Image Processing, Quantification and Model Reconstructions in SEM/FIB

Case studies

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EFUG 2010 - Gatea, Italy

About VSG

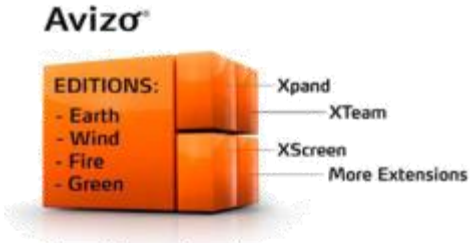
Formerly Visualization Sciences Group of Mercury Computer Systems, independent since June 2009.
25 years of expertise in visualization markets

HQ/R&D: Bordeaux, France - www.vsg3d.com – 60+ people
Offices: Boston, Houston, Dusseldorf, London, Paris
Distributors: China, India, Japan, Taiwan, South Korea, Mexico, Israël, Russia

3D development toolkit Open Inventor

- For software programmers

3D data visualization and analysis framework Avizo

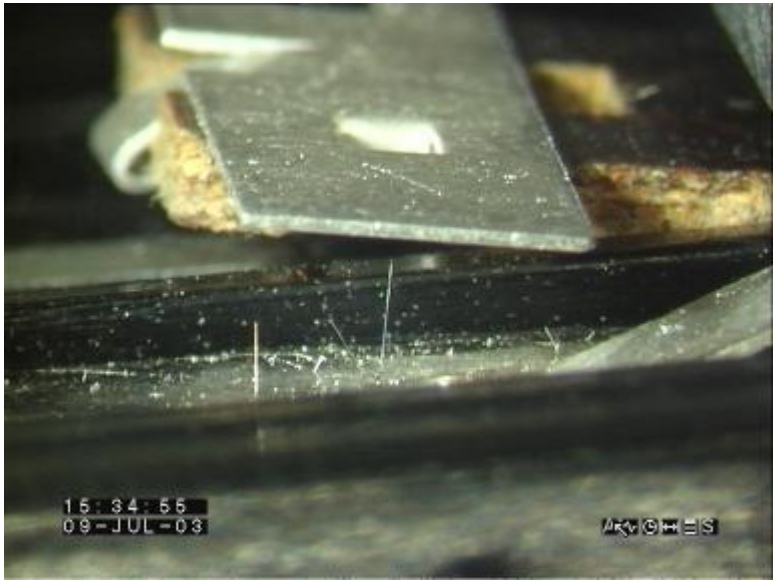


- For scientists, engineers,
  in **Materials Science, NDT, Numerical Simulation/CAE, Geoscience and Environment**
- Customizable and extensible platform for automation or specific applications developers

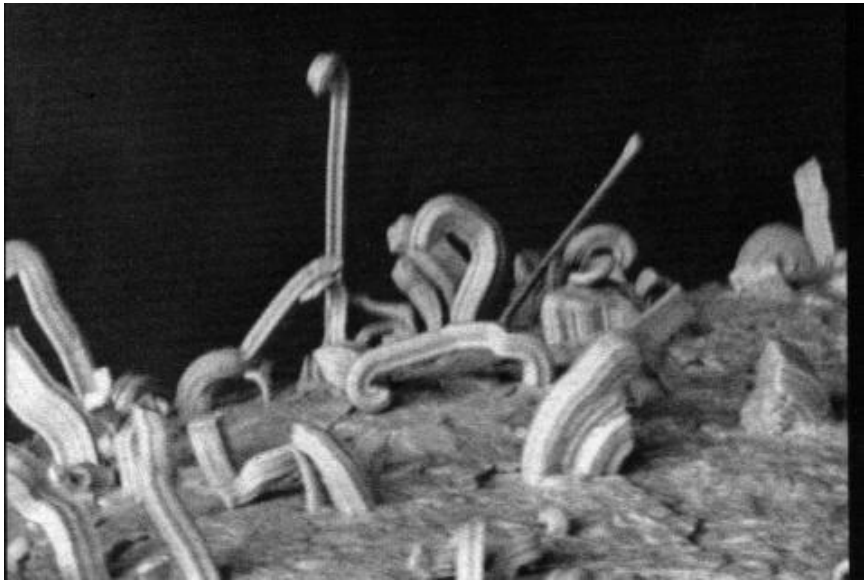
3D expertise, support, professional services, collaborative R&D

Tin Whiskers

Forest



Trees



Images from NASA Goddard Tin Whiskers website

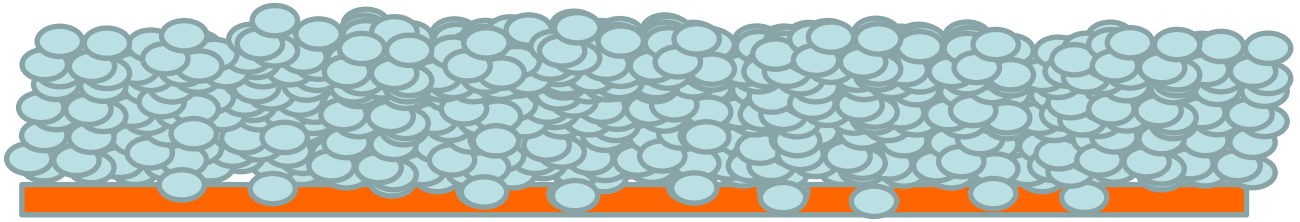
Tin whiskers & hillocks imaging case study

- Exploring FIB/SEM 3D image quantification for characterizing and understanding tin whiskers growth

- Credits
  - Maureen Williams, Kil-Won Moon, William Boettinger – NIST
    Identification of commercial products does not imply recommendation or endorsement by the National Institute of Standards and Technology
  - Mike Marsh - VSG
  - Jason Huang - Zeiss

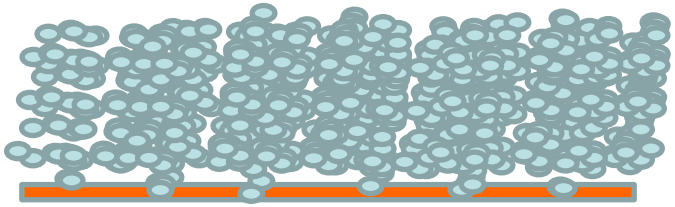
Discecting metallic microstructure

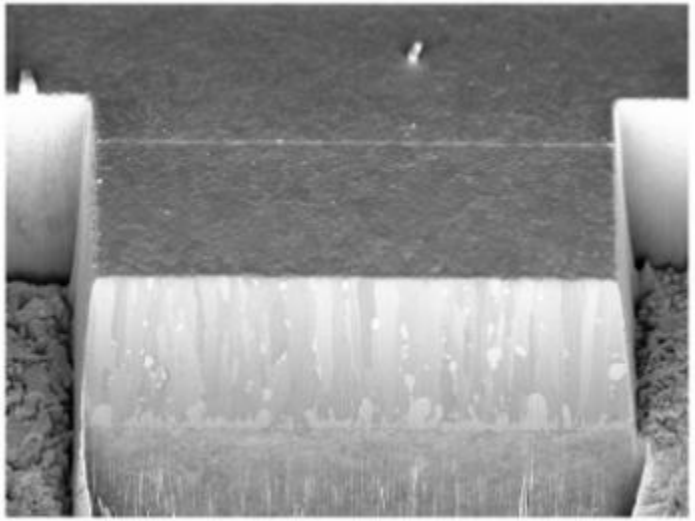
- Tin is electroplated onto copper substrate
- Individual crystals (grains) grow on the surface
- Depth is a function of electroplating duration



Plating tin

- Copper layer
- Pseudo-discrete tin grains
- Evolving basal intermetallic
- Evolving interspersed intermetallic



