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# Credible, Automated Meshing of Images (CAMI)

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Seagate-MNC AI/ML Speaker Series

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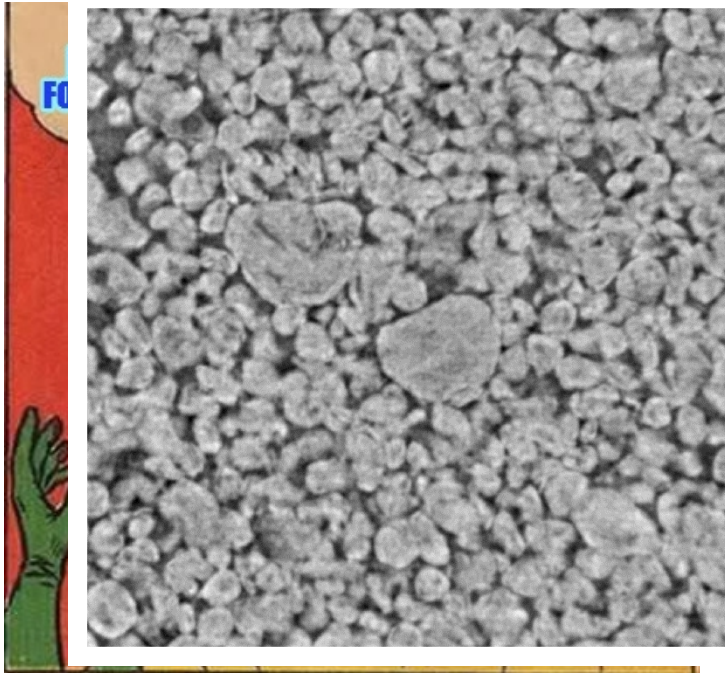




## Why image-based simulation?

We desire to perform simulations directly on images of as-manufactured components/materials

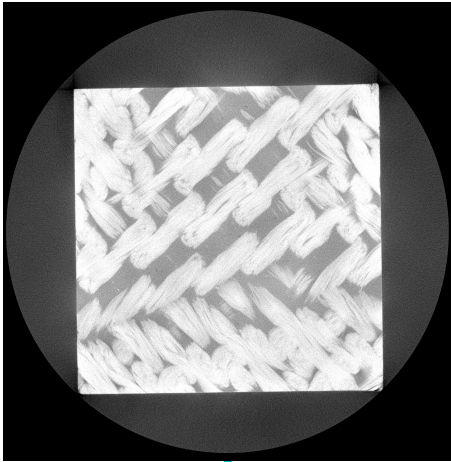
- Enabler for digital twins – captures manufacturing variability
- Allows comparison between analytical/theoretical models and real life



