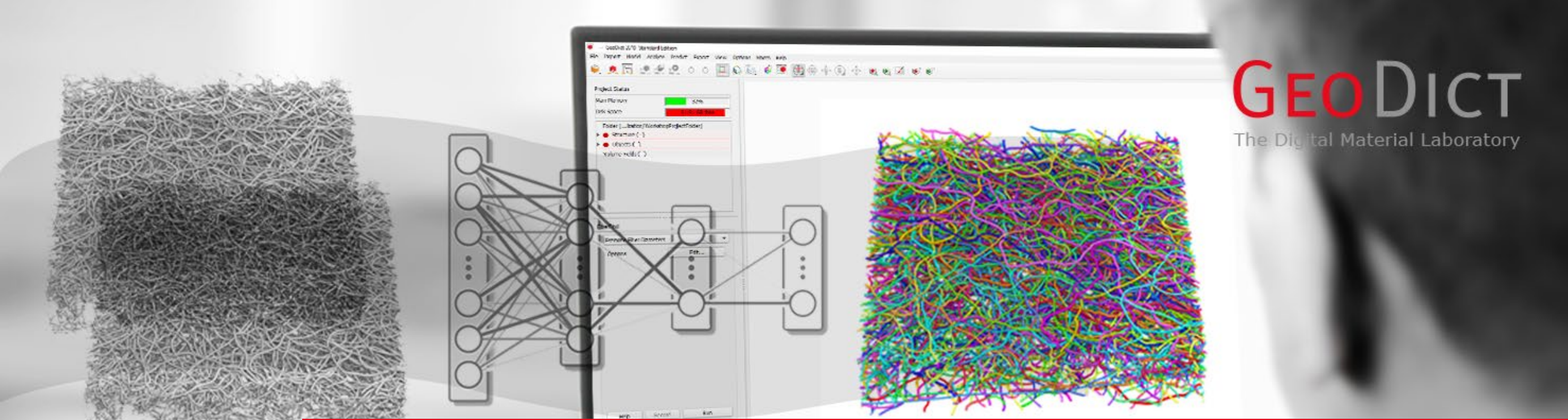

IDENTIFICATION OF FIBER CHARACTERISTICS OF A FILTER MEDIA BASED ON ARTIFICIAL INTELLIGENCE (AI) WITH GEODICT

Filtech 2019

Cologne, October 24th, 2019

FILTECH
October 22 – 24, 2019
Cologne – Germany

Andreas Wiegmann, Andreas Grießer, Rolf Westerteiger, Christian Wagner and Mehdi Azimian, Math2Market

MATH 2 MARKET

WHY DIGITALLY DESIGN FILTER MEDIA?

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and experiments

g and process
heaper than
and experiments

es

e *Augmented filter*
t by virtual
tion by
n Filtech 2019.

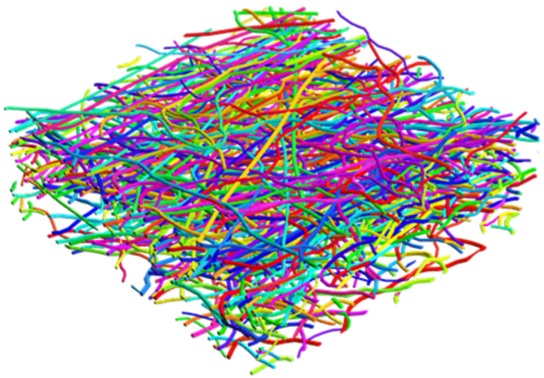
Does Digital Design require a digital twin?

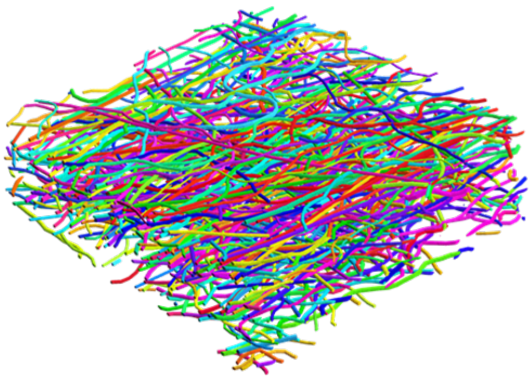
NO !

- We see segmented µCT scans of 2 cutouts of a filter media.
- They are both digital twins of the media
- Yet they differ
- They are data, not information
- And they cannot be used for filter media design!

Digital Design requires a statistical twin! (the material analogue of a digital twin)

GeoDict

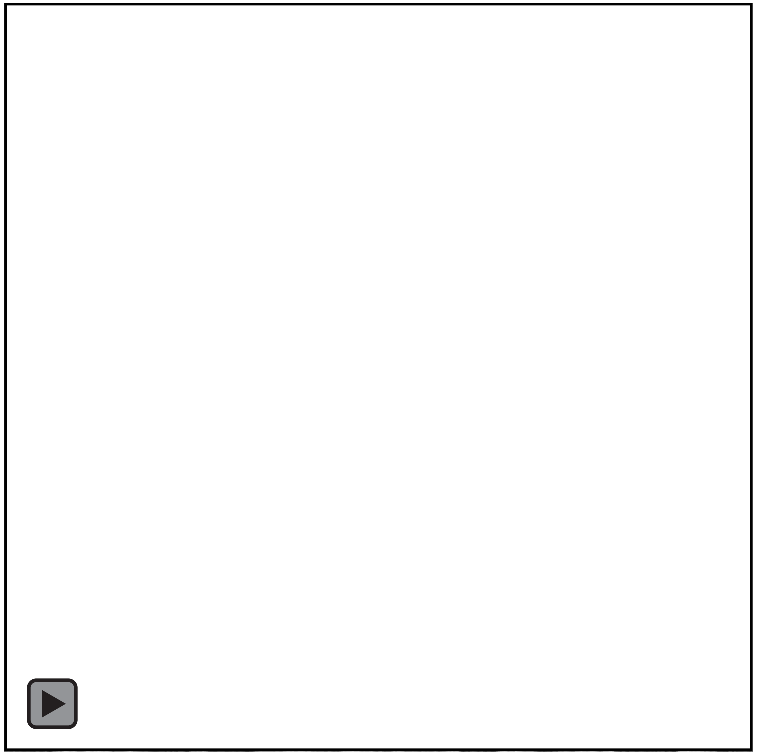




- Now we see the individual fibers
- We know their stats
  - diameters
  - orientations
  - Porosities
  - …
- The statistics are the same
- Modify the stats to optimize filter media!

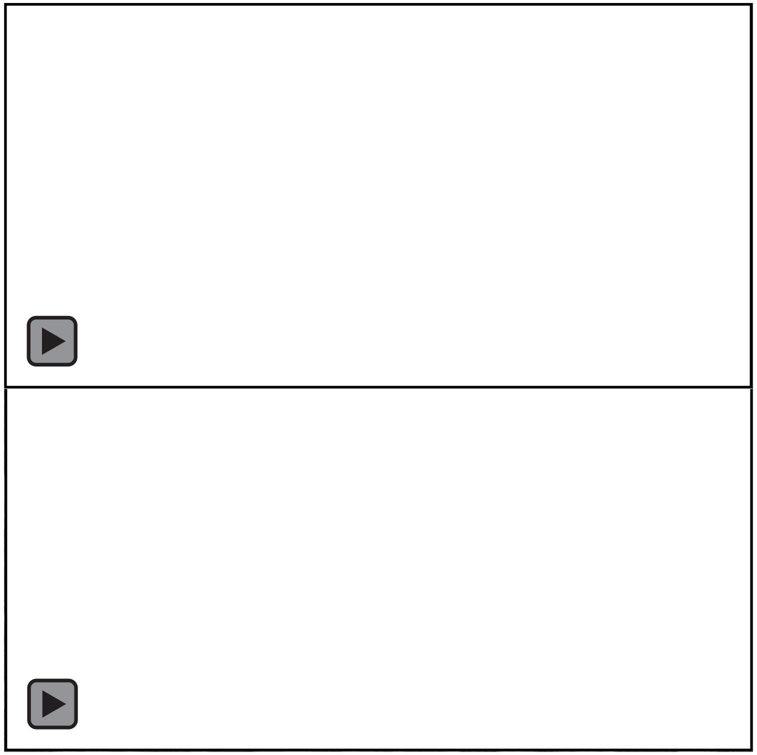
MATH 2 MARKET

What would we like to achieve?



Label Materials & objects in 3D scans

GeoDict



MATH 2 MARKET

Why label individual objects in scans?

GeoDict

- Obtain grammage total, per material or per class of objects
- Output of objects as triangulation (.stl), CAD (.dxf), etc.
- Find number of contact points per objects
- Determine shape & dimensions of individual objects
- Compute object orientation distributions
- Etc. etc.

- And then get statistics on these properties to use in stastical twins!

MATH 2 MARKET

How do we label CT scans?

GeoDict

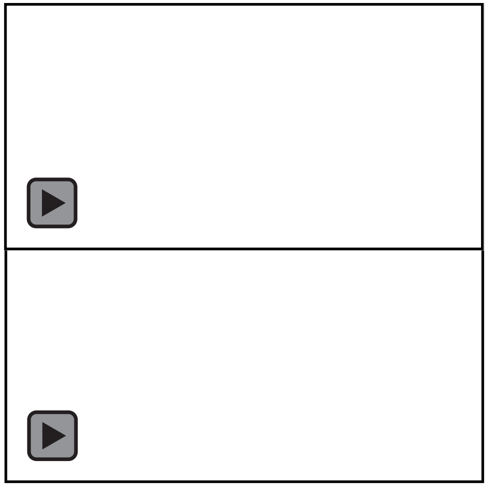
- *Now*: segment 3D scan; then label it using Artificial Intelligence
- **Soon**: label scan (gray values) directly with Artificial Intelligence

How do we do it?

GeoDict

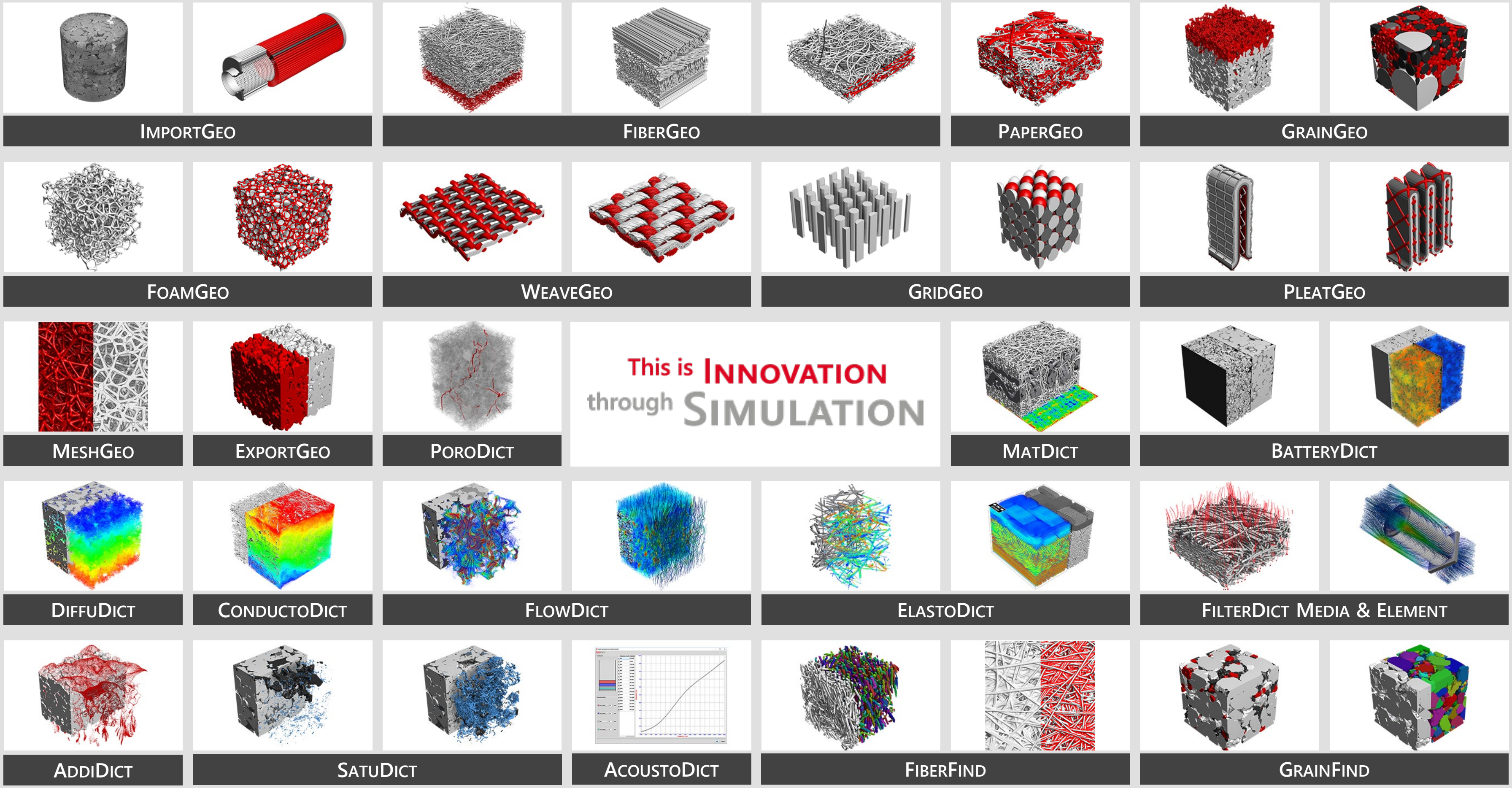
- *Now*: segment 3D scan; then label it using Artificial Intelligence
- **Soon**: label scan (gray values) directly with Artificial Intelligence

- AI requires training data / ground truth
- Segmented training data can be created with GeoDict today
- Gray value images can be created with GeoDict soon
- Both are used to train next generation neural networks in GeoDict



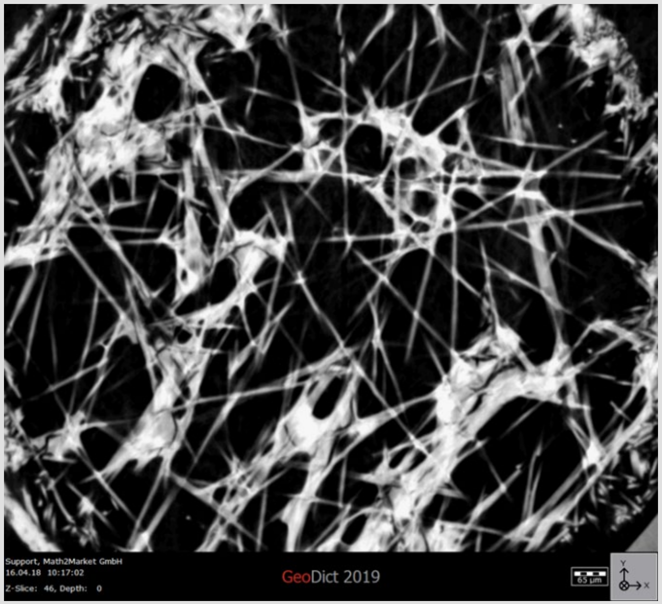
MATH 2 MARKET

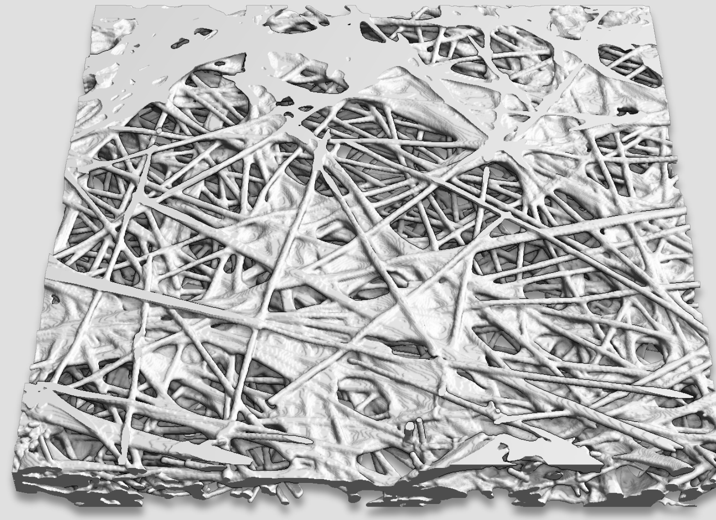
GeoDict® Models -
A Rich Source for AI Training Data