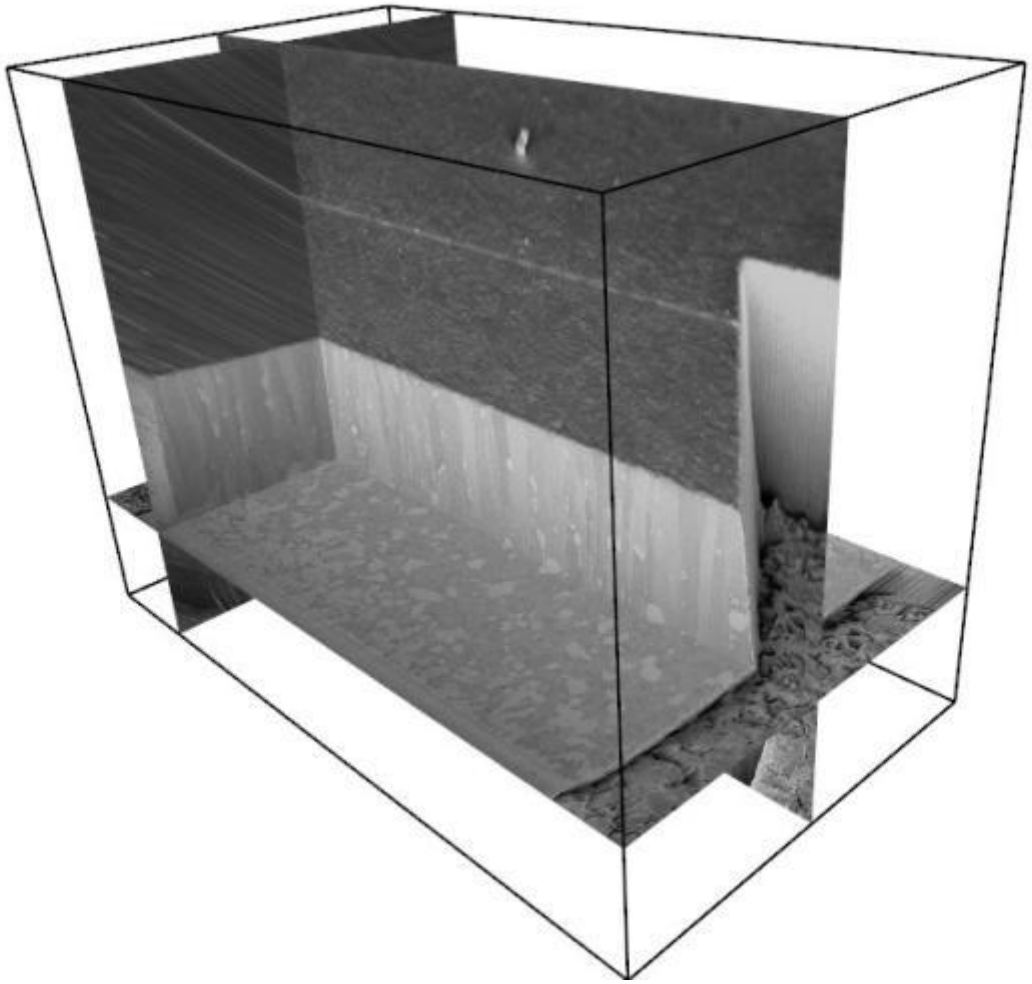


Data courtesy Maureen Williams (NIST)

Imaging

- 2D Images acquisition
  - Zeiss NVision 40 and Zeiss Neon 40 EsB SEM/FIB dual beam
  - The gallium (Ga) ion source is operated at 30 kV
  - SEM images collected at 50 nm increments
  - Sn reacts with Ga at room temperature so FIB techniques that minimize the Ga dose exposure on the cut face of the Sn electrodeposit were developed.
  - Significant contamination from redeposition can occur if milling is extended below the Sn layer into the Cu substrate

Image stack is not directly interpretable



Processing

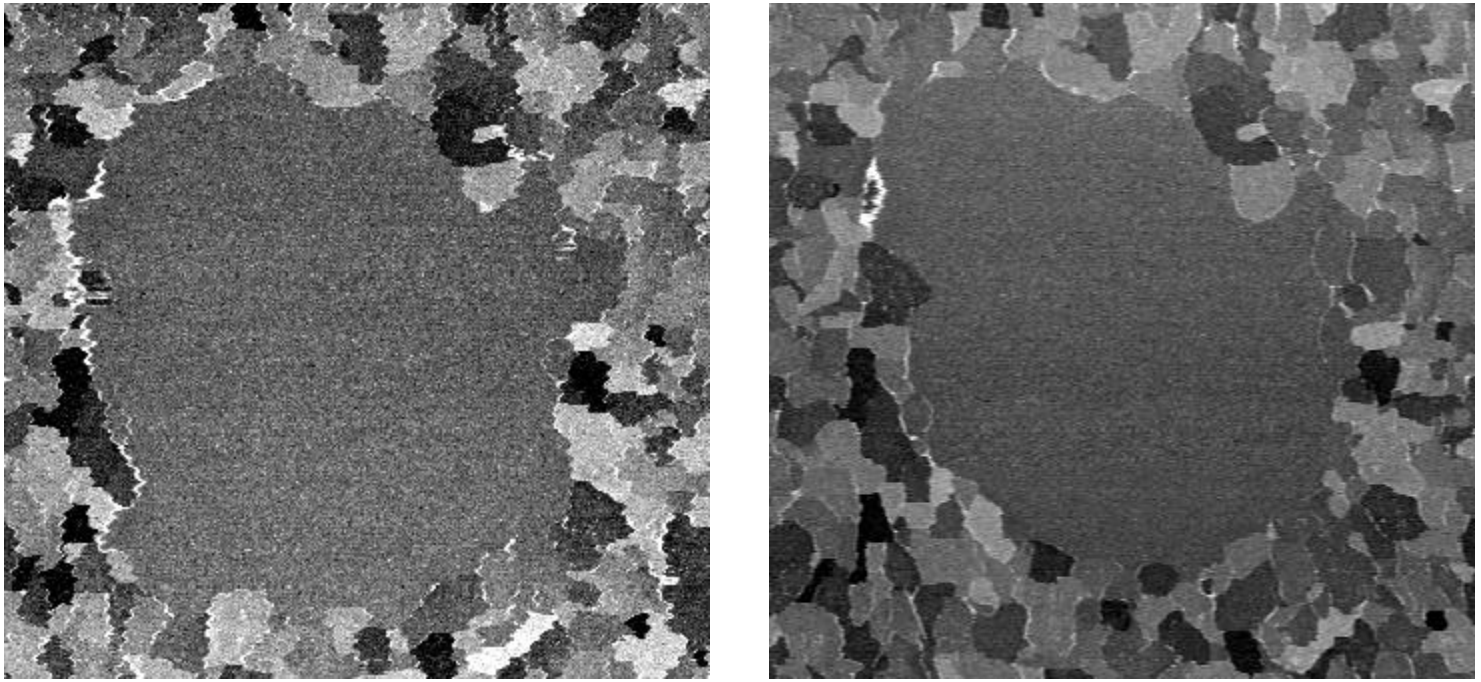
- Processing needs
  - Unique to FIB/SEM
    - Alignment (and shearing)
    - Foreshortening correction
    - Shadowing correction
    - Masking out extrinsic signal
  - Common to most imaging techniques
    - Image filtering
    - Segmentation to identify features of interest
    - Measurements to quantify features

Alignment

- Automated alignment
  - Center-of-mass, Least-squares, Edge-detection, Marker-based, rotation constrained, etc.
  - Also correlation or mutual information registration
- Manual refinement
- Alignment proxy: align stack using arbitrary reference images and mask (filtered, sub-region)
- Non-rigid / elastic alignment needed in some cases

Alignment

- After alignment, filtering, and shearing (xz slice)