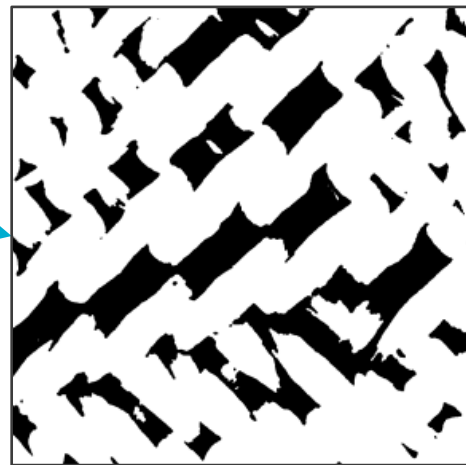


# Credible, Automated Meshing of Images (CAMI) LDRD

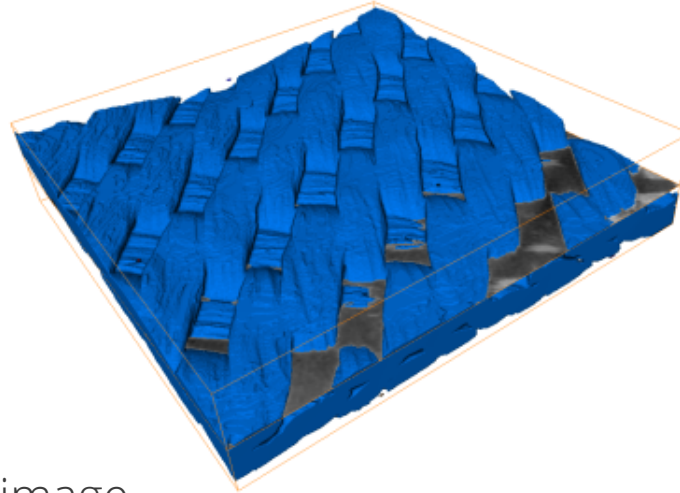
Raw greyscale image (XCT)



Segmented image



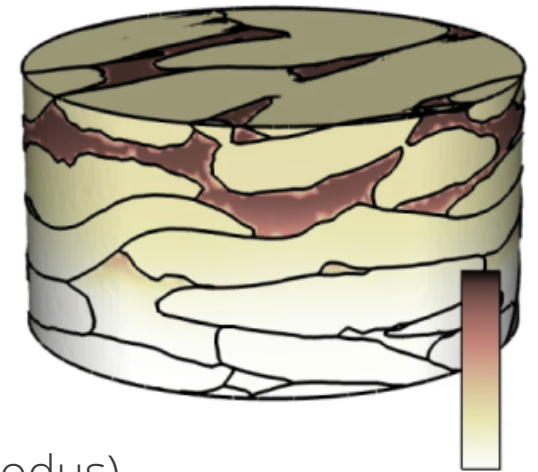
Surface mesh (STL)



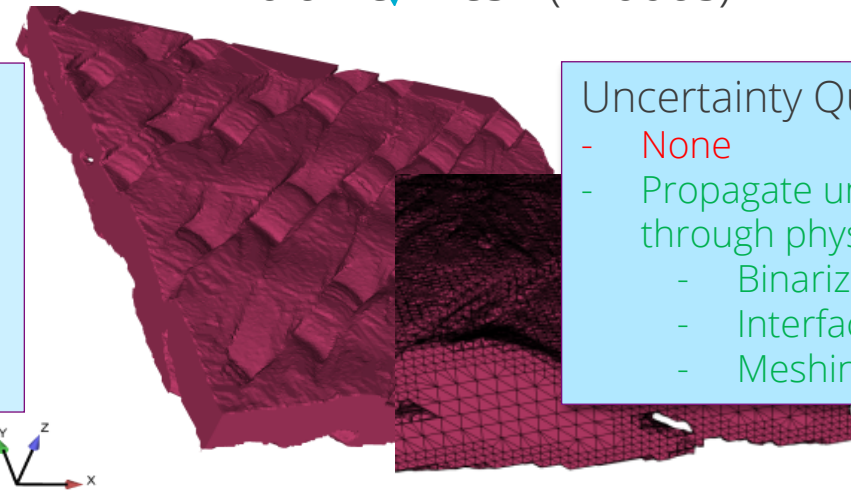
Meshing:

- Cubit
- CDFEM
- Poor quality
- CDFEM + snap + Emend
- High quality

Physics simulation



Volume mesh (Exodus)



Uncertainty Quantification:

- None
- Propagate uncertainty through physics predictions
  - Binarization (BCNN)
  - Interface identification
  - Meshing/resolution

Interface Identification:

- Avizo stair mesh
- Arbitrary smooth
- Manual
- Marching cubes on smooth data

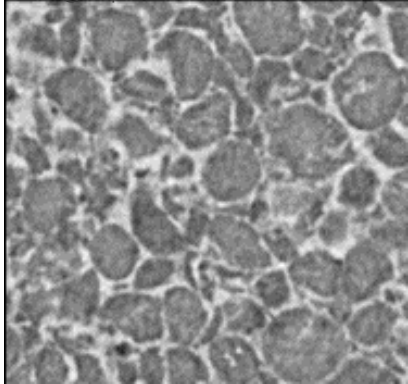
Segmentation:

- Manual thresholds
- SME-dependent
- Non-repeatable
- Deep learning Automatic
- Repeatable

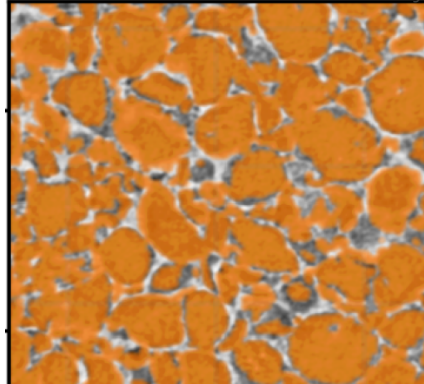


# Deep learning for 3d image segmentation

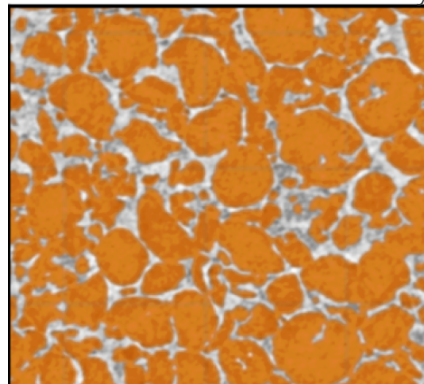
Slice from CT image of graphite electrode



Human label (orange) overlaid on CT scan of battery



Deep learning label (orange) overlaid on CT scan of battery

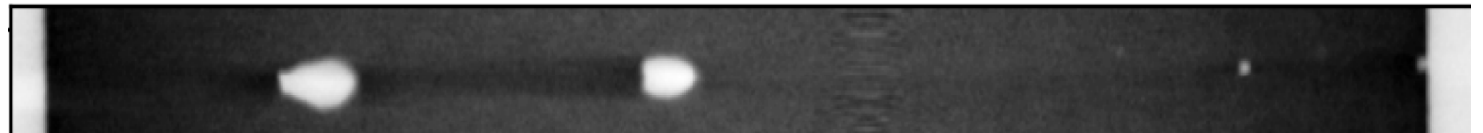


LIB: Incrementally trained DL model segments to high accuracy, higher than human labels in some cases

Laser welds: 99.2% accuracy to manual labels with uncertainty maps on ambiguous features.

DL inferences takes minutes on GPU vs. days manually!