SEGMENTATION OF A SCAN

GEODICT





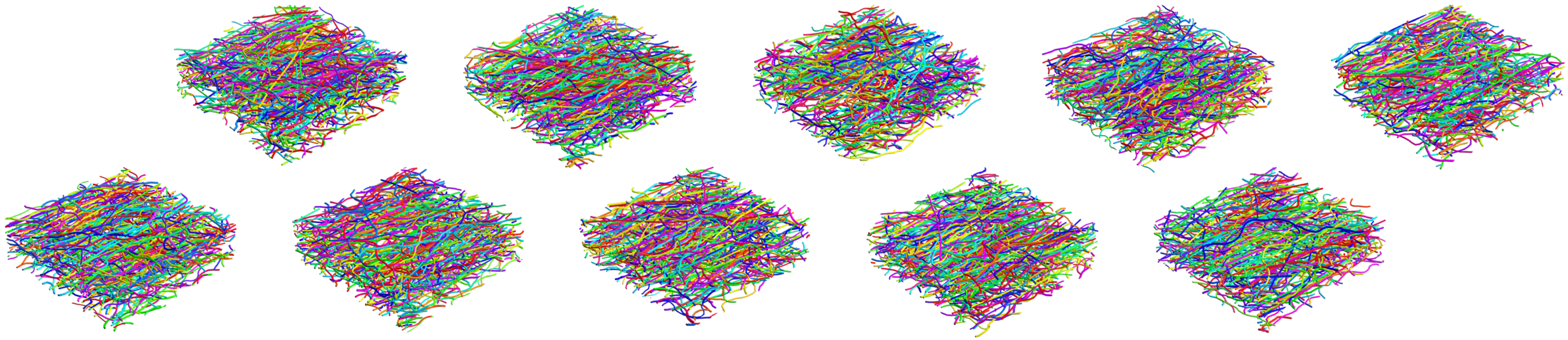
From stack of gray value slices

To 3-D empty / solid image

MATH 2 MARKET

Statistical Siblings provide ground truth

GeoDict

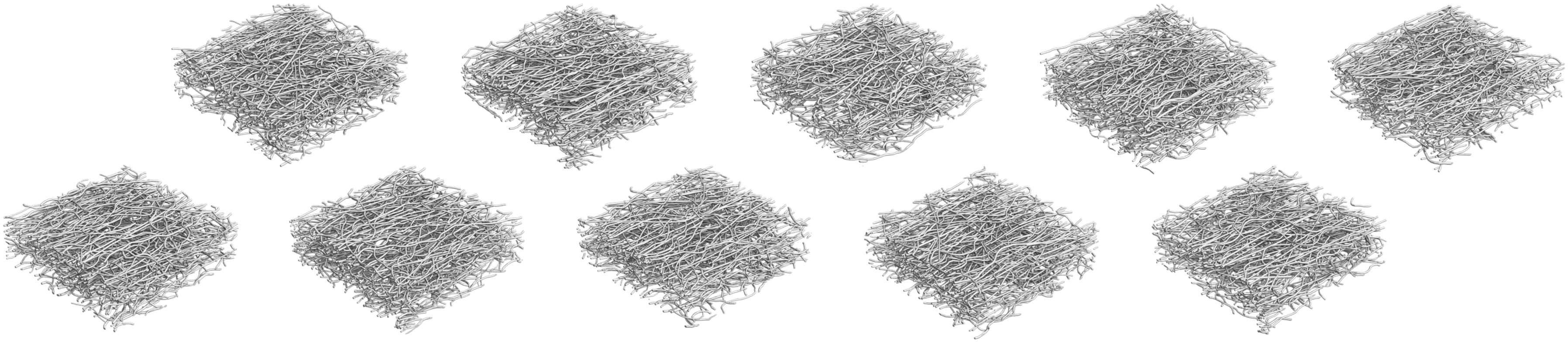


Training Data: Use GeoDict's unique fiber modelling capabilities:

- Modeled 10 Statistical siblings (512x512x256 Voxels) as training data
- Varied fiber curvature, orientation, length and diameter
- Corresponded to ~0.5 billion solid voxels as training data points

MATH 2 MARKET

Statistical siblings mimic segmented scans

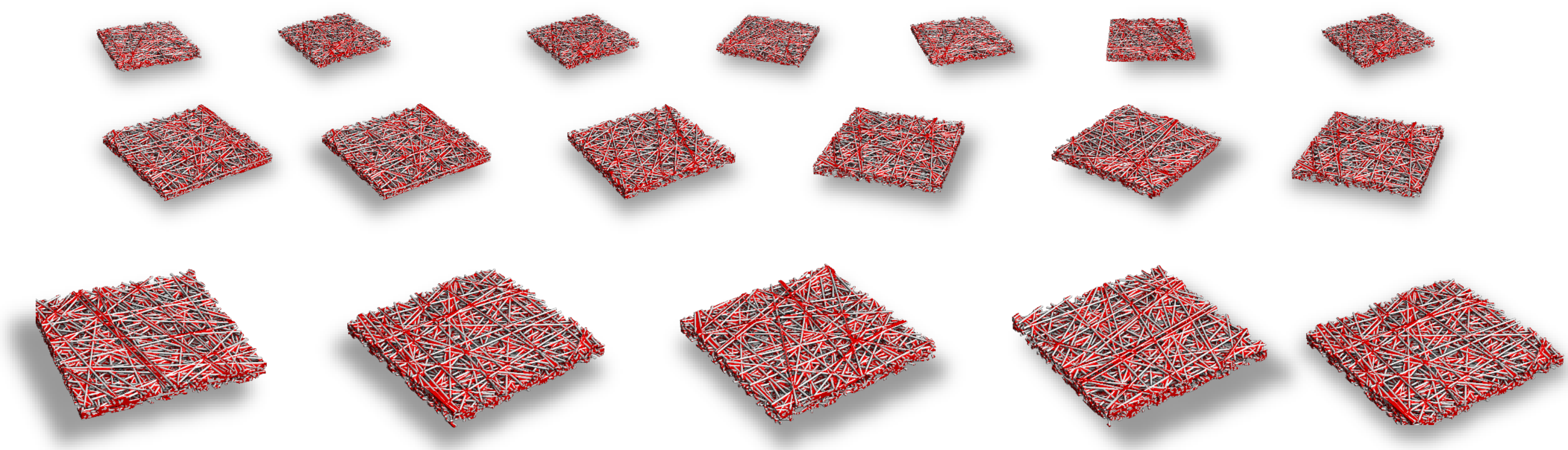


Training Data: Then make the models look like binarized scans!

- All fibers in the models get the same gray value, just as in the segmented 3D scans

STATISTICAL SIBLINGS ALSO WITH BINDER

GEODICT



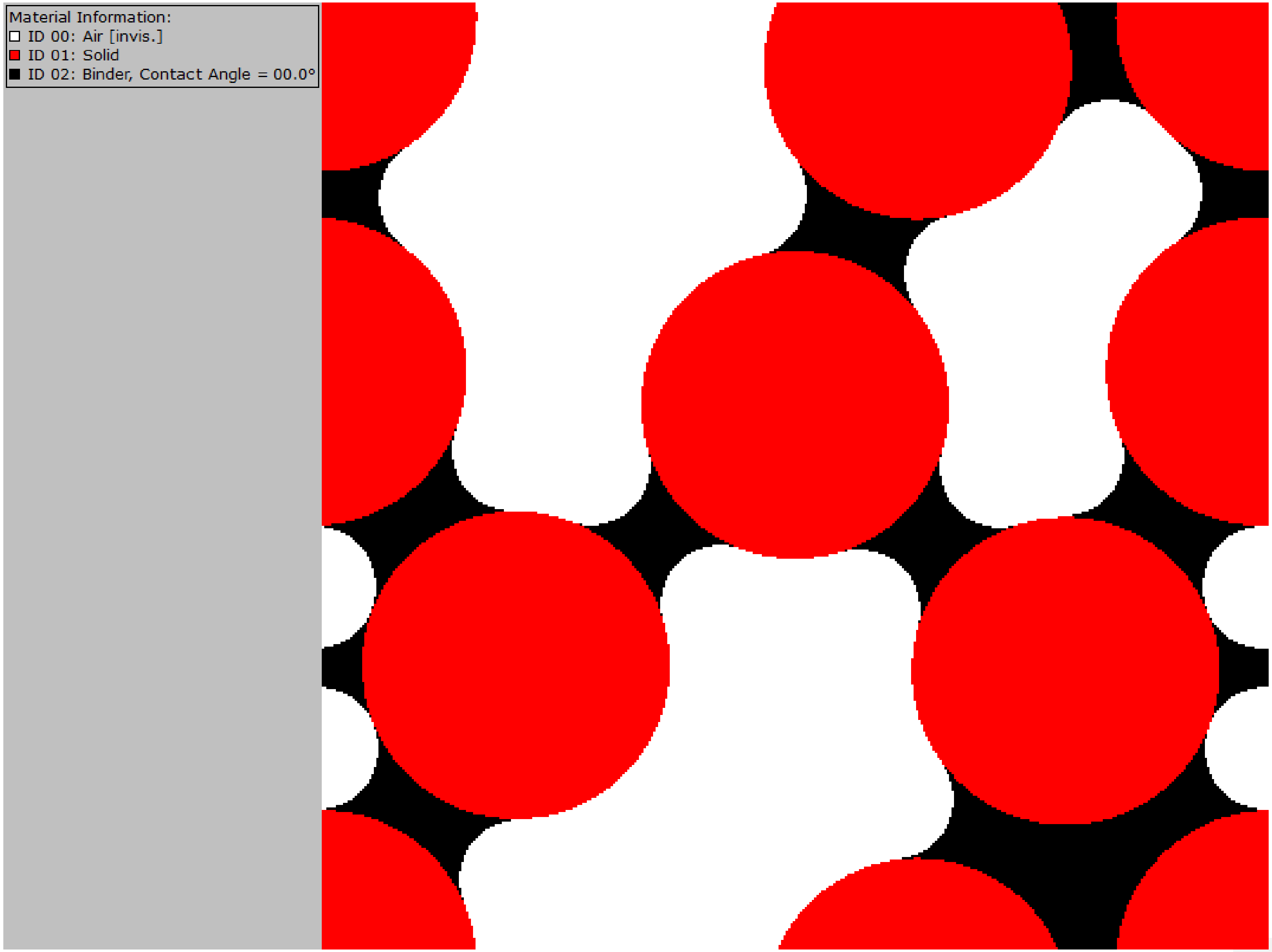
Solution: Use GeoDict's unique material modelling capabilities

- modeled 18 statistical siblings (512x512x256 Voxels) as training data
- varied porosity, binder parameters as estimated
  for 4 different (Toray GDL) samples
- corresponds to ~0.8 billion solid voxels as training data points