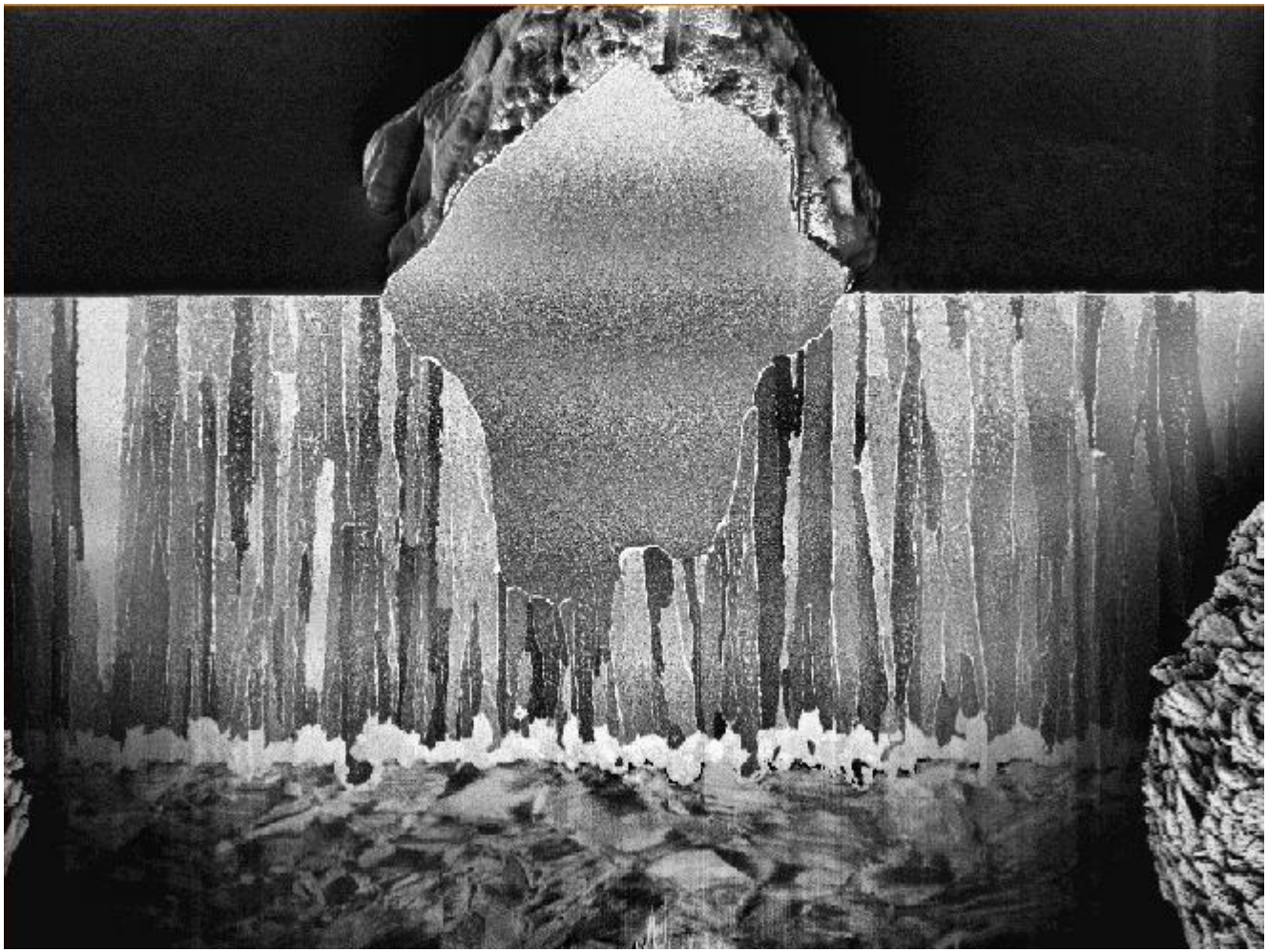
Shadowing

- Shadowing correction

Shadowing

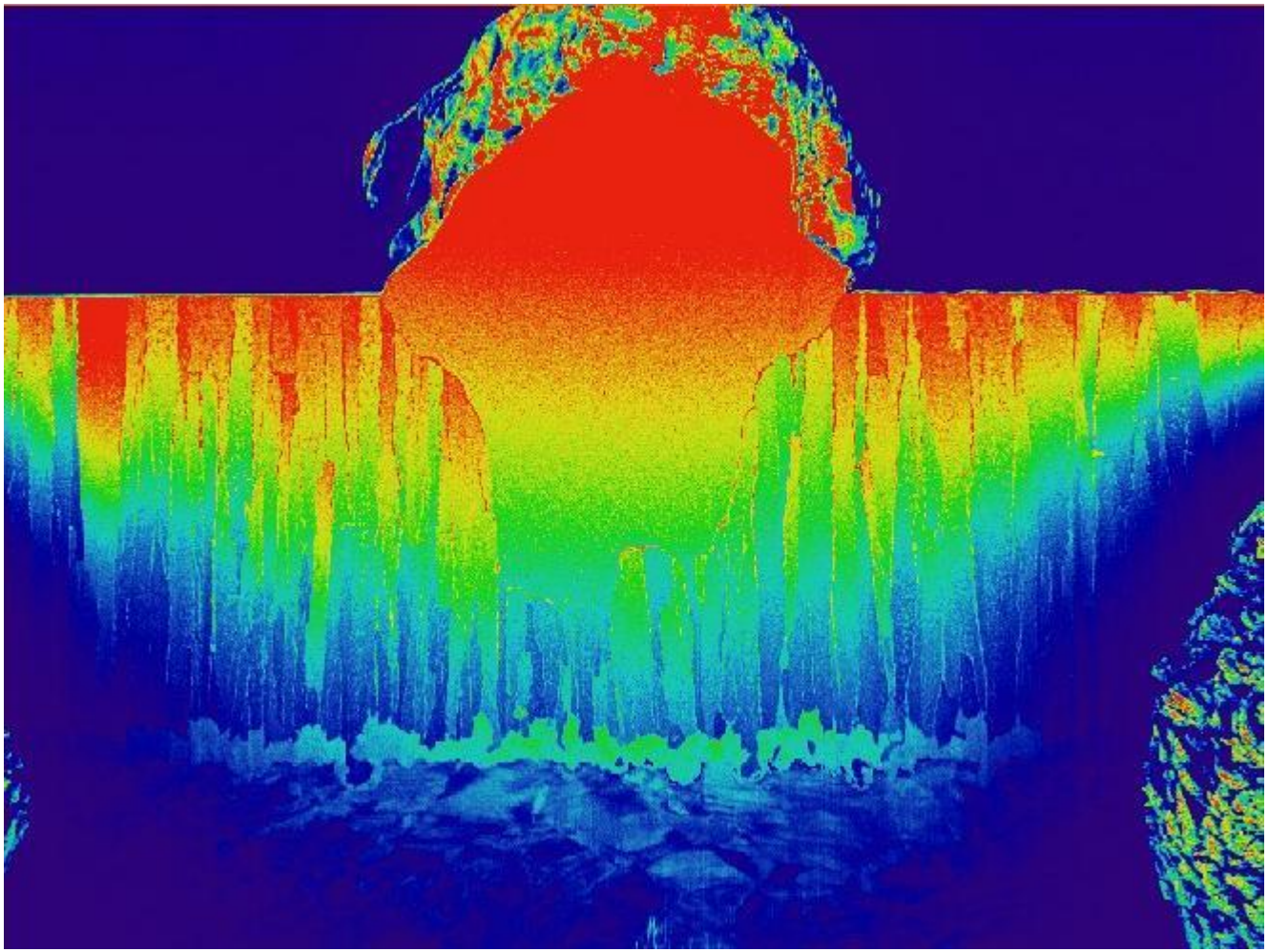
Linear grey ramp

Image is noisy



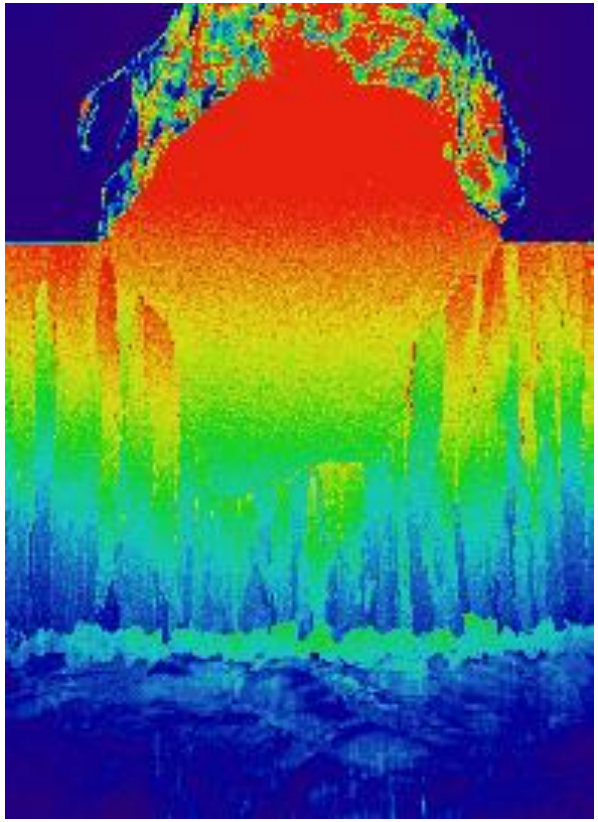
Histogram equalized

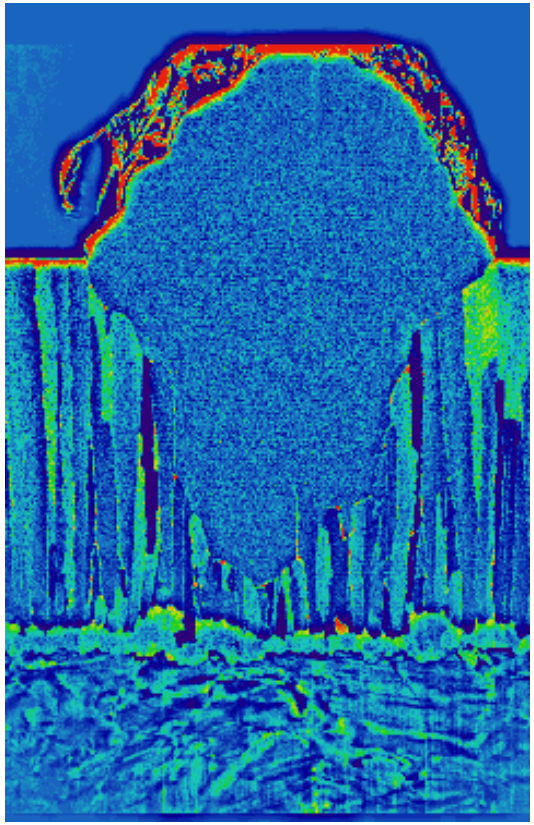
Shadowing has caused an image gradient



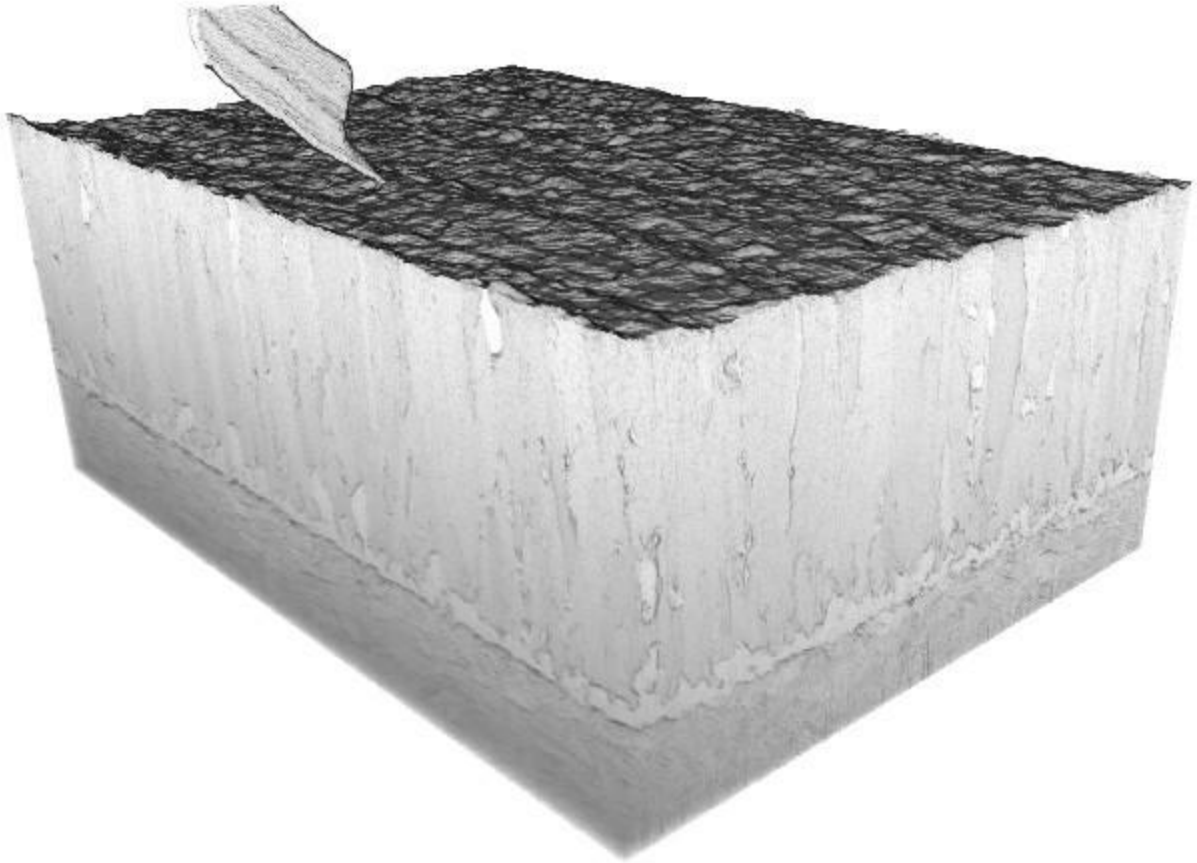
