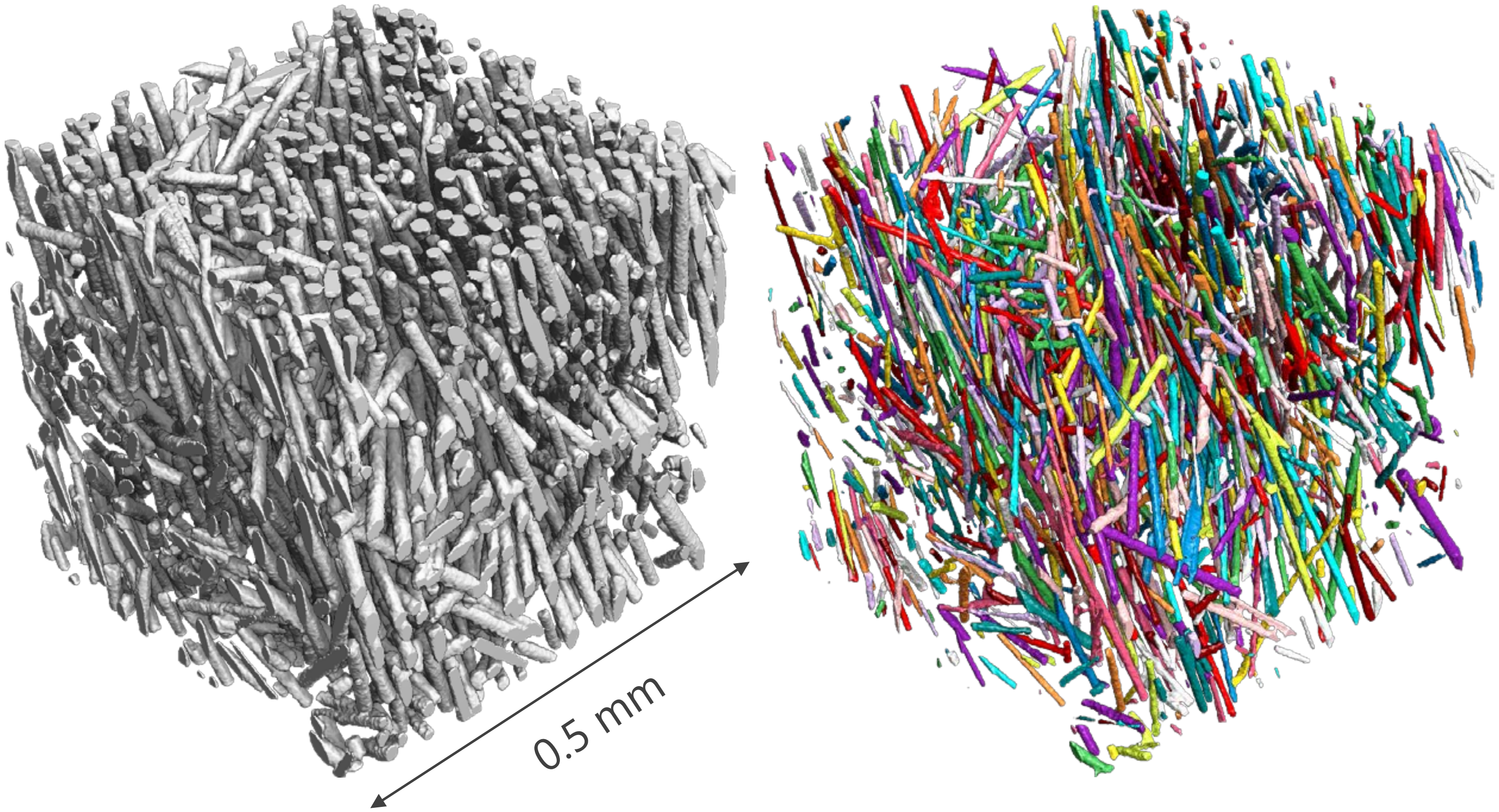
- By identifying contact voxels and removing them we can split up fibers that are touching each other
- For GeoDict generated fiber structure models information about the contact voxels is available easily



- 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



- GFRP scan
- 1000^3 Voxels
- 500nm Resolution

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

Future Work

- Investigate influence of anisotropic 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!