MATH 2 MARKET

ADDING BINDER: CONTACT ANGLE 0°

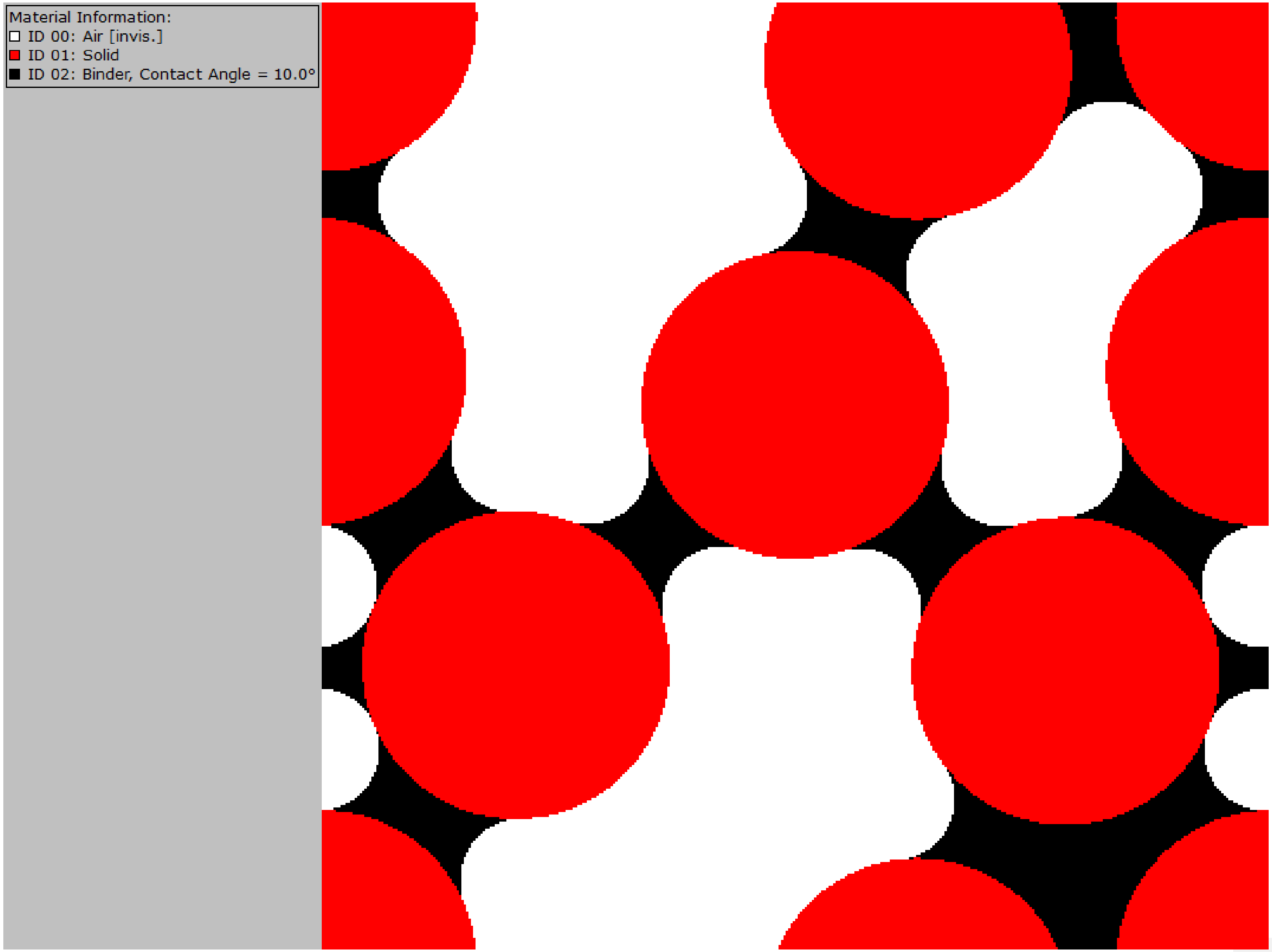
GEODICT



MATH 2 MARKET

Adding binder: contact angle 10°

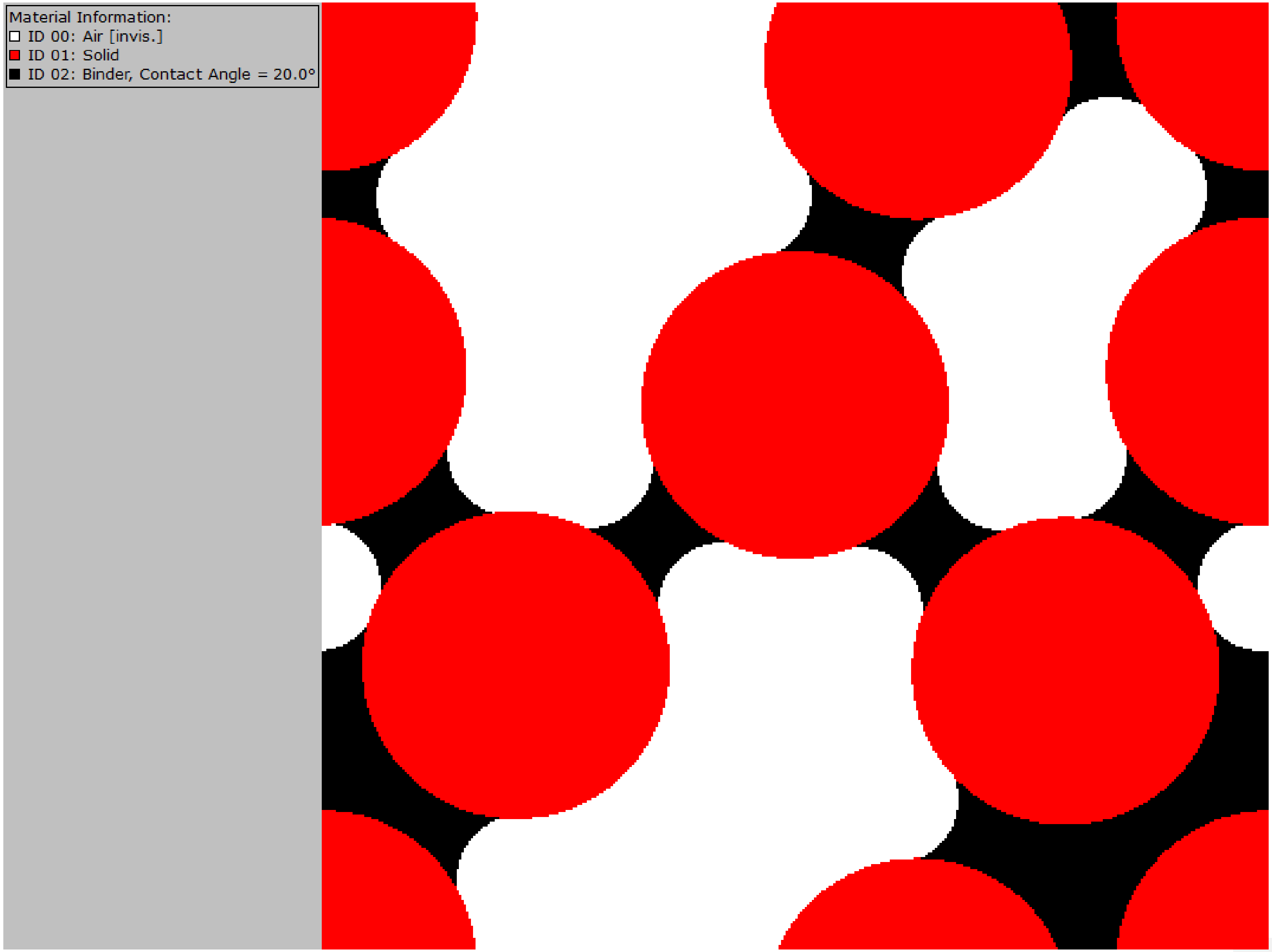
GeoDict



MATH 2 MARKET

Adding binder: contact angle 20°

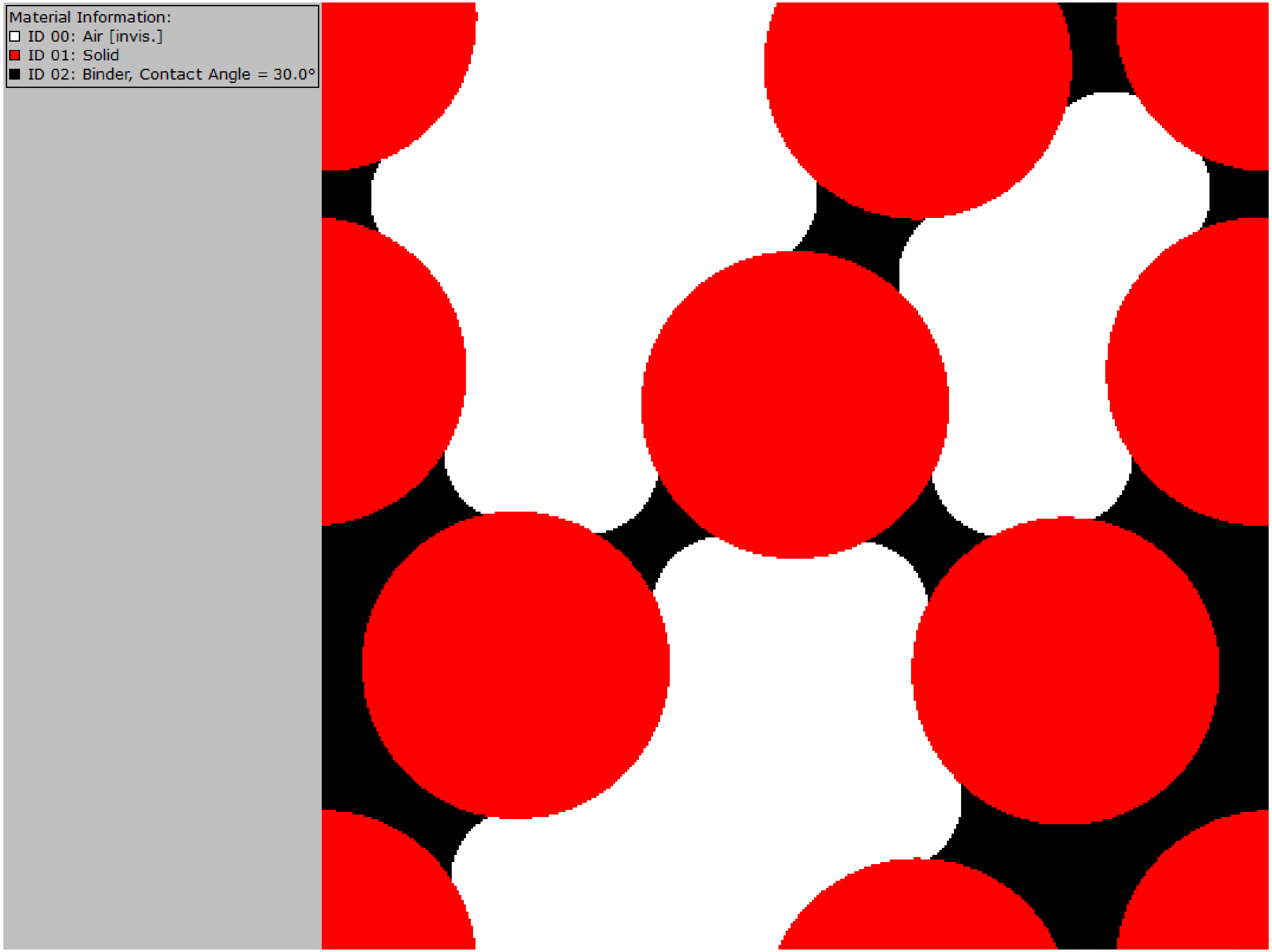
GeoDict



MATH 2 MARKET

Adding binder: contact angle 30°

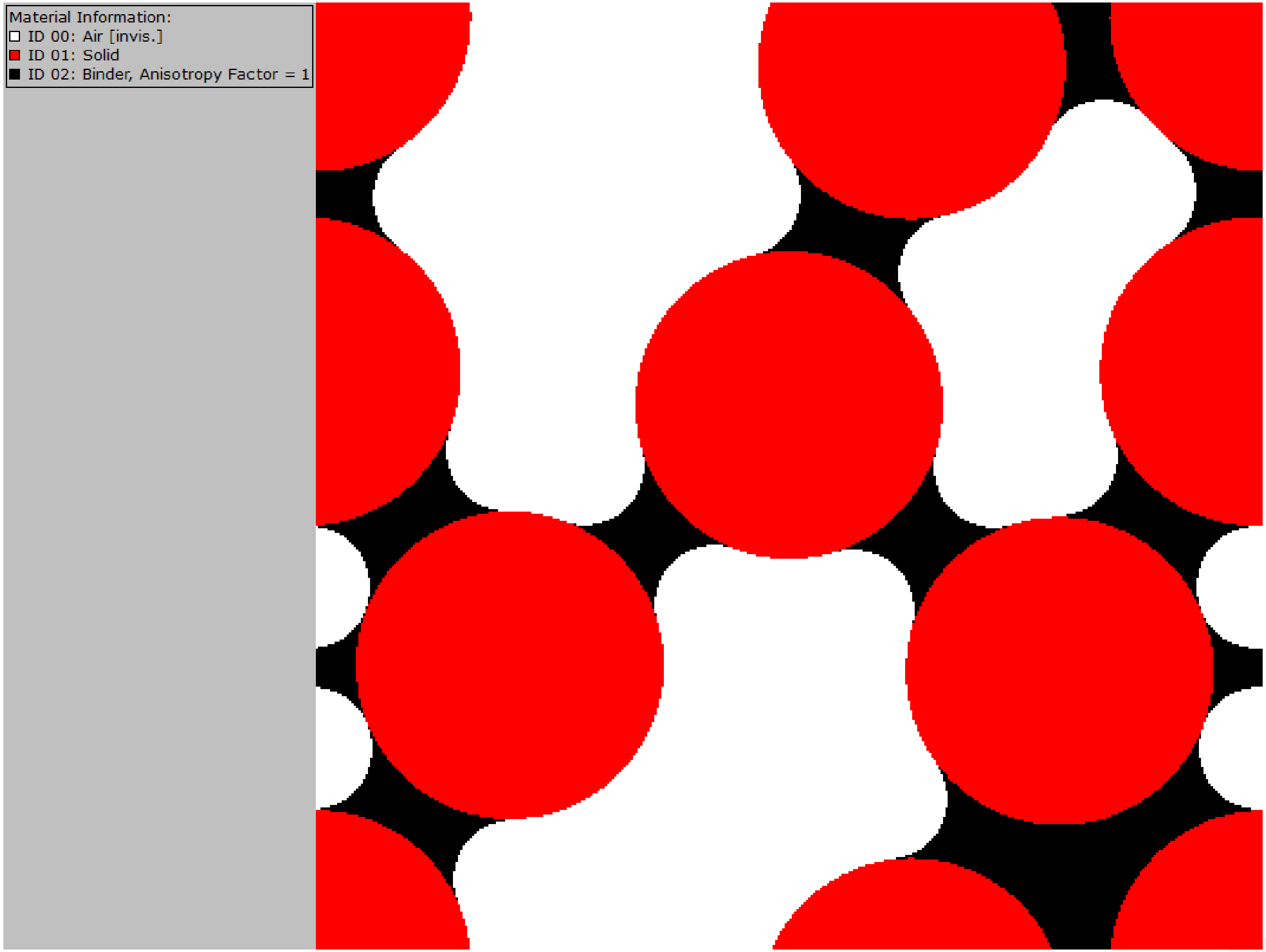
GeoDict



MATH 2 MARKET

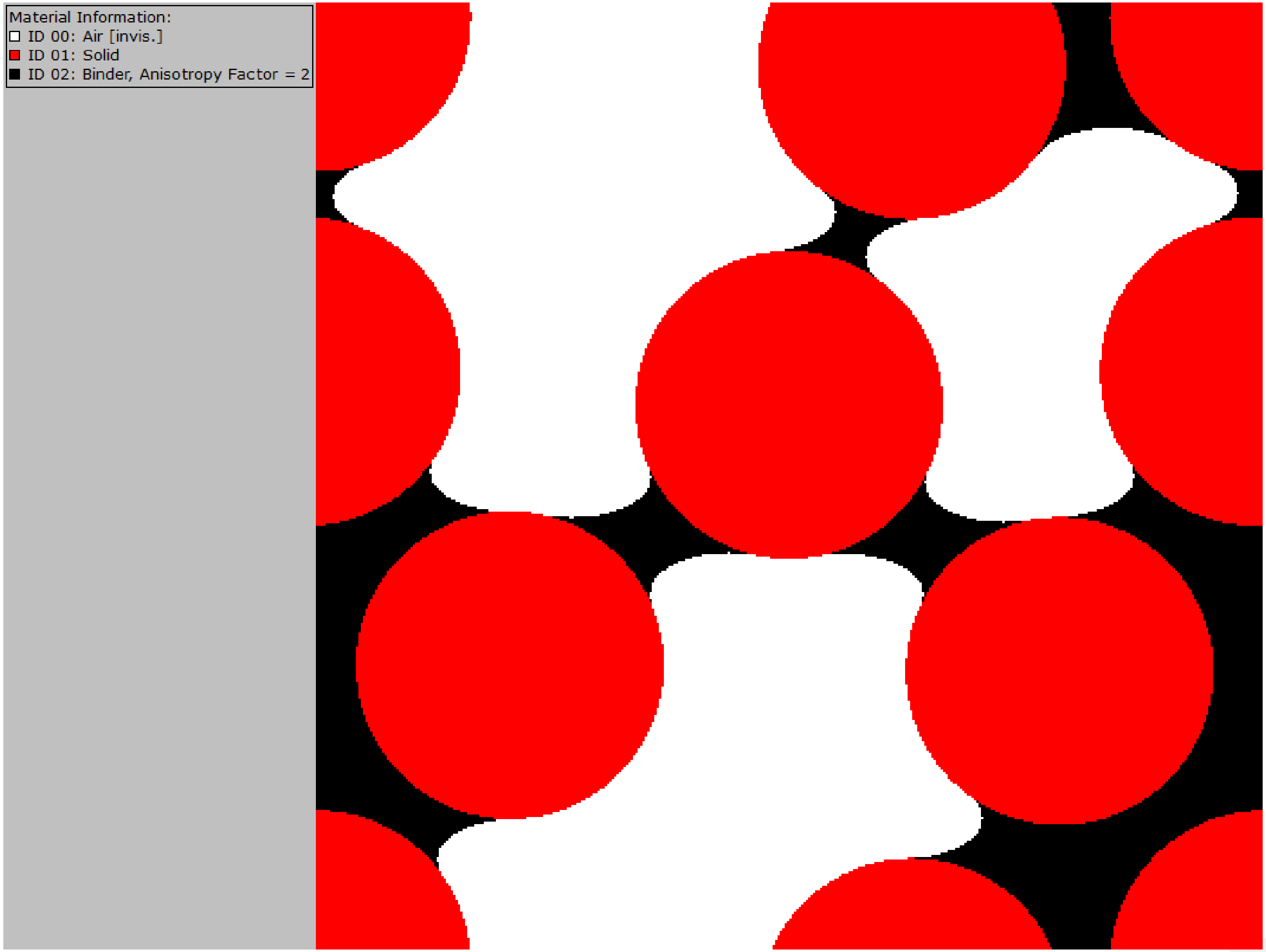
Isotropic binder (Anisotropy Factor 1)