Heatmap

Gradient correction



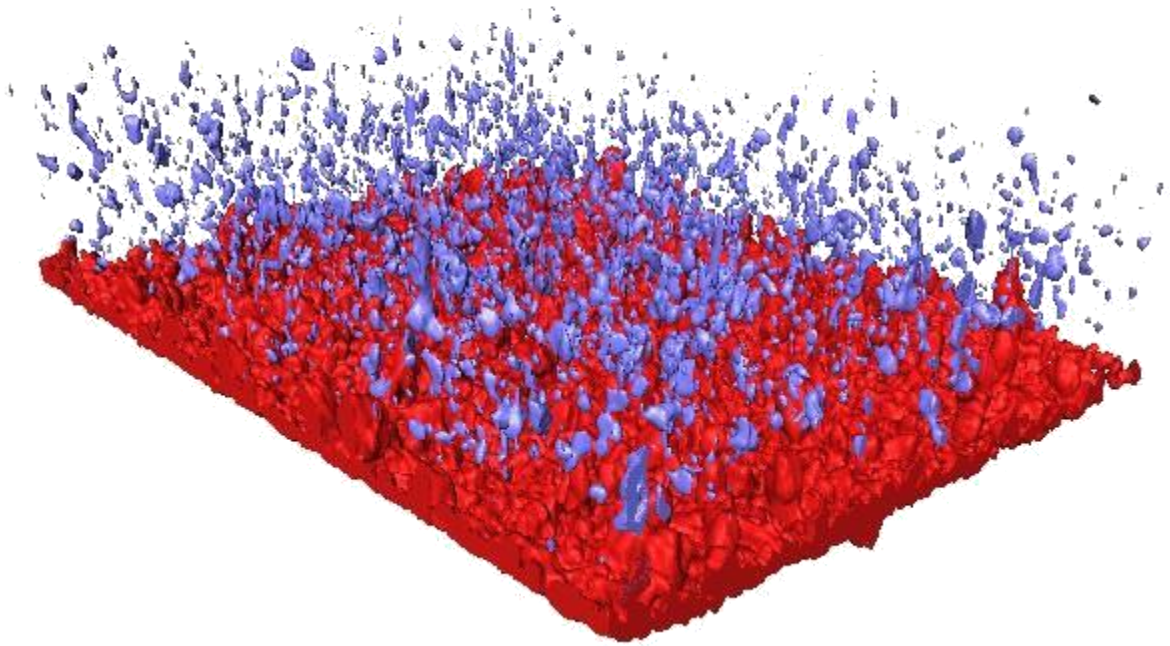


Aligned, Sheared, Deshadowed, Masked

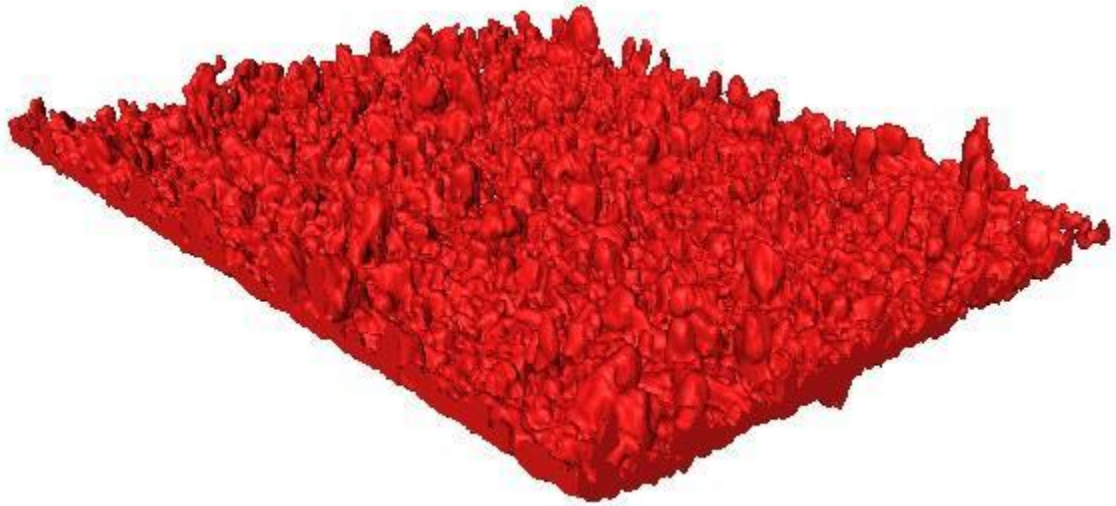


Segmented Intermetallics

- Processing steps applied:
  - Median filter, edge preserving diffusion filter
  - Threshold to get easies
  - Tophat to get extra
  - Filtering by y-position