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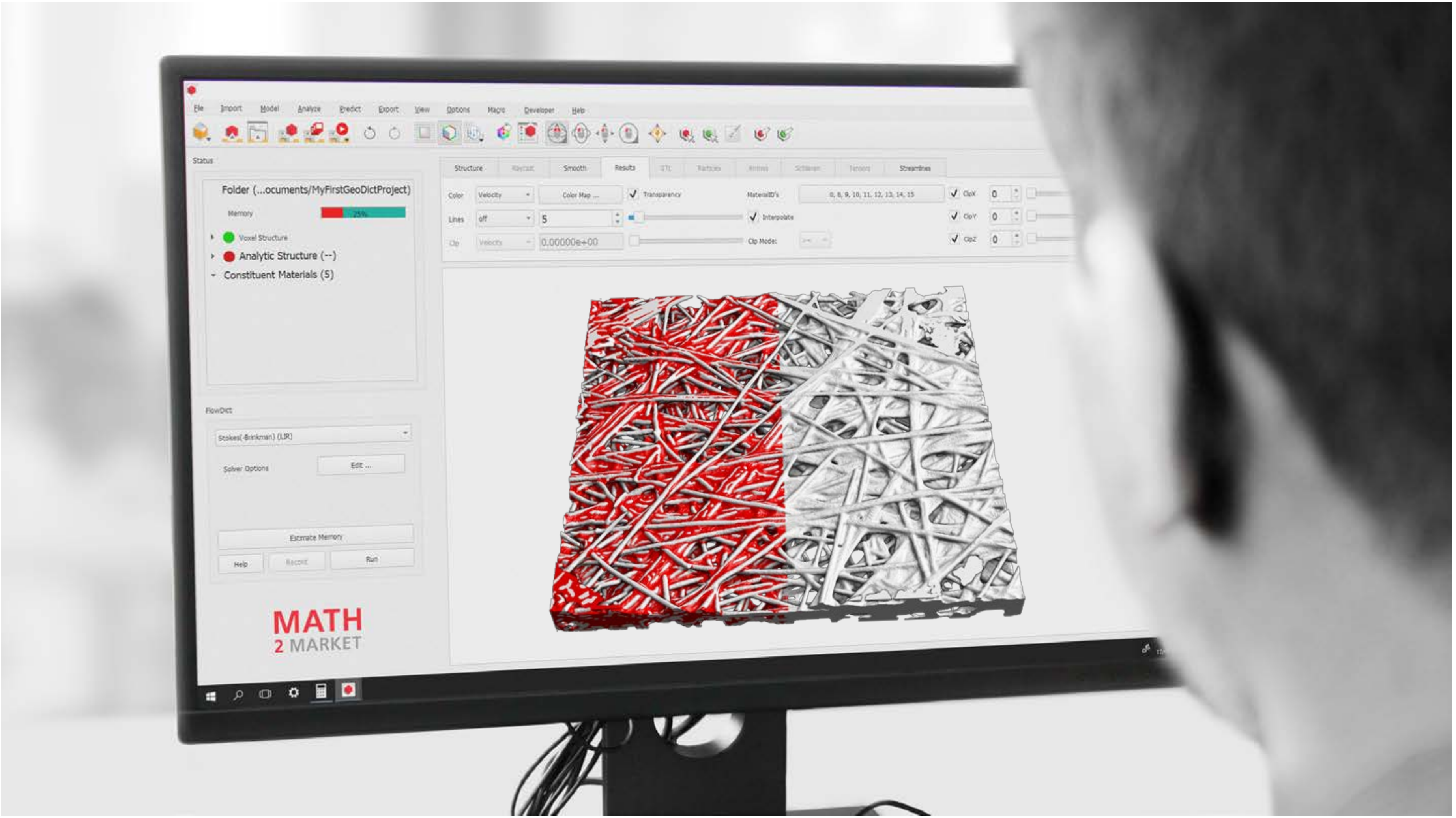

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BOOTH #8