GeoDict



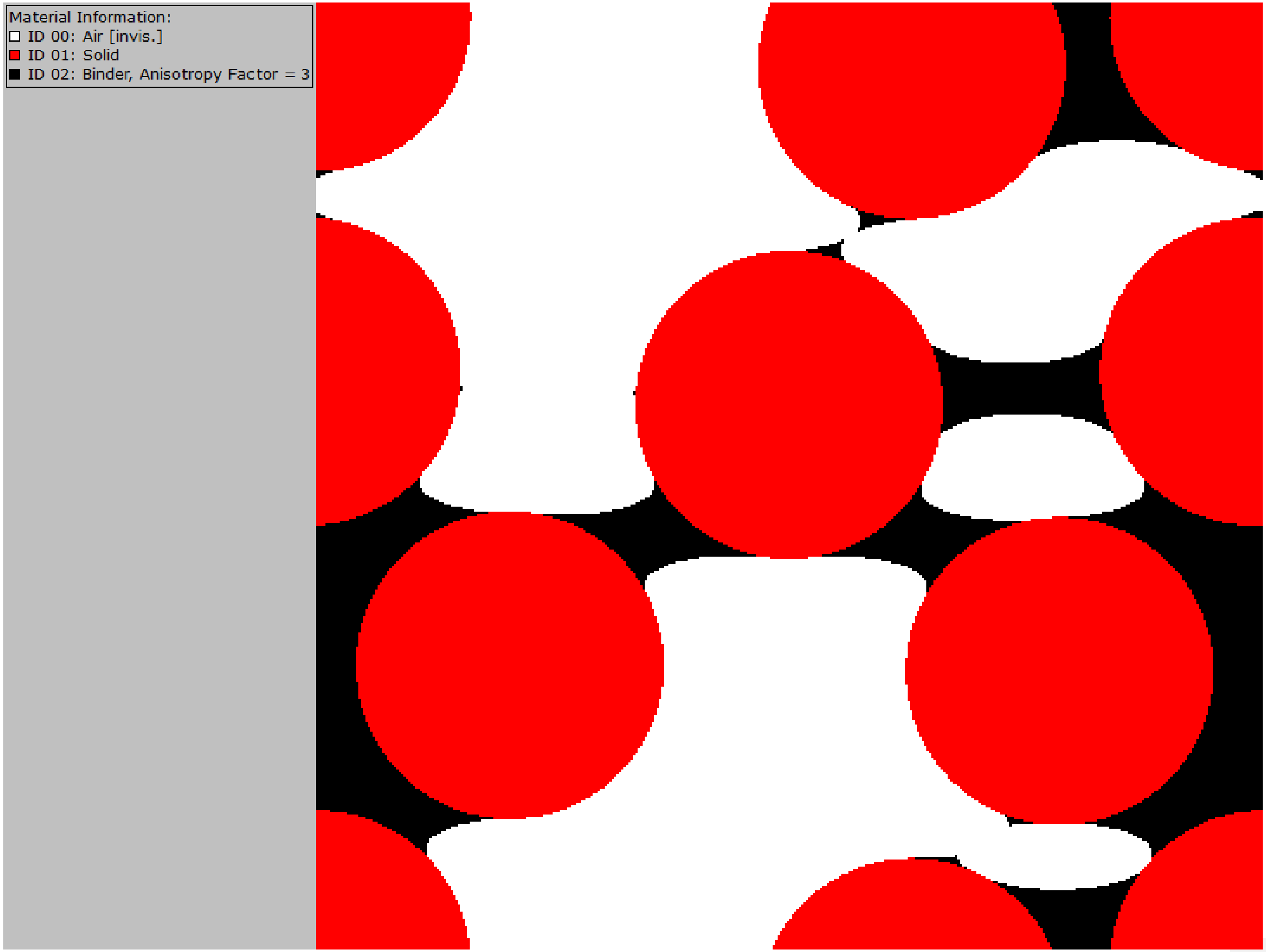
MATH 2 MARKET

Ansotropic binder (Anisotropy Factor 2)



Ansotropic binder (Anisotropy Factor 3)

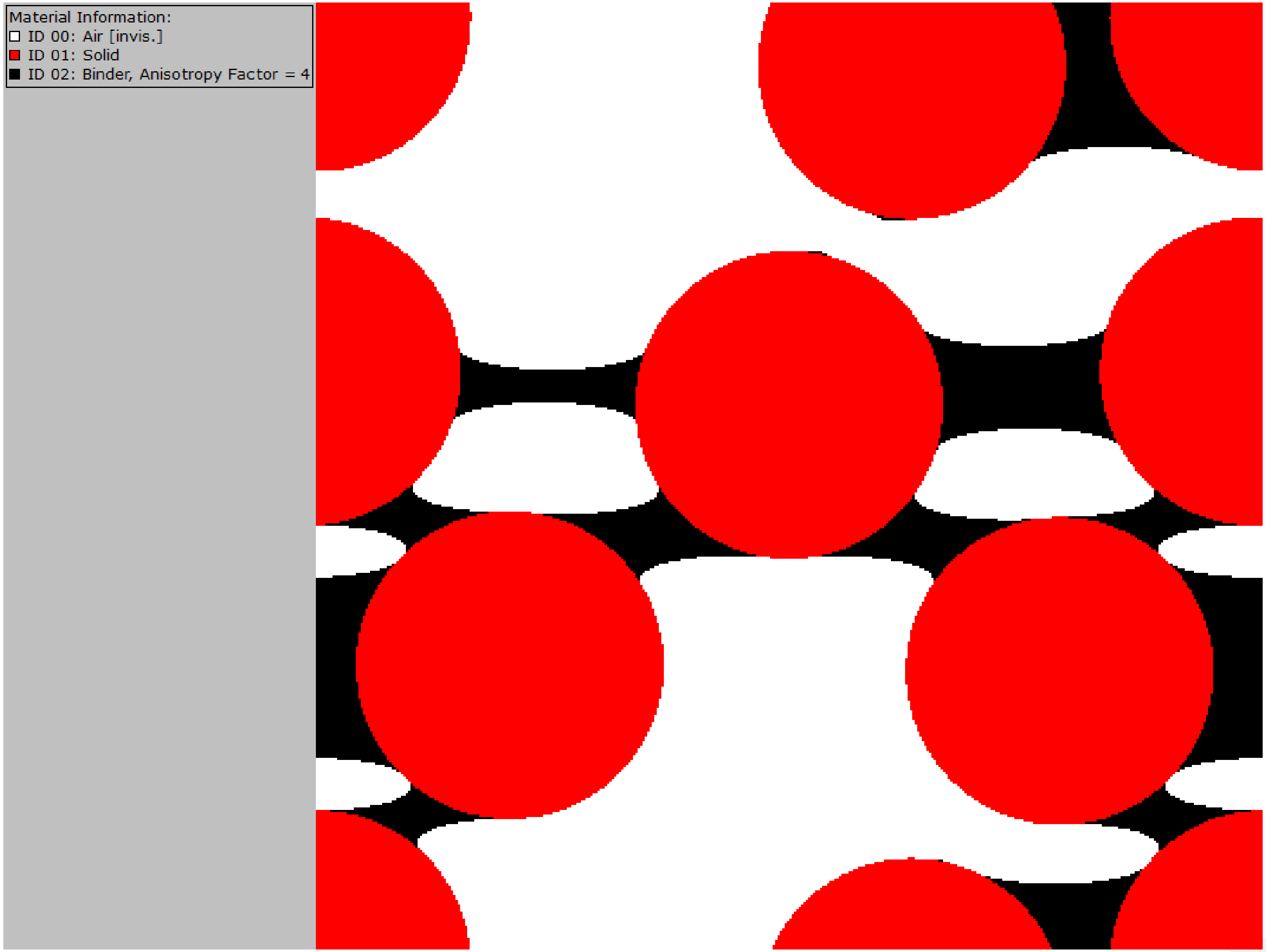
GeoDict



MATH 2 MARKET

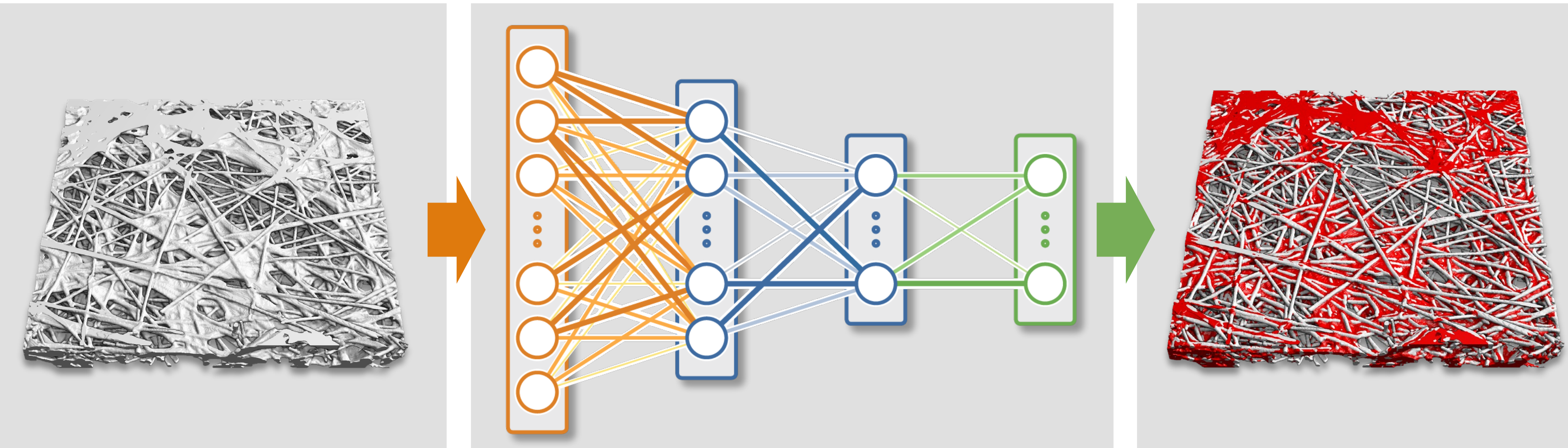
ANSOTROPIC BINDER (ANISOTROPY FACTOR 4)

GEODICT



MATH 2 MARKET

Neural network (N.N.) training & usage phases



Training: **N.N. learns edge weights** **from input and output**

- input: Statistical Twin data: binarized version
- output: Statistical Twin data: labeled binder and fibers version

Usage: **N.N. predicts labeled output** **from input and edge weights**

- input: 3D scan data: binarized
- output: 3D scan data: labeled binder and fibers

Toray Paper TGP-H-030, 05% Wet Proofing

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

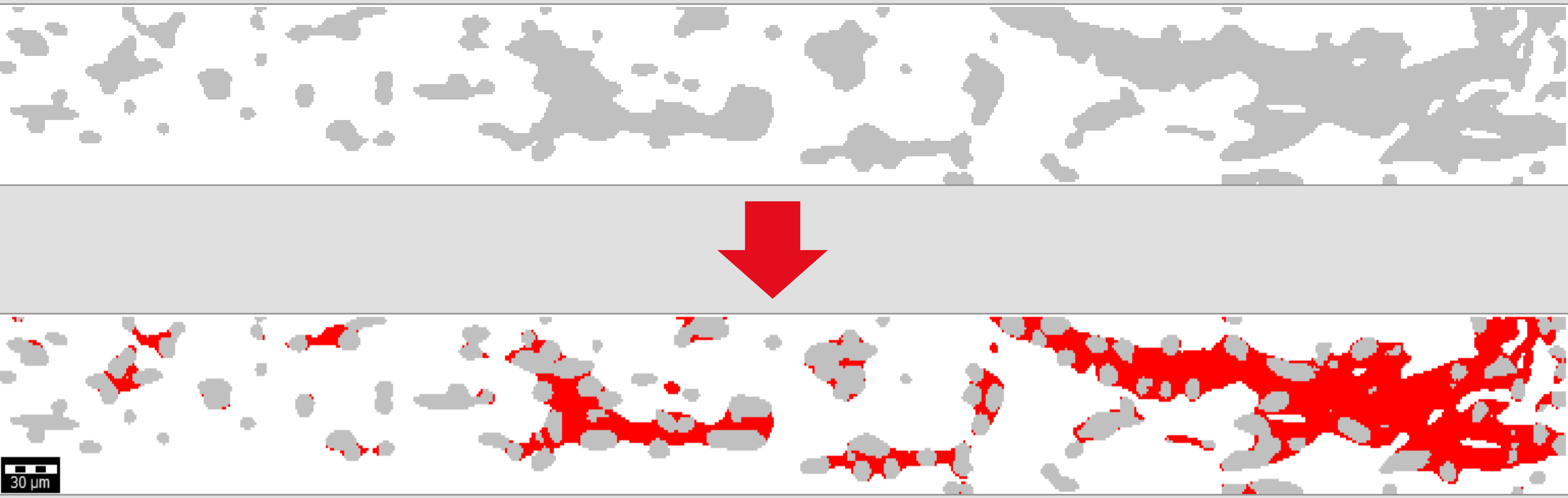
Toray Paper TGP-H-030, 30% Wet Proofing

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

Binder identification in Gas Diffusion Layer

GeoDict

Crossection in X-Direction:

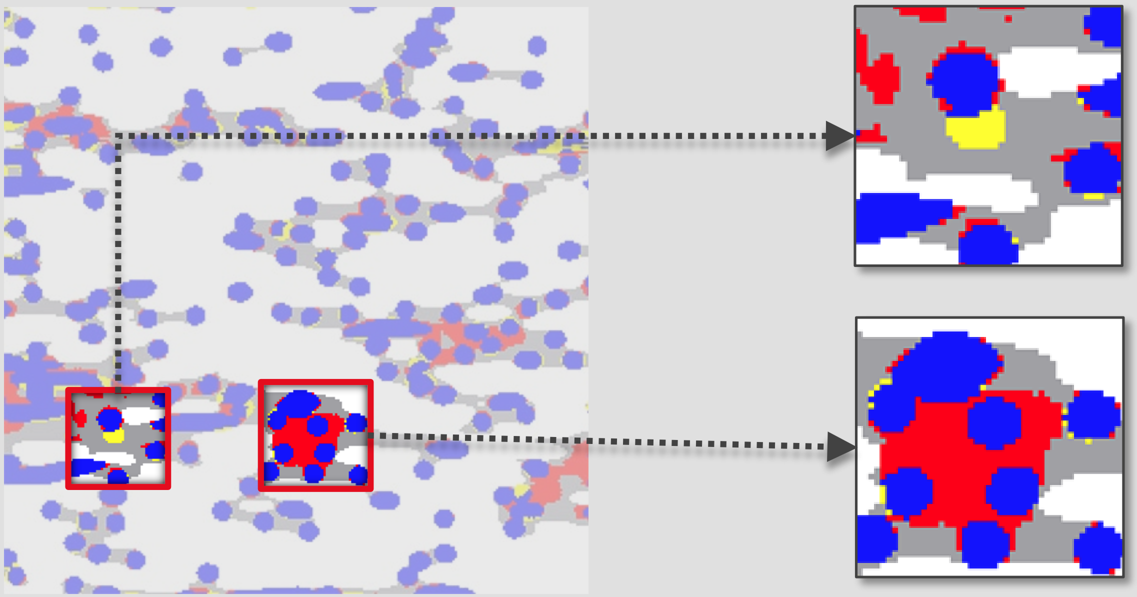


Idea: Maybe create 3-D Statistical Twins from 2-D images using AI in the future?