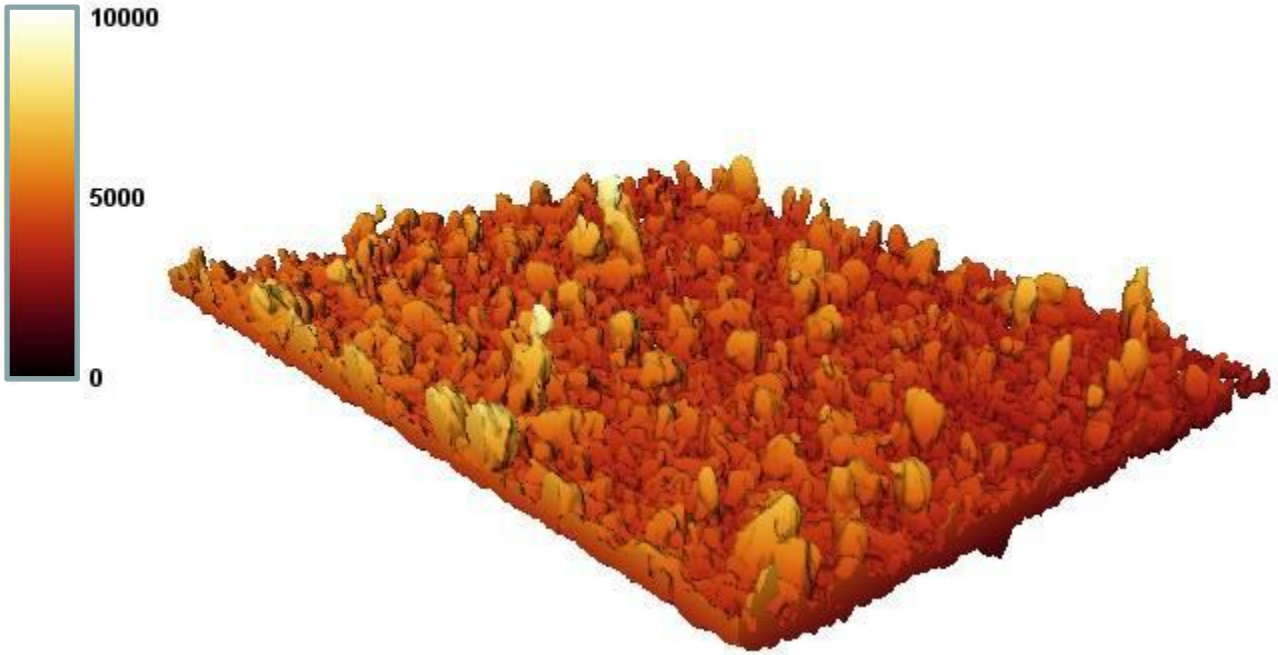


Basal intermetallic layer



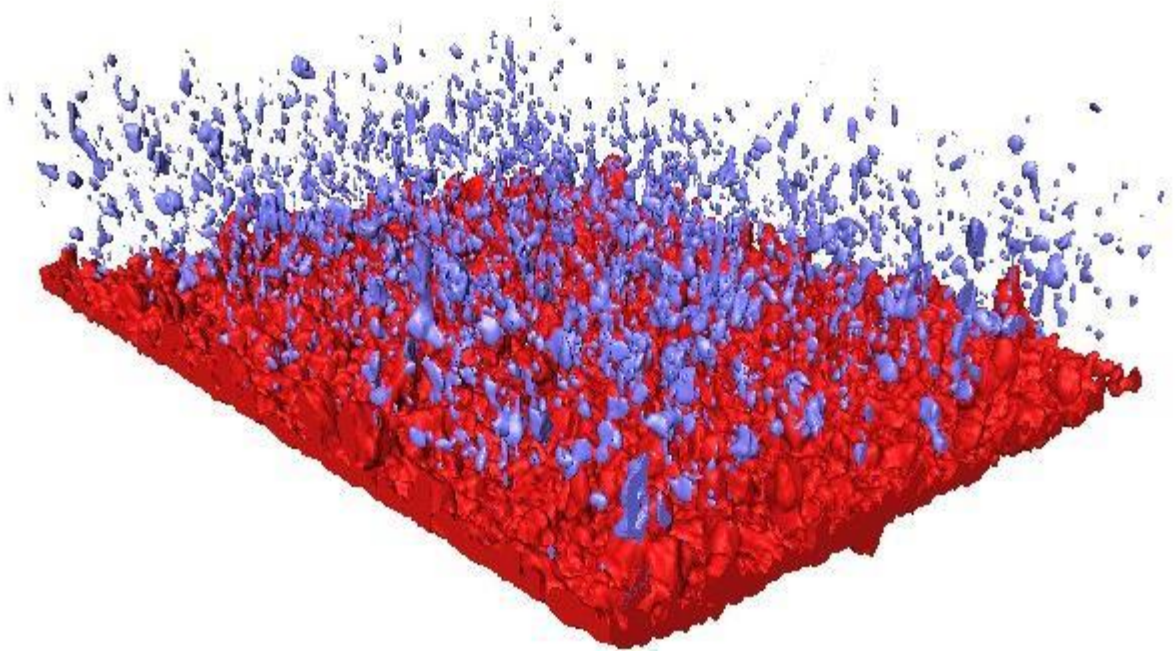
Basal intermetallic layer

- Roughness evaluation



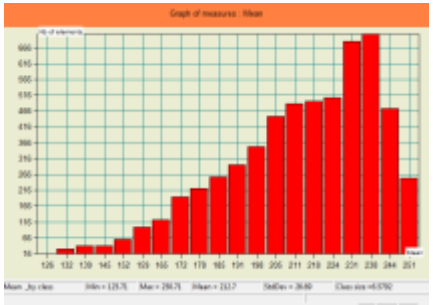
Quantification

- Global Metrics
  - Fractal dimension of basal surface: 2.31
  - Degree of anisotropy of interspersed: 0.598
  - 3D Density of interspersed Intermetallics : 0.13 grain / μm^3

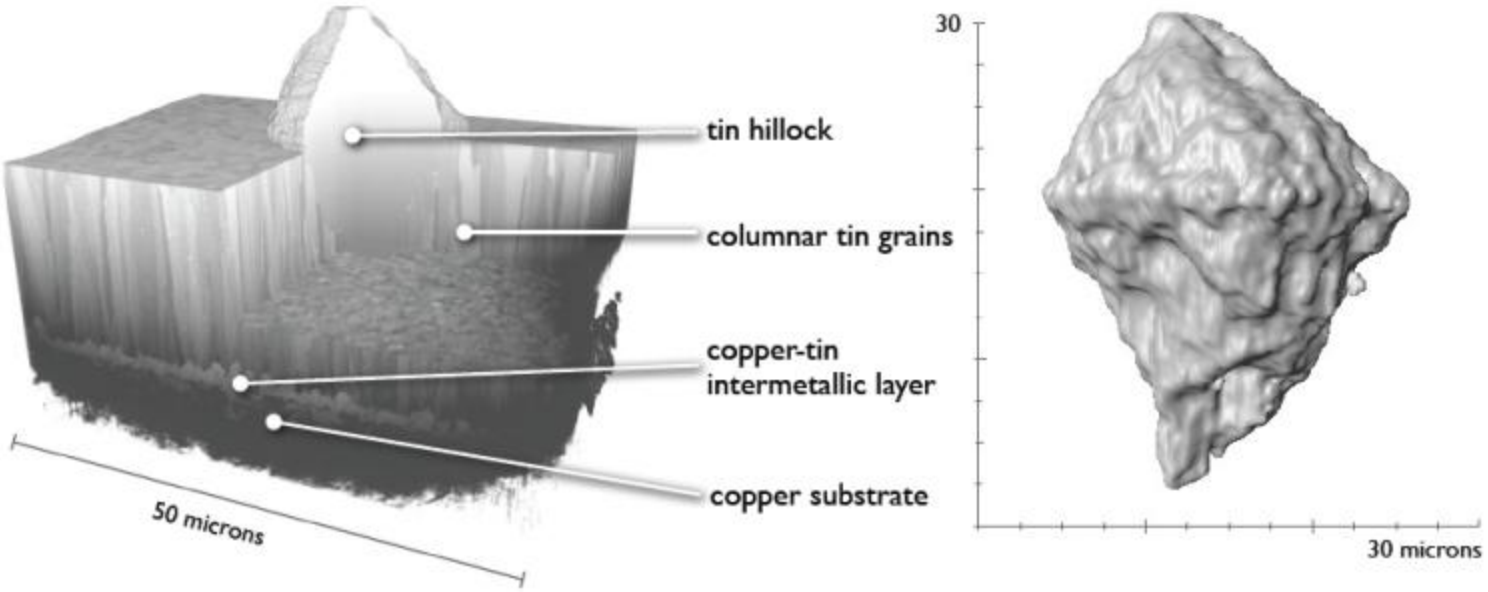


Quantification

- Global Metrics
  - Fractal dimension
  - Degree of anisotropy
  - 3D Density of Interspersed Intermetallics
- Population Metrics (individual measures)
  - Volume
  - Surface Area
  - Length
  - Width
  - Aspect Ratio
  - Intensity
  - Orientation (both euler angles)
  - Position (x, y, z)
  - Multi-parameter filters