MATH 2 MARKET

VALIDATION – MISSCLASSIFICATION ANALYSIS OF BINDER / FIBERS

GEODICT



Red error: 8% of binder falsely classified as fiber

Yellow error: 3.6% of fibers falsely classified as binder

Direct comparison of ground truth Statistical Twin to n.n. result

- Blue/gray/white: correctly identified fiber/binder/pore
- Total binder volume percentages: True **13.1%**, predicted **11.5%**

MATH 2 MARKET

EXAMPLES OF COMPUTABLE QUANTITIES

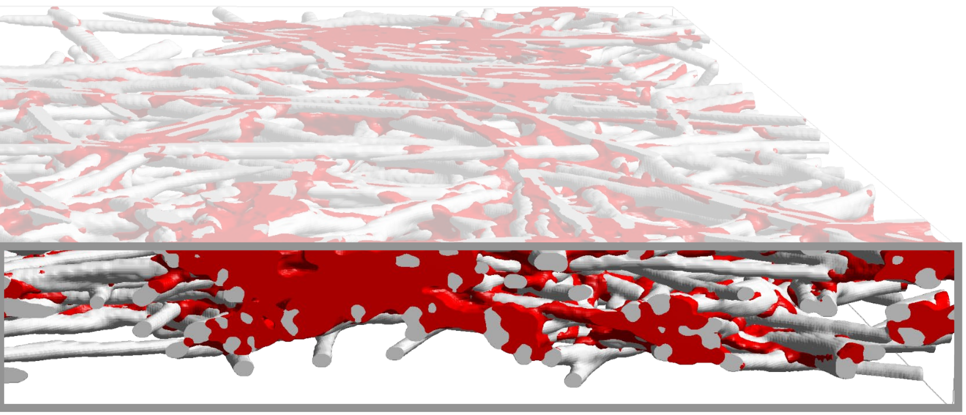
GeoDict

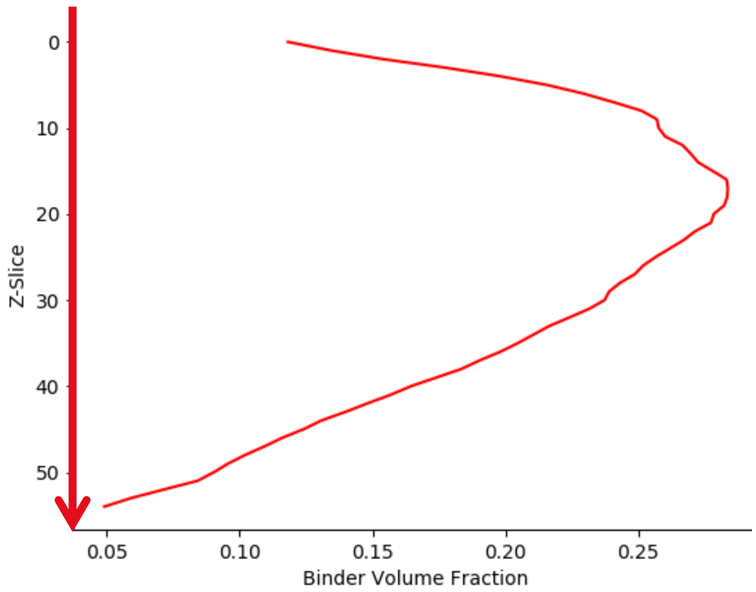
- **Grammage / volume percentages: total, binder only or fibers only**
- **Binder distribution in through-plane and in-plane directions**
- Size-distribution of binder points
- Total number of binder blobs/components
- Output of binder or fibers as triangulation (.stl), CAD (.dxf), etc.
- Number of contact points per fiber
- Length of individual fibers
- Curvature distribution along individual fibers

MATH 2 MARKET

Binder Distribution in Z direction

GeoDict



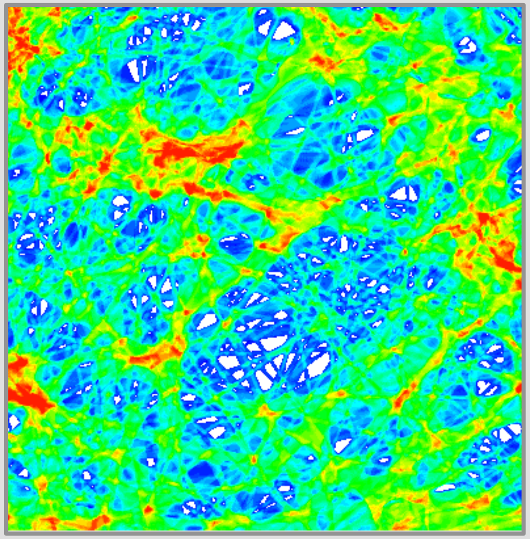


- In production, binder is applied to the top of the fiber and, then, intrudes into deeper layers
- After labelling binder voxels, we can compute the distribution of binder in through direction (right)

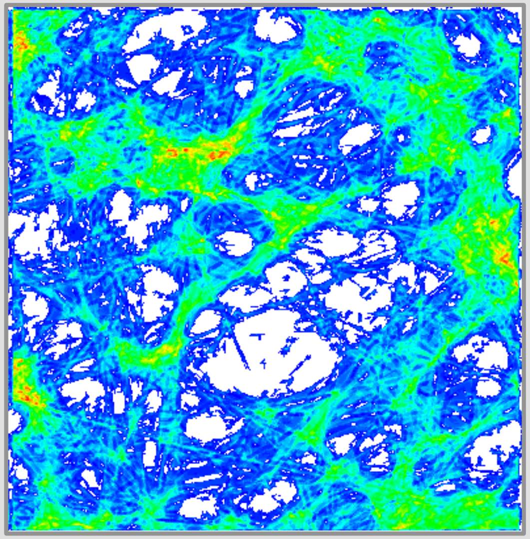
MATH 2 MARKET

IN-PLANE MATERIAL DISTRIBUTION (MATDICT)

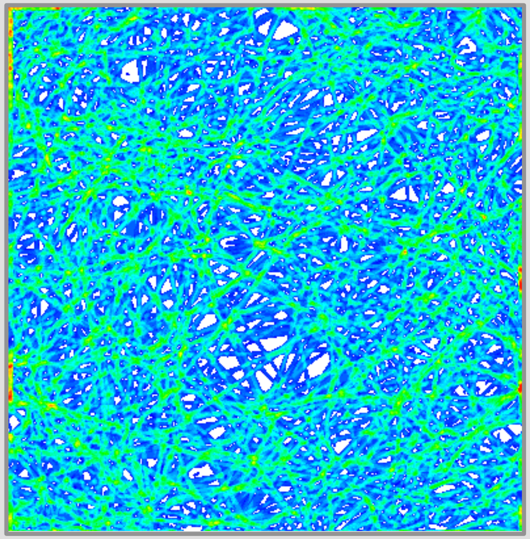
GEODICT



Both materials



Binder only

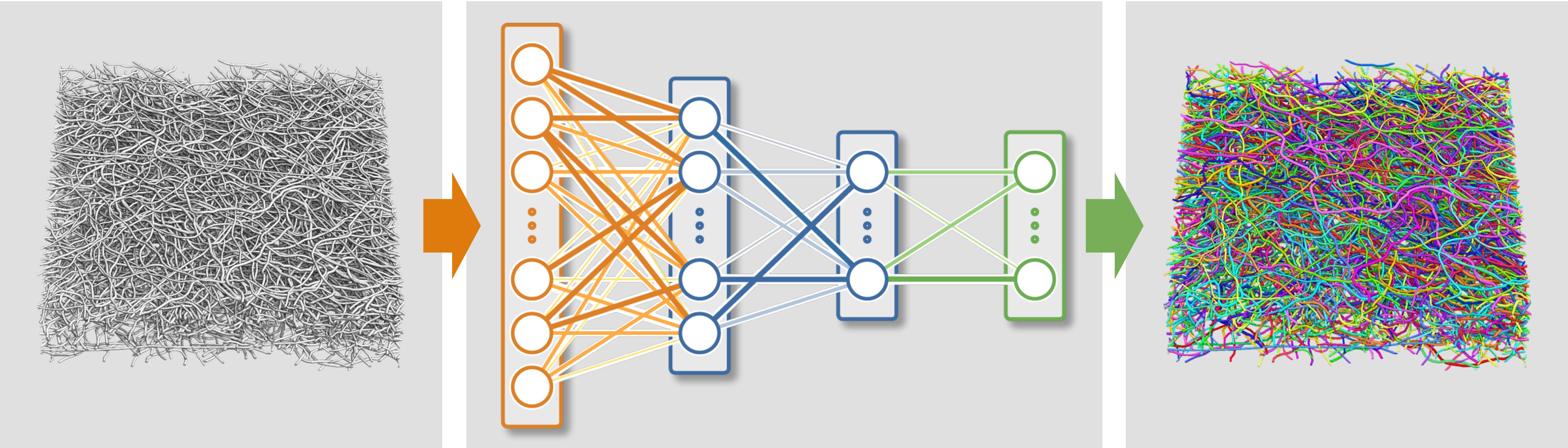


Fibers only

Scale: White: 0% volume fraction, Red: 7.2% volume fraction

MATH 2 MARKET

NEURAL NETWORK (N.N.) TRAINING & USAGE PHASES



Training: **N.N. learns edge weights from input and output**

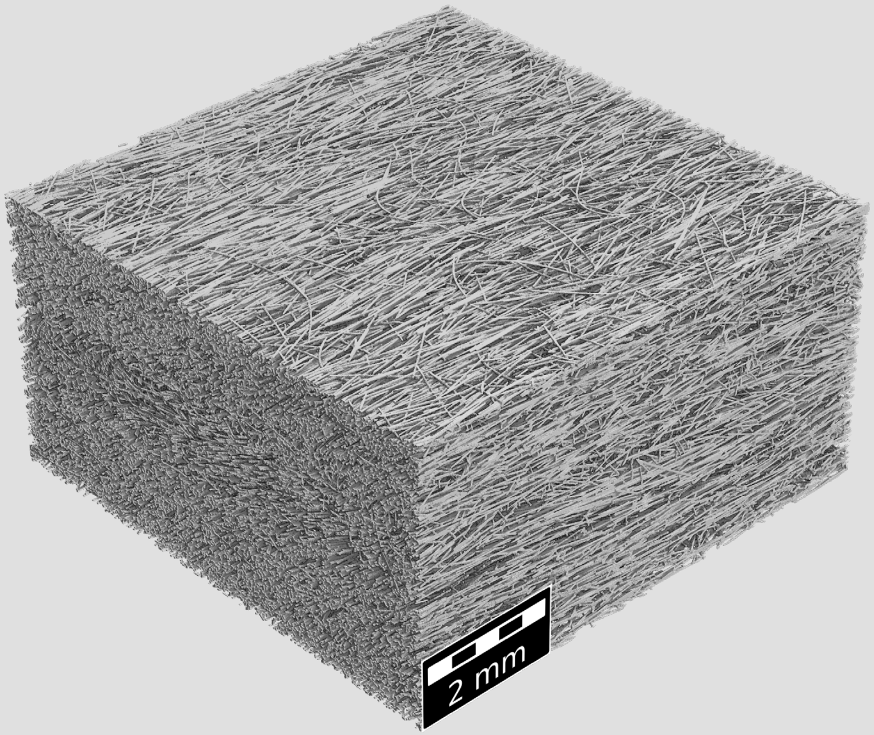
- input: Statistical Twin data: binarized version
- output: Statistical Twin data: labeled fibers version

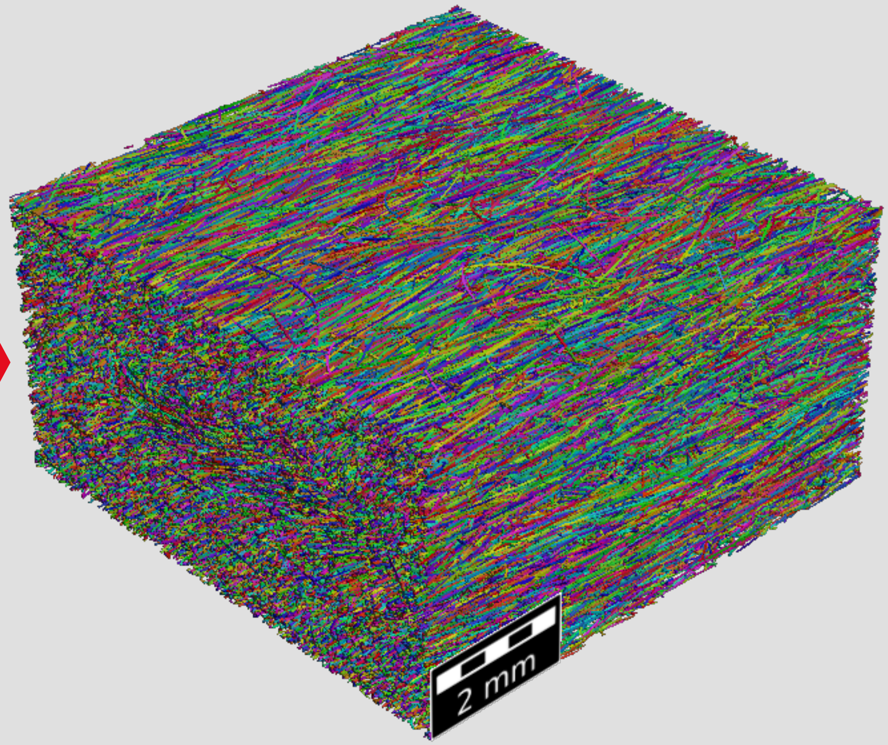
Usage: **N.N. predicts labeled output from input using weights**

- input: 3D scan data: binarized
- output: 3D scan data: labeled fibers

CT SCAN OF FIBER REINFORCED COMPOSITE

GeoDict





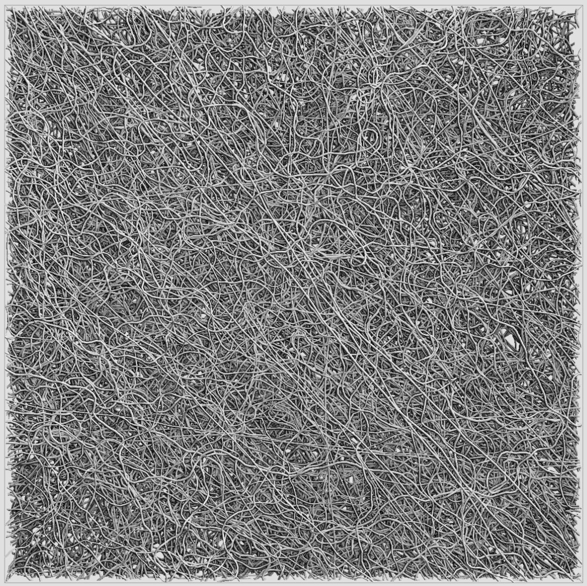
Input: segmented µCT scan

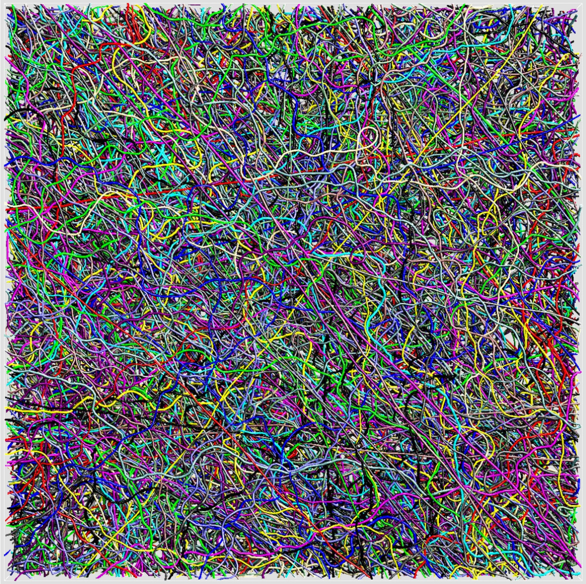
Output: labeled fibers

MATH 2 MARKET

CT SCAN OF NONWOVEN

GEODICT





Input: segmented µCT-Scan

Output: labeled fibers

MATH 2 MARKET

More Examples of computable quantities:

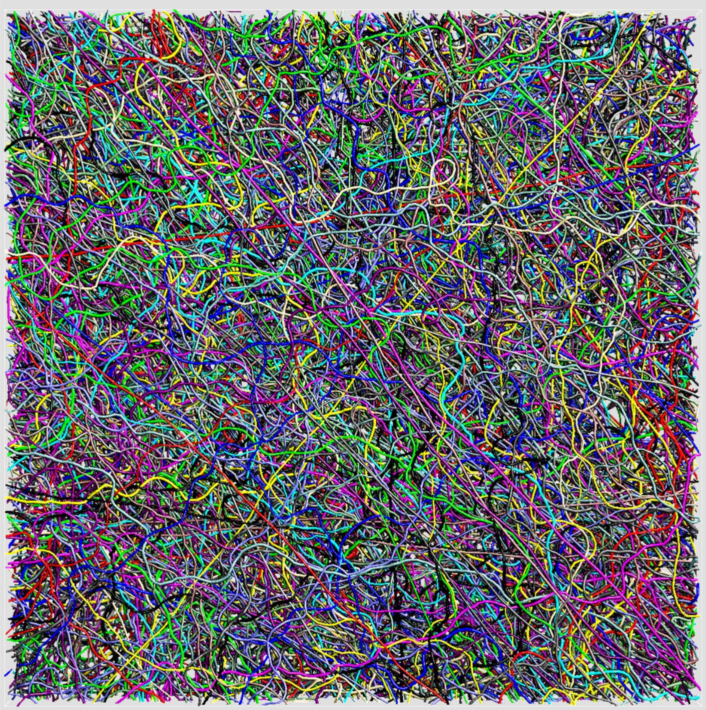
GeoDict

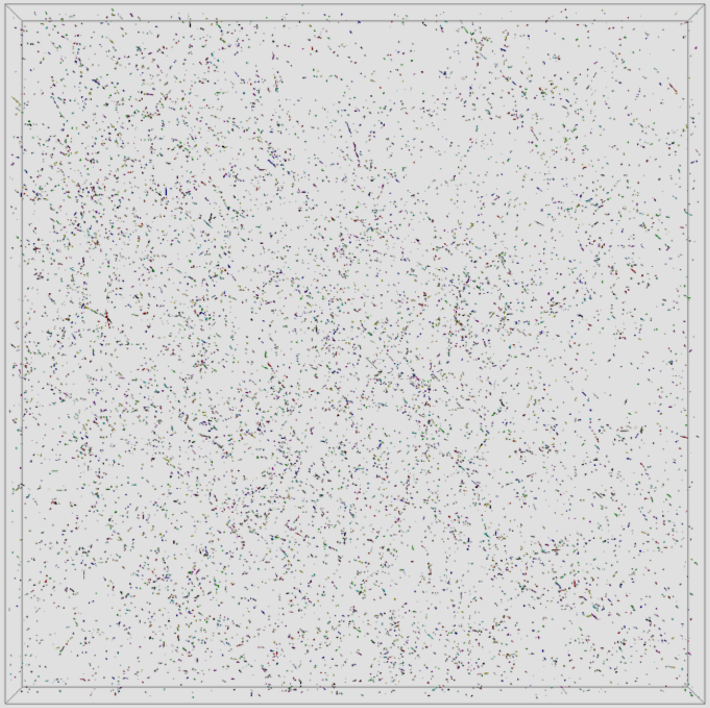
- Grammage / volume percentages:
  total, binder separate or fibers separate
- Binder distribution in through-plane and in-plane directions
- Size-distribution of binder points
- Total number of binder blobs/components
- Output of binder or fibers as triangulation (.stl), CAD (.dxf), etc.
- Number of contact points per fiber
- Length of individual fibers
- Curvature distribution along individual fibers
- Fiber orientation distribution

MATH 2 MARKET

Detection of 14995 bond poin

GeoDict





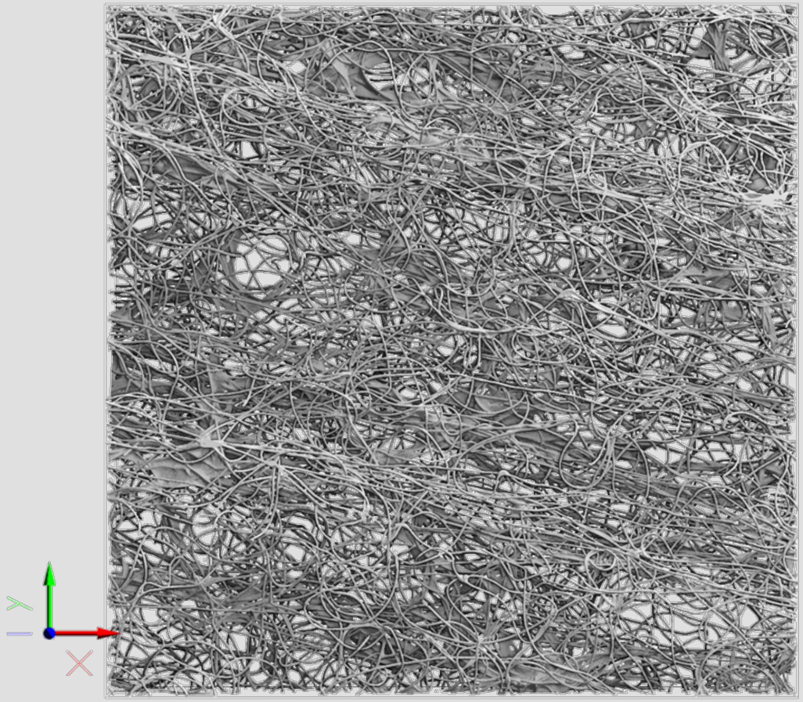
Input: labeled individual fibers

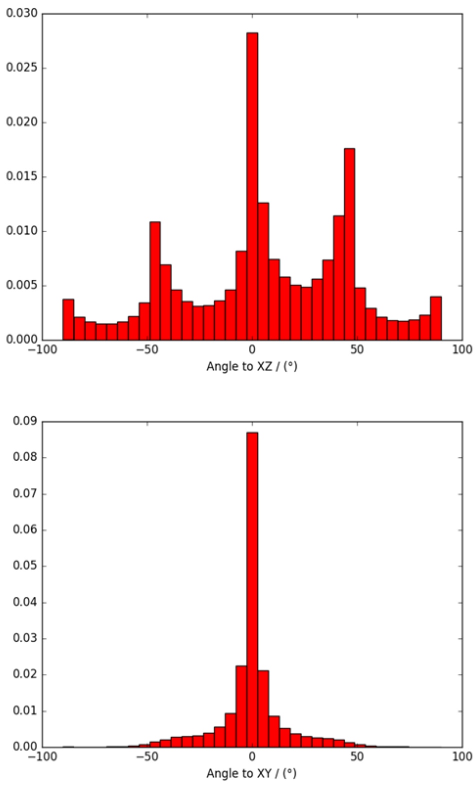
Output: labeled individual bonds

MATH 2 MARKET

Orientation Analysis

GeoDict





Input: segmented CT scan

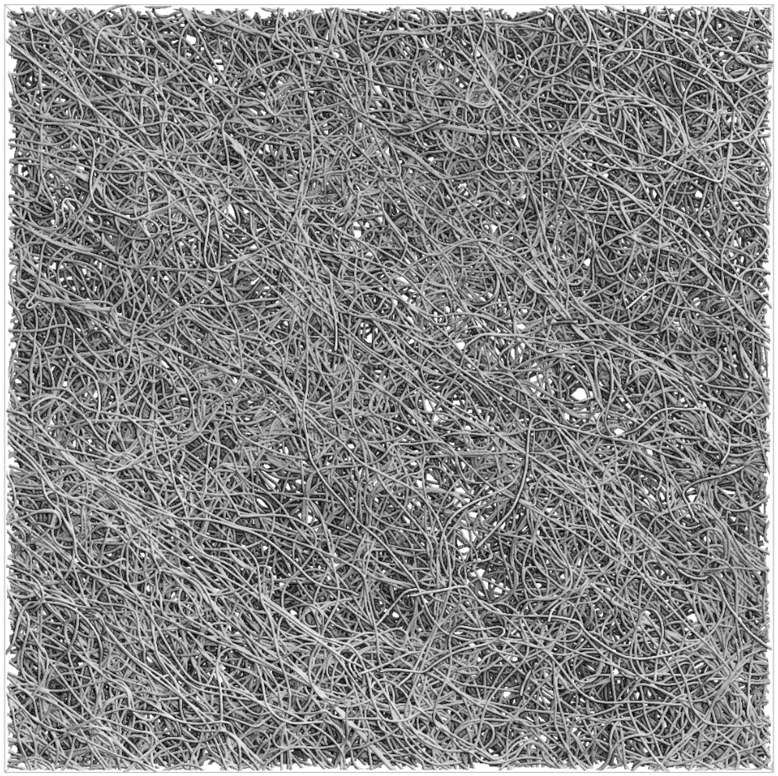
Output: orientation plots

MATH 2 MARKET

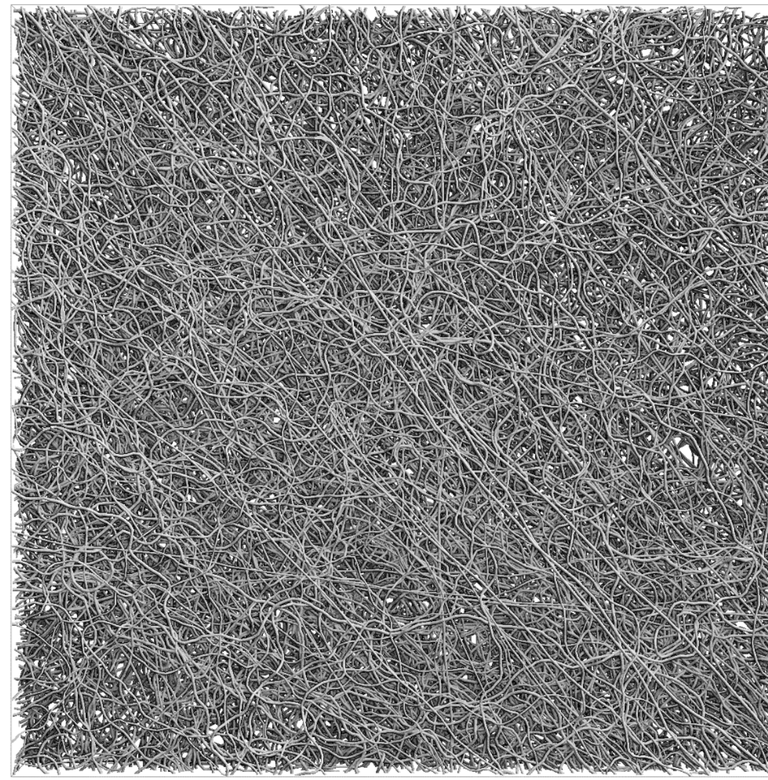
Statistical Twins with GeoDict

- Next three slides show manually created statistical twins
- This is right now one of the bottle necks: n.n. need models close to the real data
- One of the future works is to use generative adversary networks g.a.n. to create the models
- Another future work is the creation of gray value images from models that include the typical artefacts like rings and noise to use as left side in the training and usage phases of FiberFind-AI.