Surfaces reconstruction



Findings

- Tons of quant info to mine
  - Many mature tools for correcting artifacts
  - Many sophisticated quantitative measurements from image or reconstructed geometry
- Unsolved Problems
  - Grain resolution- EBSD possible answer
  - Need for FIB recon wizard script

Conclusions

- Image Processing Pattern
  - Image Acquisition
  - Reconstruction
  - Filtering
  - Segmentation
  - Quantification (Measurements and Analysis)

Conclusions

- XRay CT
  - Image Acquisition
  - Reconstruction
  - Filtering
  - Segmentation
  - Quantification (Measurements and Analysis)

Conclusions

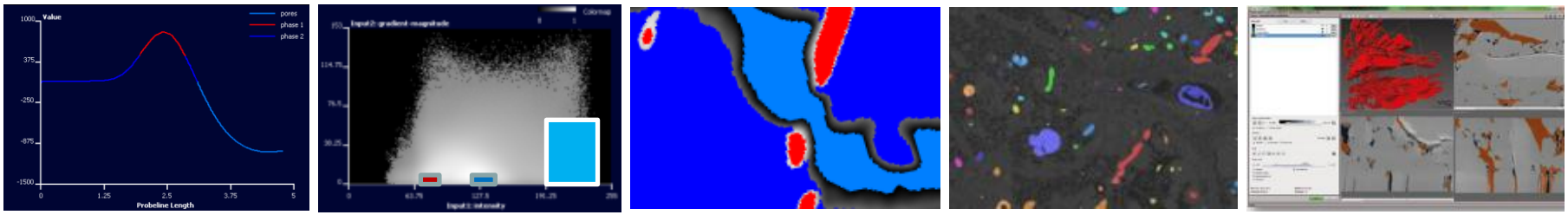
- FIB/SEM
  - Image Acquisition
  - Reconstruction
  - Filtering
  - Segmentation
  - Quantification (Measurements and Analysis)

Conclusions

- Quantification: the easy part
- Reconstruction: can be painful
- Segmentation: can be hard

Solving difficult segmentation

- Issues
  - Multiphase, non uniform, shadows, holes...
  - Resolution requiring further separation
  - Large datasets
- Tools
  - Sophisticated filtering - diffusion, adaptive filters, NLM, etc.
  - Morphological maths, gradient watershed, separation, snakes, ridgeline tracking, texture classification, etc.
  - Segmentation interactive editor semi-automatic tools
  - Large data management multi-resolution, out-of-core
  - Multi-core or GPU accelerated processing



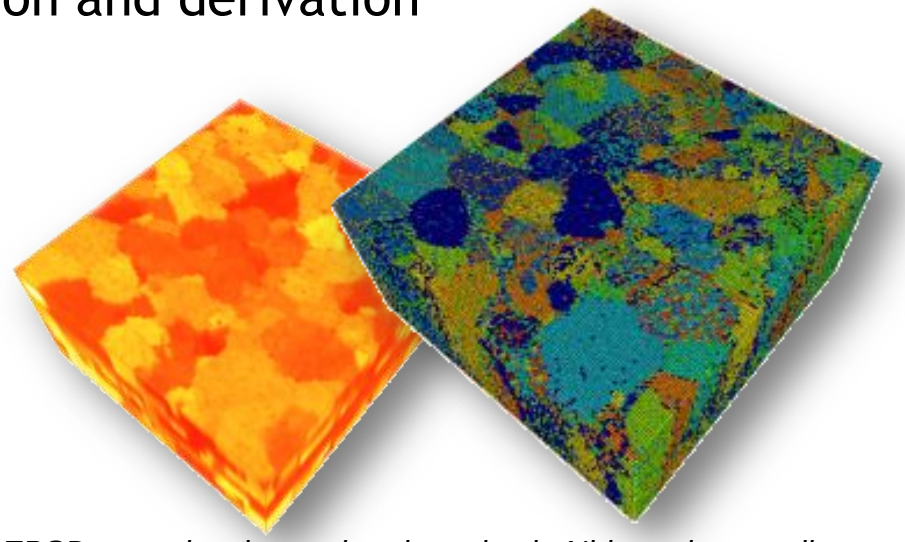
Multi-phase profile, correlation histogram, gradient watershed, structures separation and labeling, segmentation editor

Data fusion

- Multiple data channels can enhance segmentation or enable compositional analysis, e.g. BSE, EBSD, X-ray spectroscopy, etc.

- Multiple modalities and scales can be combined for correlative analysis, e.g. microCT, nanoCT, AFM, etc.

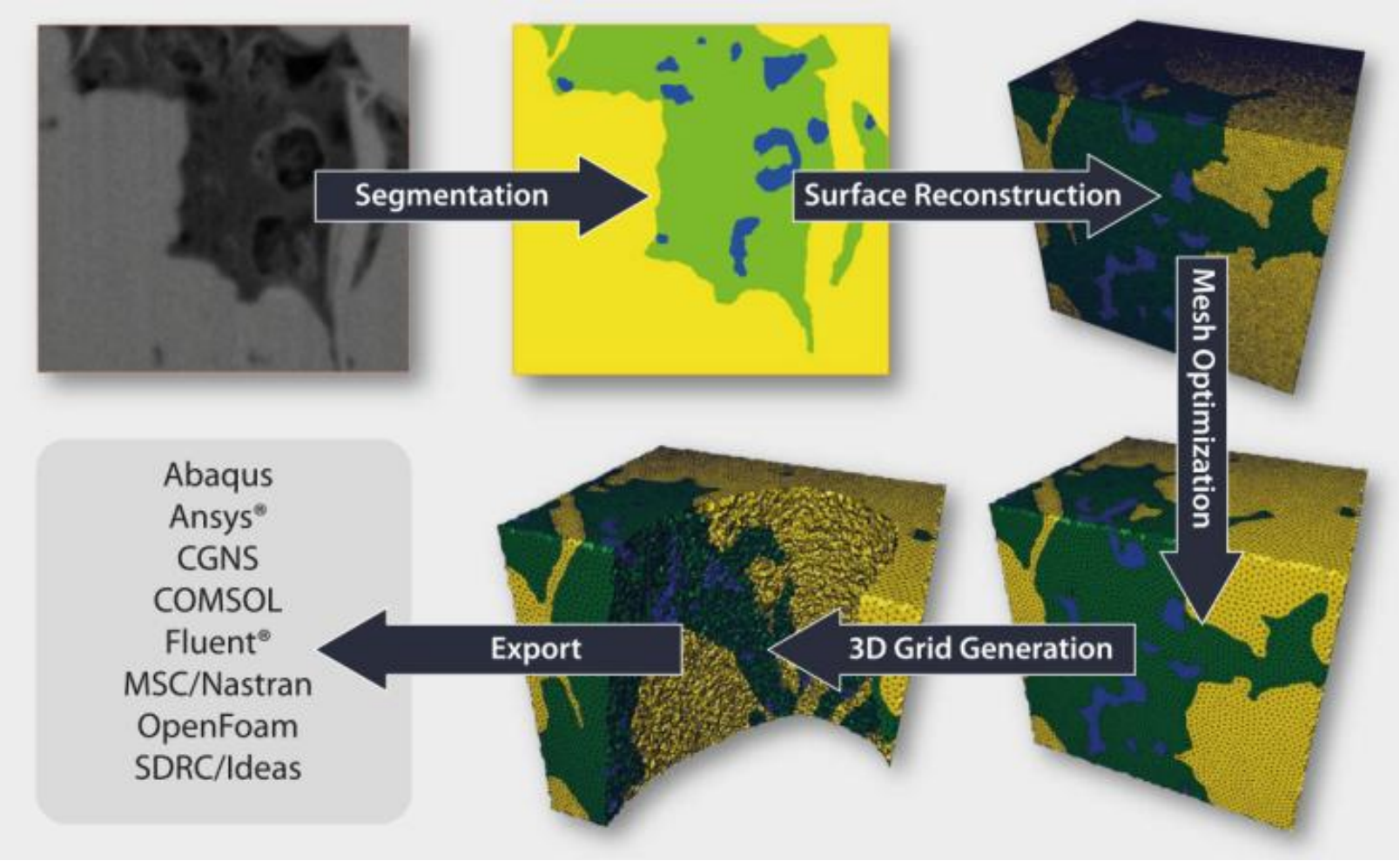
- Tools
  - Automatic, landmark-based or manual registration
  - Arithmetic-based data fusion and derivation
  - Correlation, classification