CT-scan vs Statistical Twin generated in GeoDict



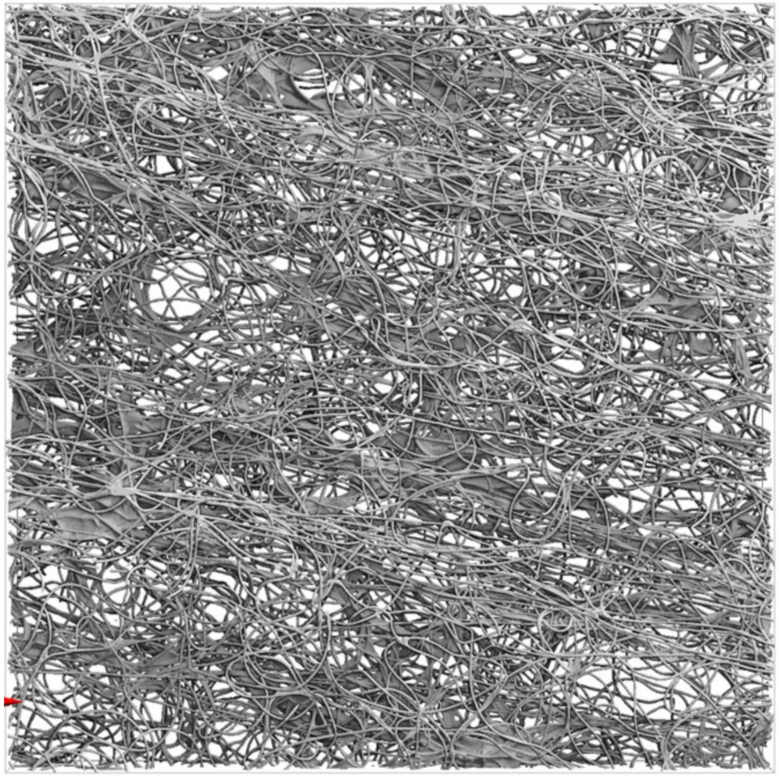
µCT-scan



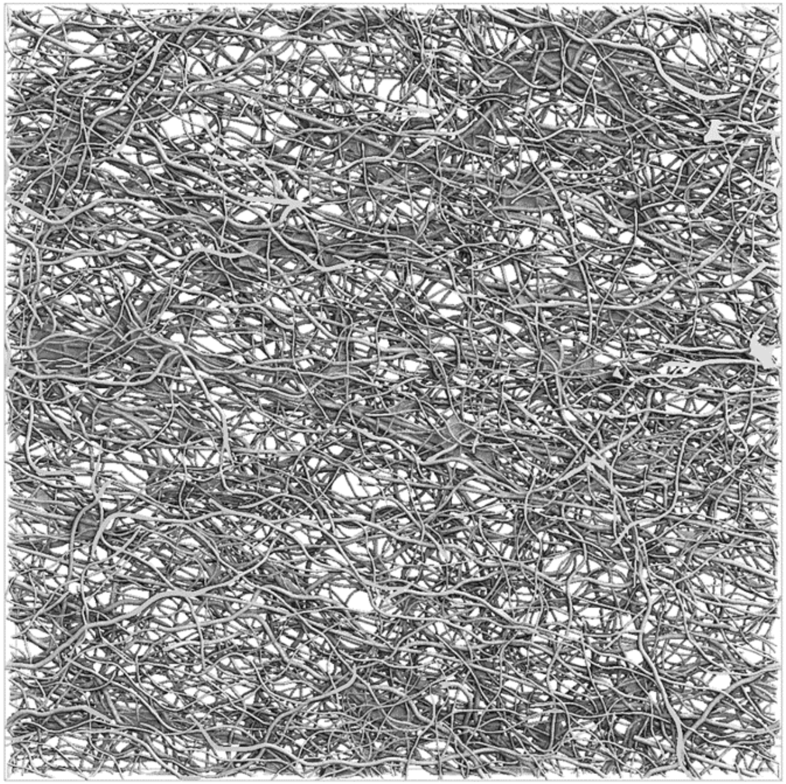
Statistical Twin

CT-scan vs Statistical Twin generated in GeoDict

GeoDict



µCT-scan

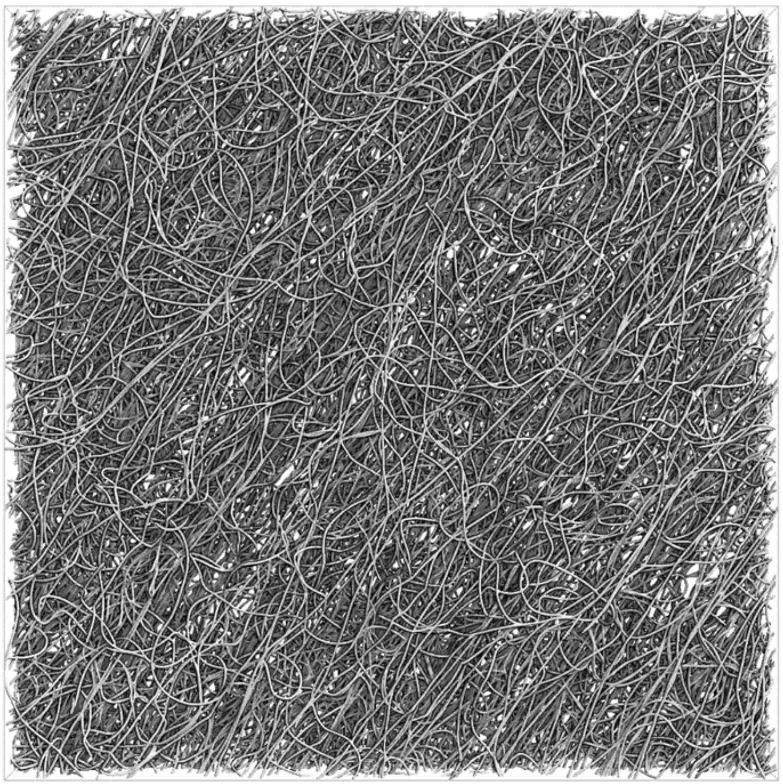


Statistical Twin

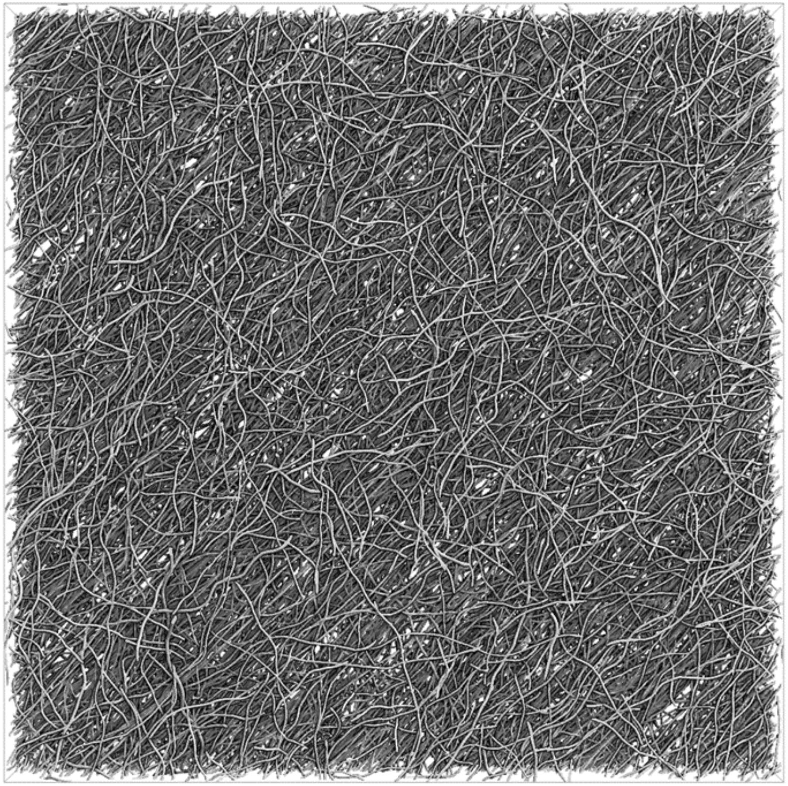
MATH 2 MARKET

CT-scan vs Statistical Twin generated in GeoDict

GeoDict



µCT-scan



Statistical Twin

MATH 2 MARKET

Analysis of 2 largest samples so far

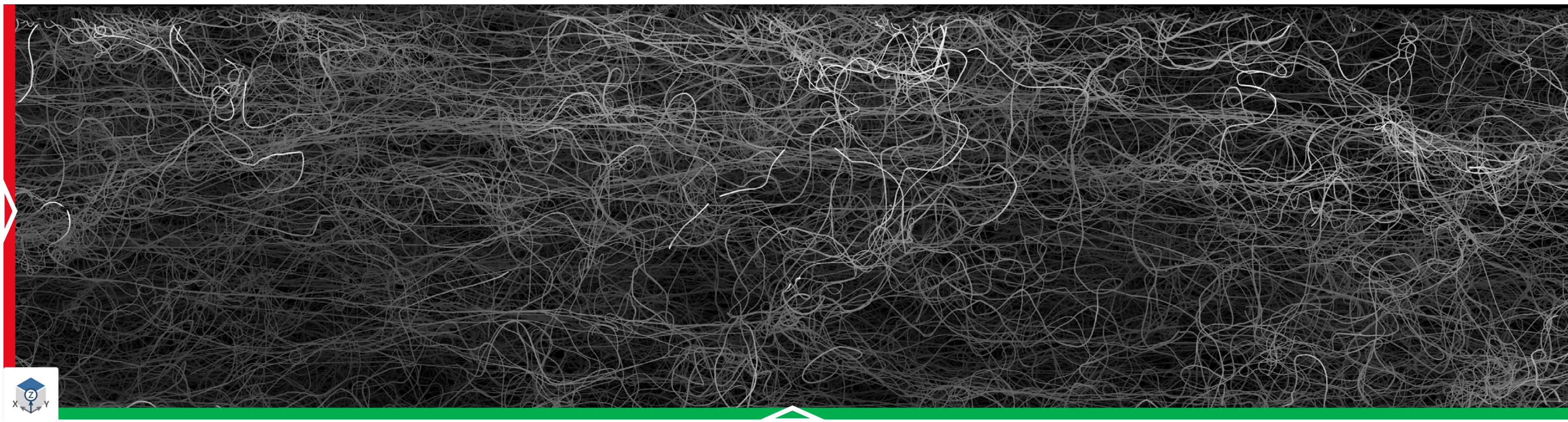
GeoDict

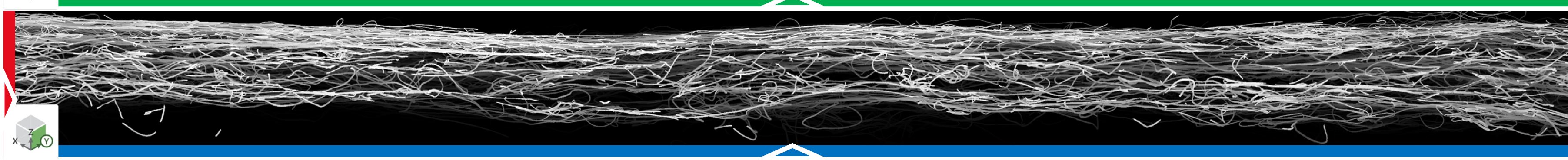
Sample Name	Resolution	Physical dimensions	Domain sizes in voxels
A	2.4µm	43.9 x 11.6 x 4.1 mm	18,310 x 4,816 x 1,704 = 150 Giga Vox
B	2.7µm	42.2 x 10.9 x 4.8 mm	15,619 x 4,032 x 1,796 = 113 Giga Vox

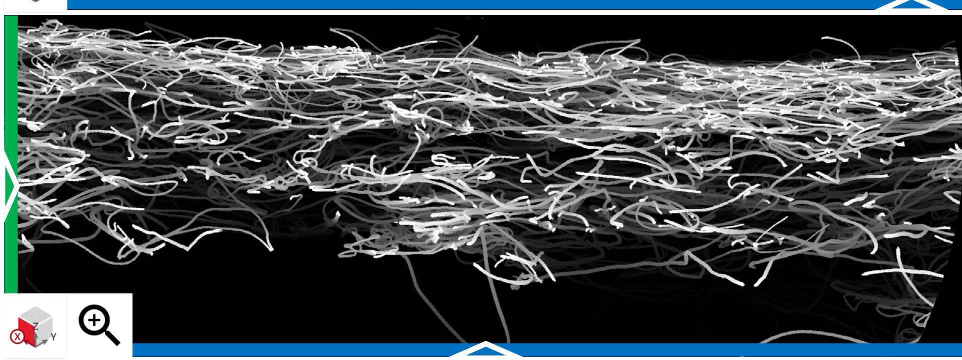
- Carded nonwoven samples
- Scanned and stitched together by Bruker microCT
- Analyzed by Math2Market on workstation with 1TB of memory

MATH 2 MARKET

SAMPLE A – SEM VIEW



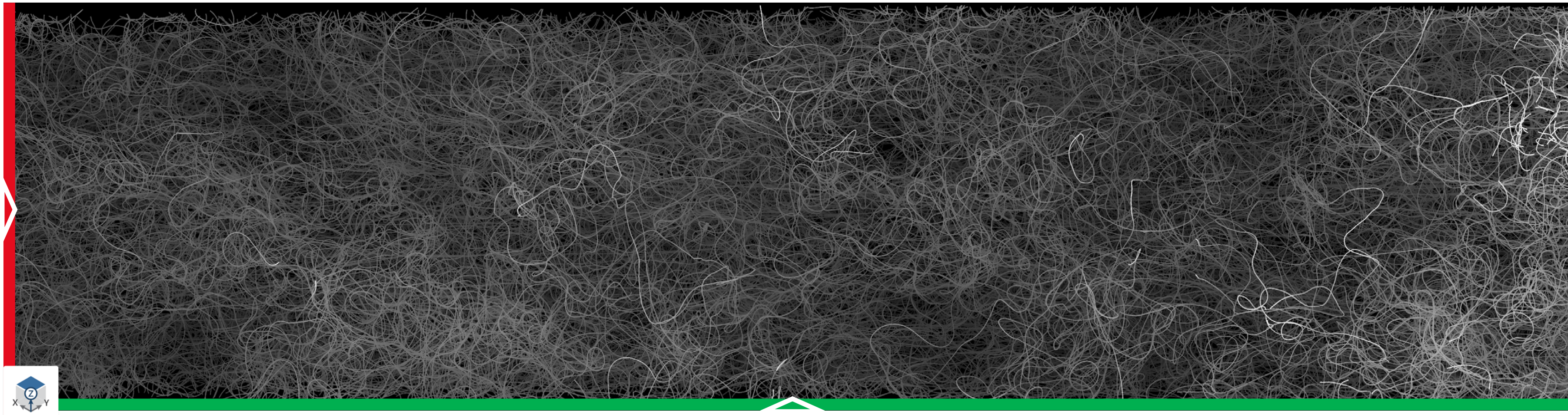


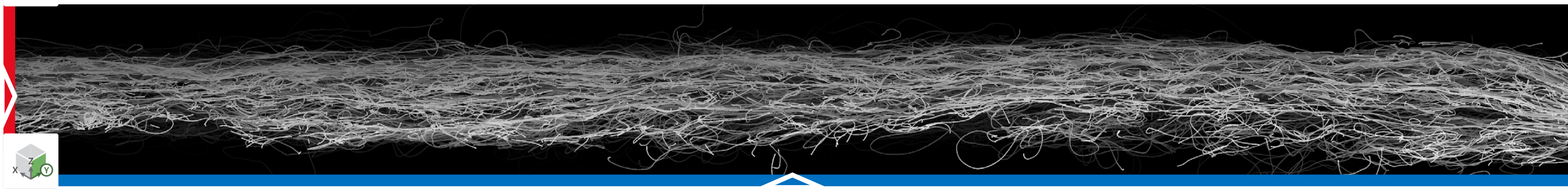


Reso-lution	Physical dimensions	Voxel dimensions
2.4µm	43.9 x 11.6 x 4.1 mm^3	18,310 x 4,816 x 1,704

Sample B – SEM view

GeoDict



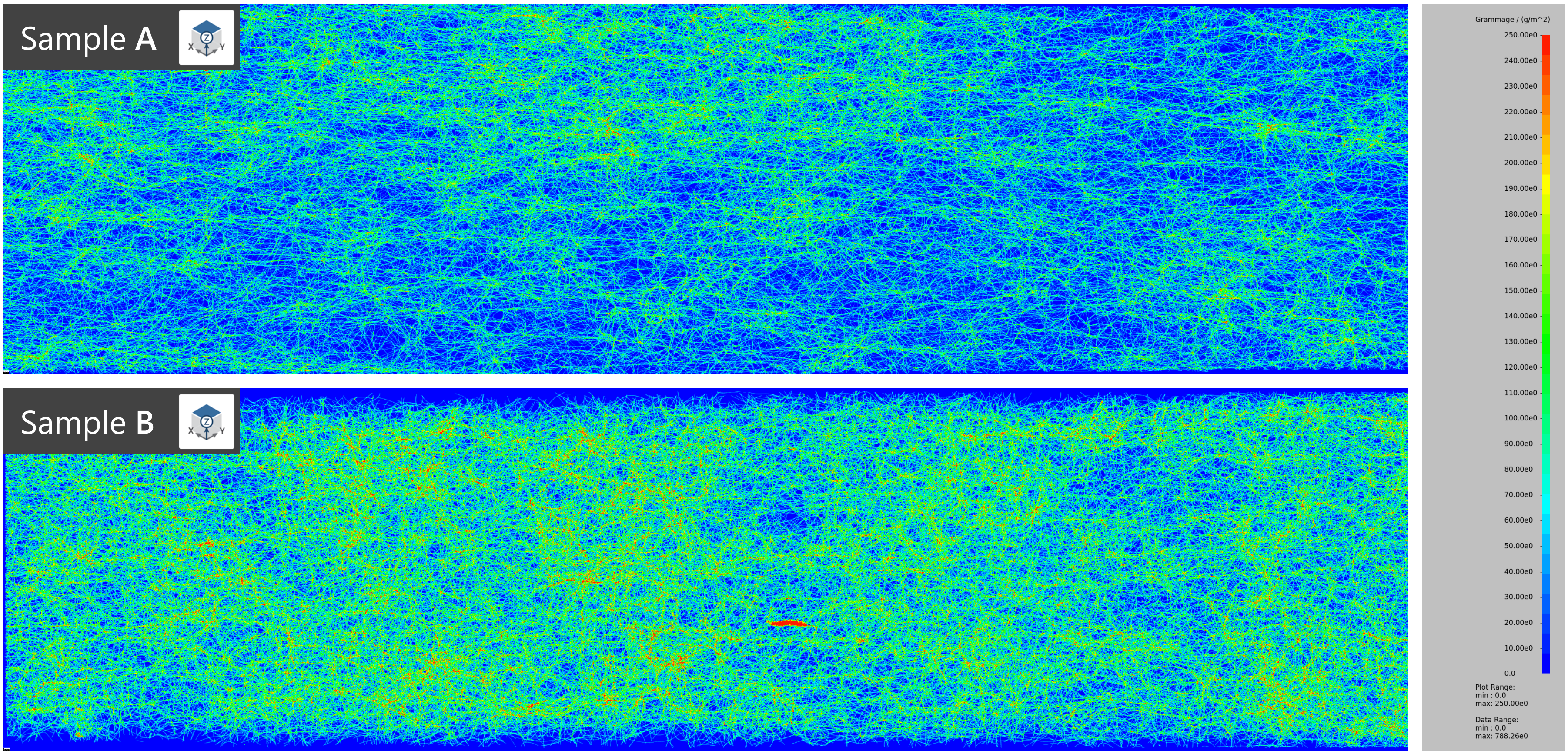


Resolution	Physical dimensions	Voxel dimensions
2.7µm	42.2 x 10.9 x 4.8 mm^3	15,619 x 4,032 x 1,796