EBSD map showing grain orientation in Ni-based superalloy

3D surface or volume reconstruction

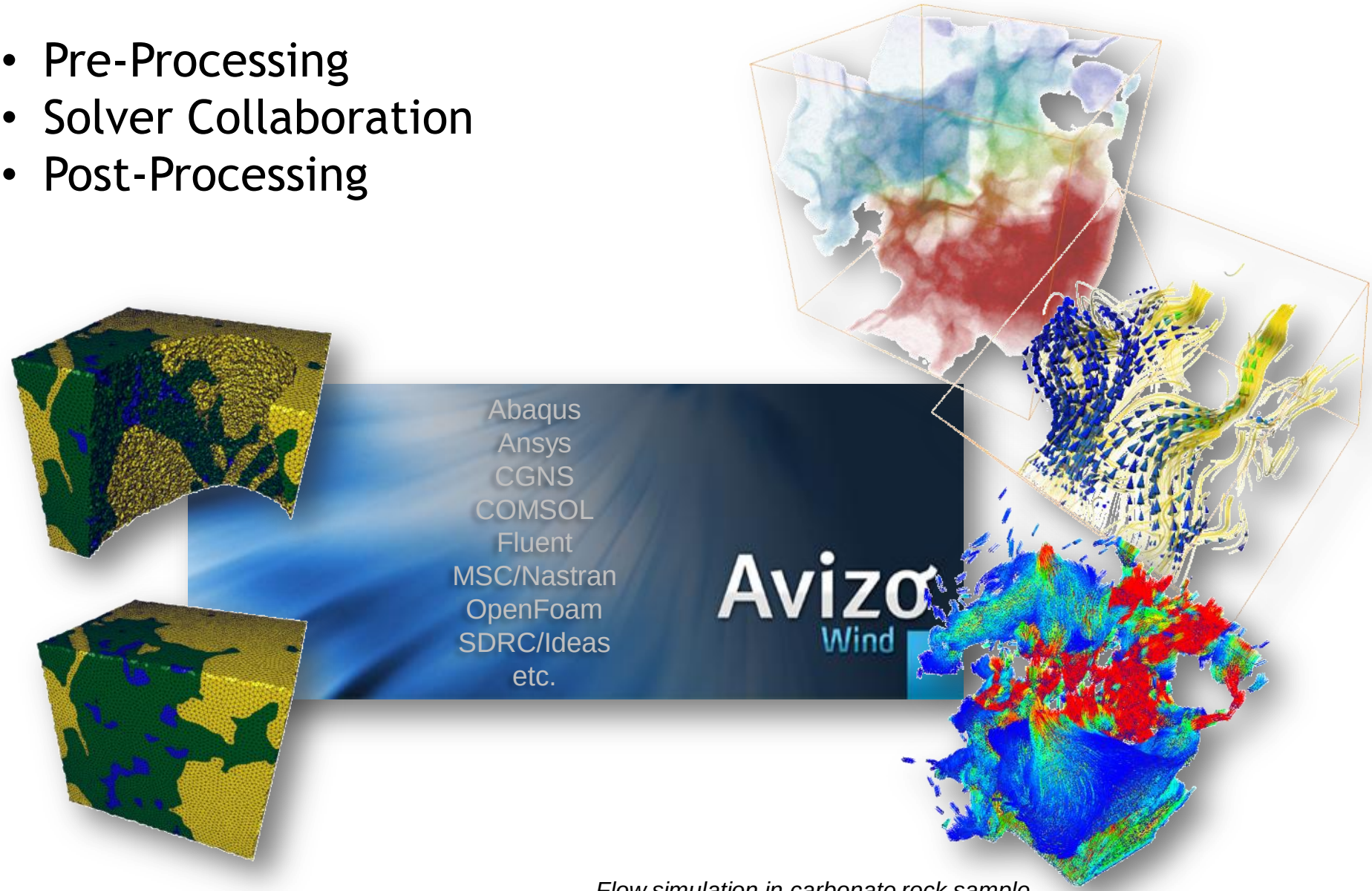
- High quality meshing enable geometry analysis or FEM and CFD numerical simulations



Geometry reconstruction from carbonate rock FIB/SEM imaging

Simulation post-processing

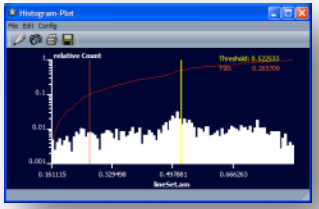
- Pre-Processing
- Solver Collaboration
- Post-Processing

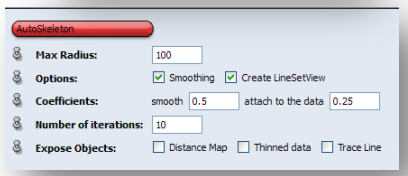


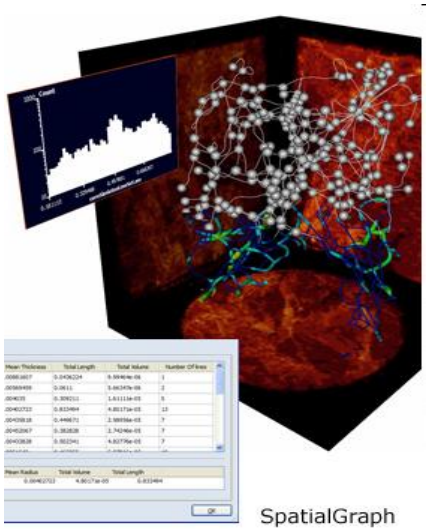
Flow simulation in carbonate rock sample

Spatial graph reconstruction

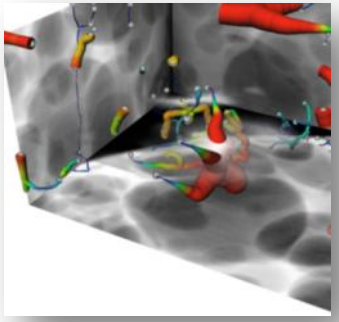
- 2D/3D image skeletonization enables phases or pore network modeling approaches for analysis and numerical simulation

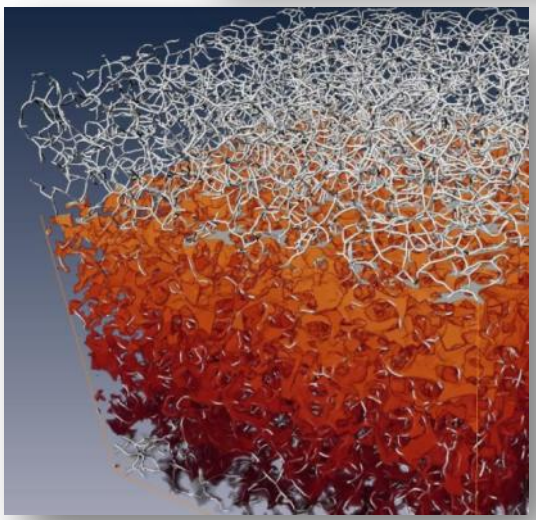


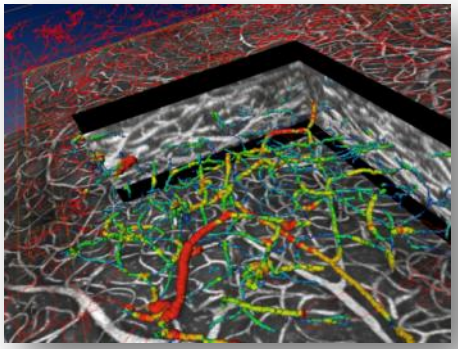




SpatialGraph





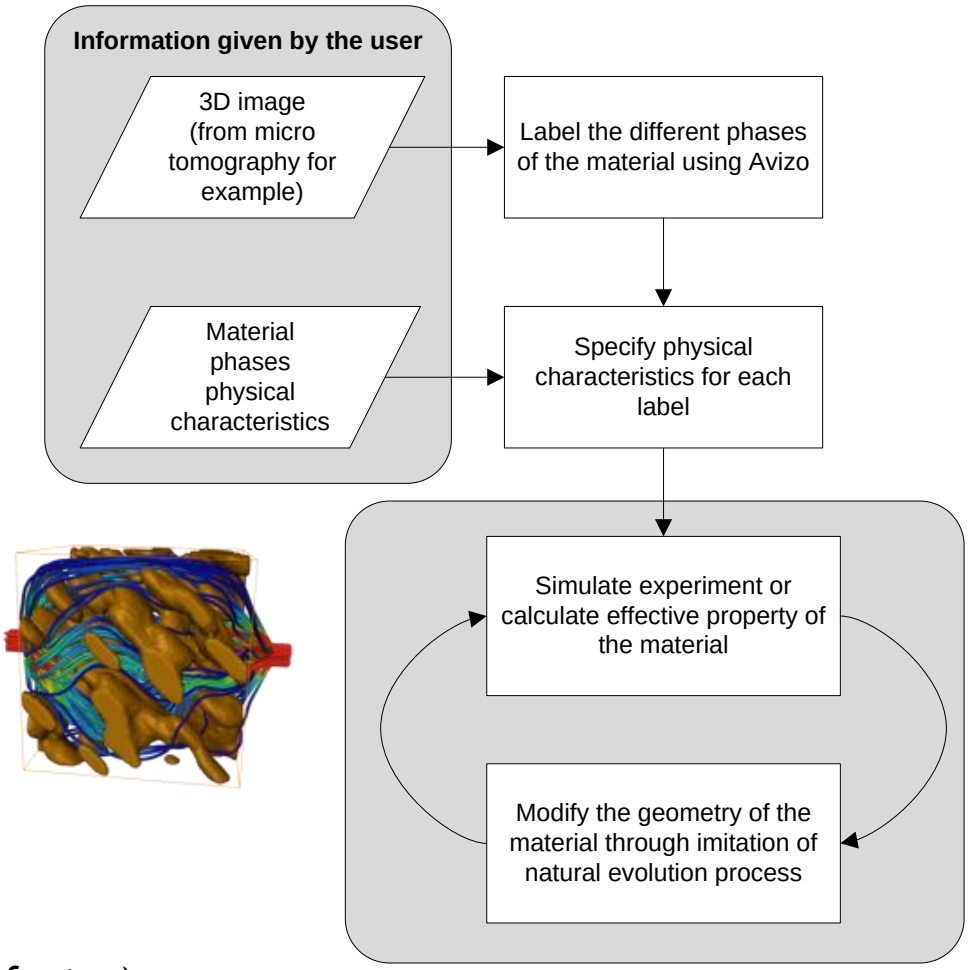


Sandstone pore network modeling - Data courtesy IFP

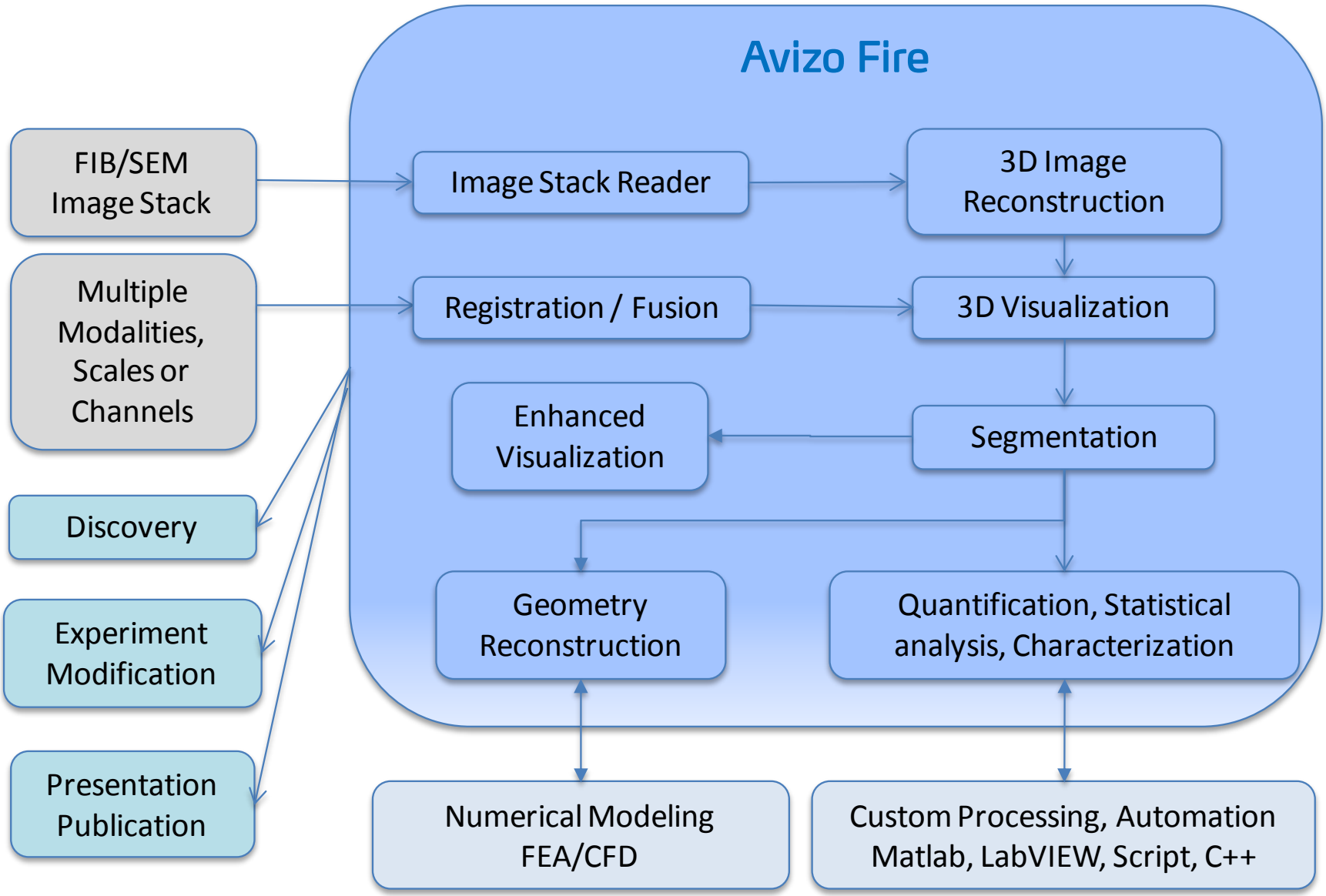
Virtual Studio for Materials Characterization

- Collaborative research

- Simulator for physical properties
  - Computes directly from 3D label image:
    - Effective property
    - Lab experiment simulation
  - For properties:
    - Absolute permeability
    - Molecular diffusion
    - Heat conduction
    - Electrical resistivity (formation factor)
  - Integrated with Avizo platform

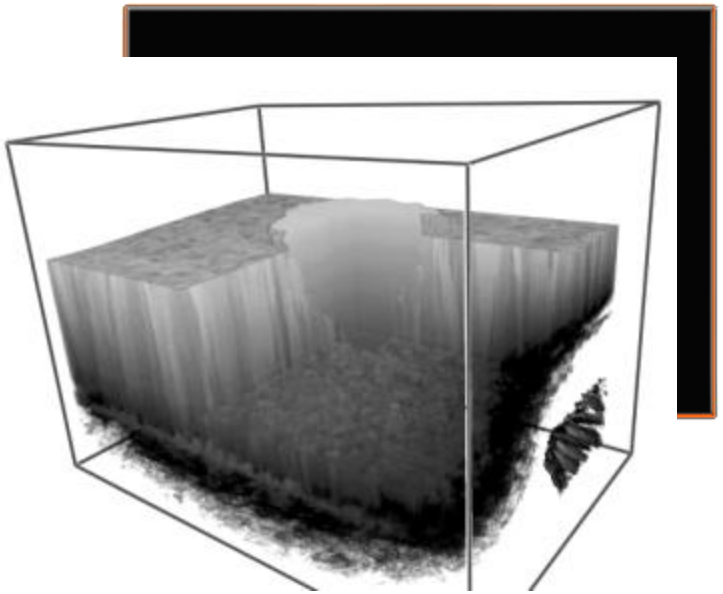


FIB/SEM image workflows



Feedback

- Questions / Comments?
- How can we help?
- Discussion list ?
- Upcoming Webinar on Vis & Processing for FIB/SEM images



Courtesy Maureen Williams (NIST)

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