MATH 2 MARKET

DENSITY MAP (CLOUDINESS)

GEODICT

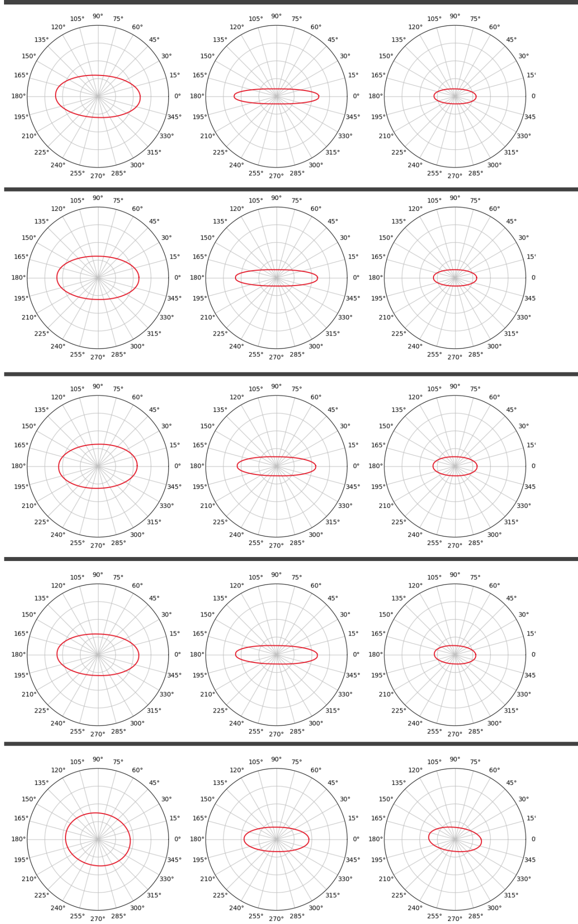


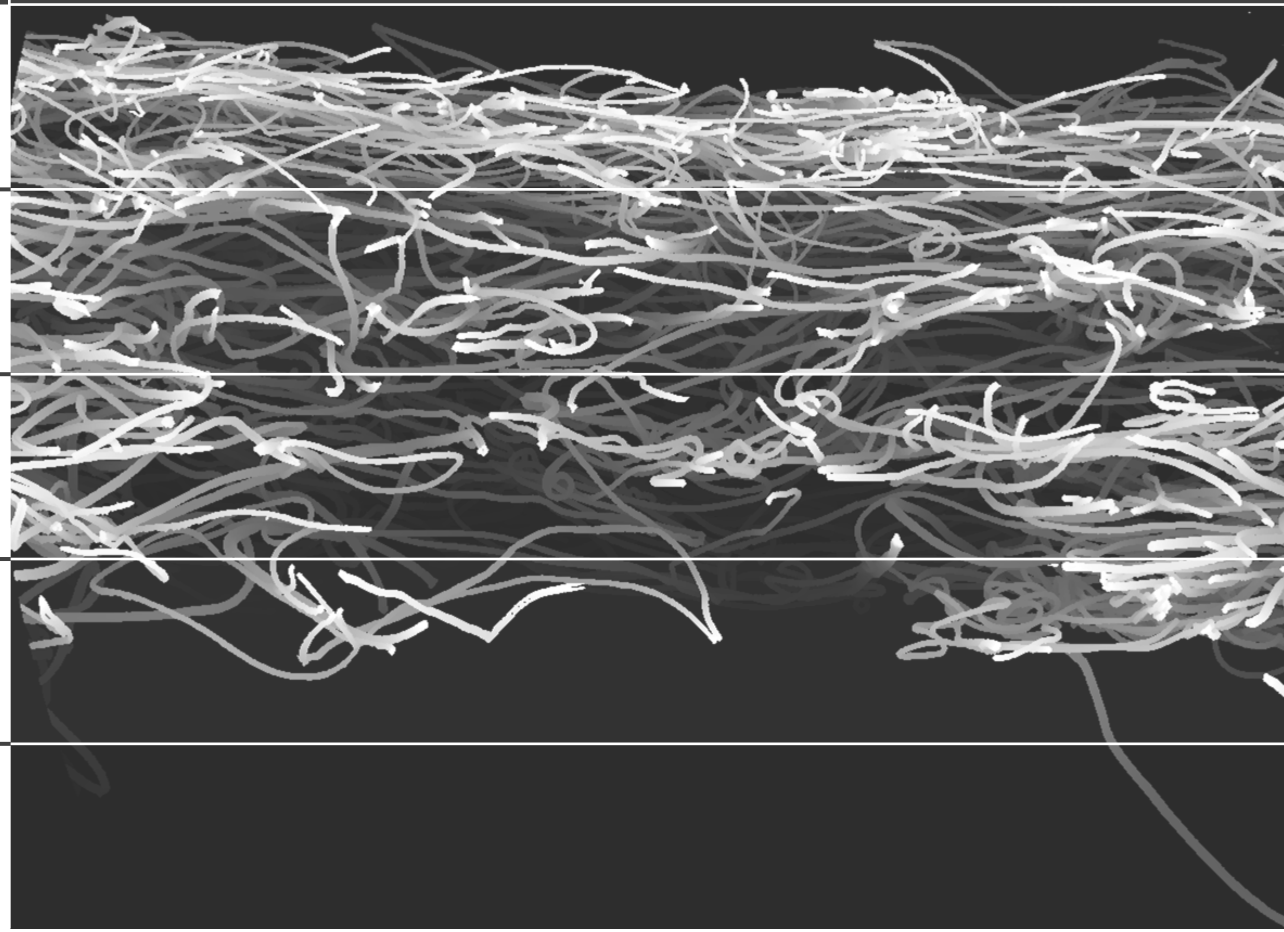
MATH 2 MARKET

FIBER ORIENTATIONS – SAMPLE A

GeoDict

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



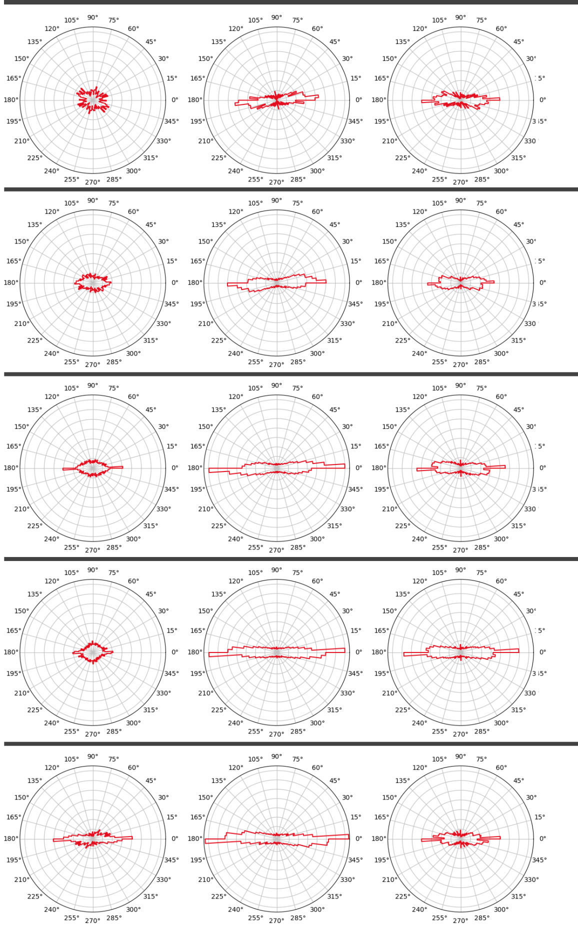


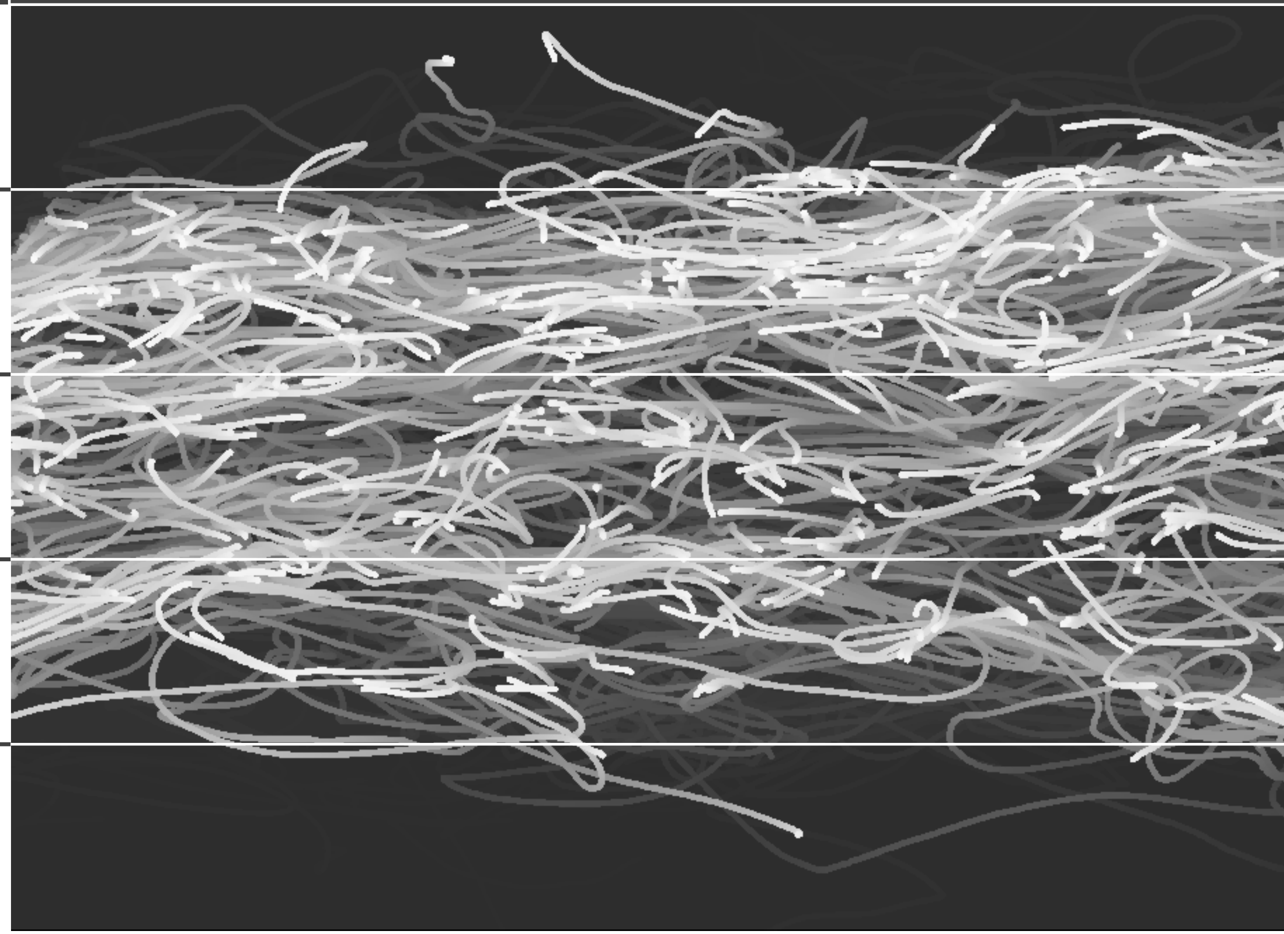
MATH 2 MARKET

FIBER ORIENTATIONS – SAMPLE B

GEODICT

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





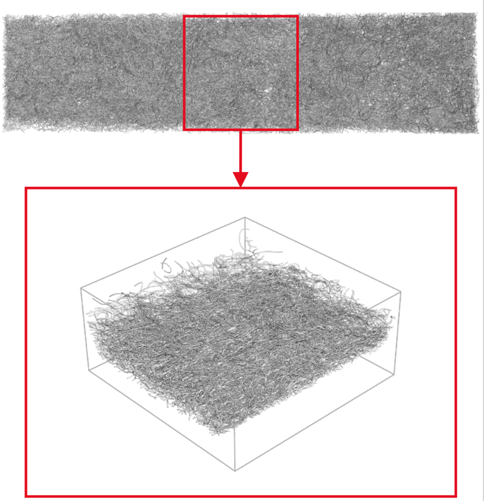
MATH 2 MARKET

Fiber identification on Sample B

Sample B

FiberFind was used on the complete sample.

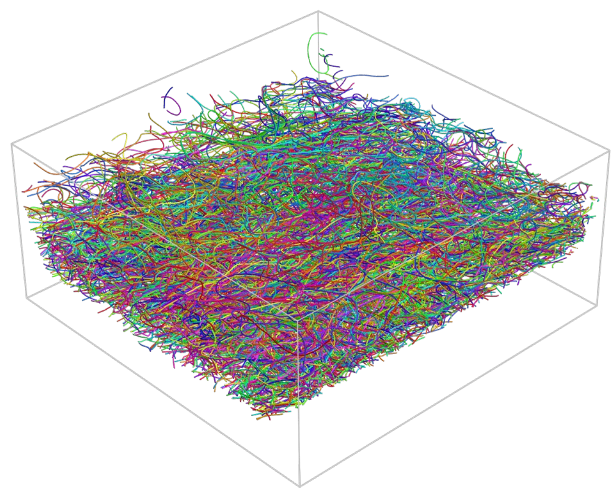
Process is explained on a smaller cutout



Labeling of fibers

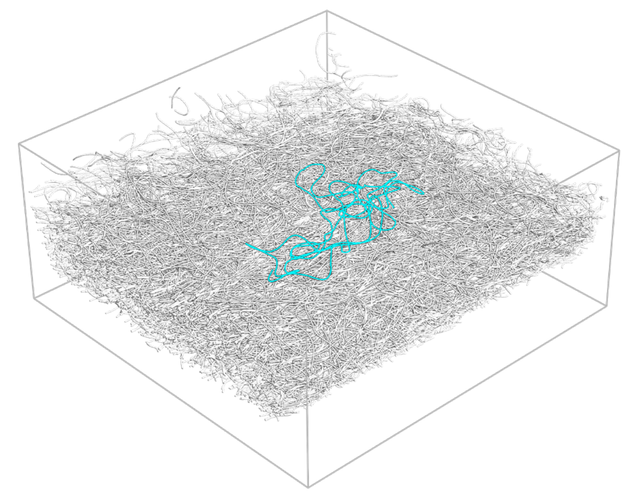
The artificial intelligence separates the solid voxels in the image data into individual fibers.

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.



CONCLUSIONS

- Neural networks separate binder and fibers and identify individual fibers
  - based on learning shapes
- N.N. can label multi-material scans where materials can not be separated by thresholding or classical image processing
- N.N. require training data consisting of segmented and labeled scans
- These can be created easily using material models from GeoDict
  - Models continuously improve, e.g. by improving the binder model
- We continue to improve the capabilities by
  - Increasing the fidelity
  - Speeding up the computations
  - Extending the capabilities to other types of materials
  - Placing the capability to train N.N.s in your hands

Creating statistical twins and the digital design of filter media have just gotten a lot easier!

Statistical Twins for

- Granular filter media,
- Woven filter media,
- Open cell foams
- etc. etc.

can all be found by this technology!