CT scan of laser welded material



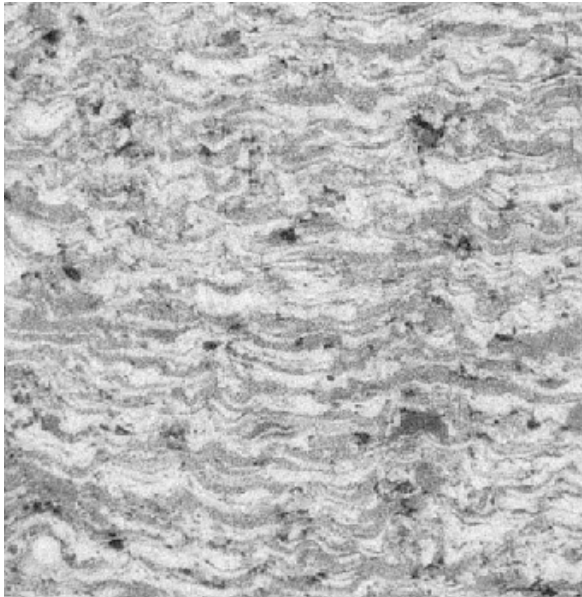
Accurate deep learning segmentation



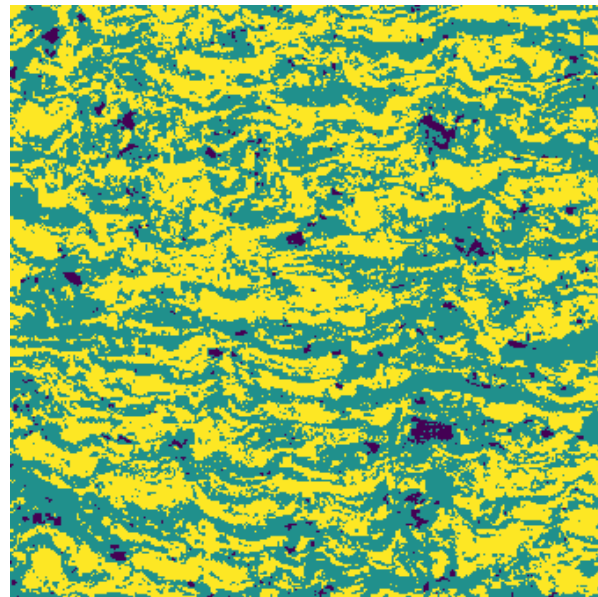


# Deep learning segmentation is *not* thresholding

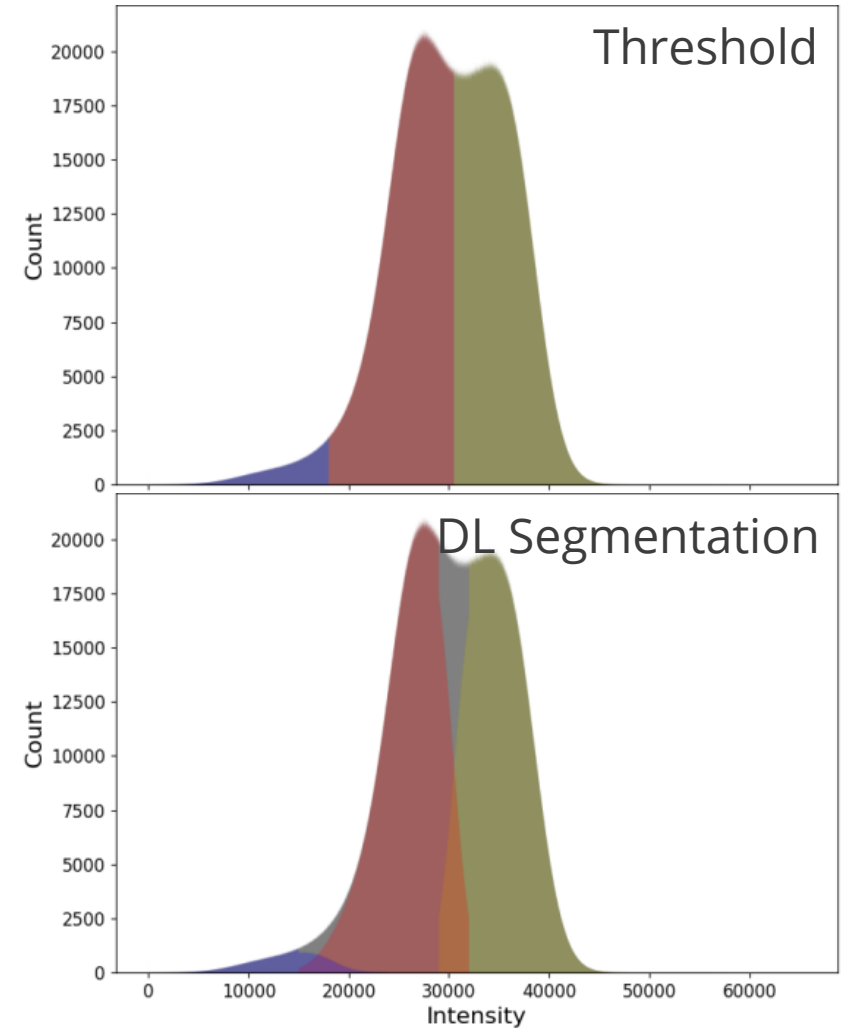
Three-material thermal sprayed metallic coating



Greyscale



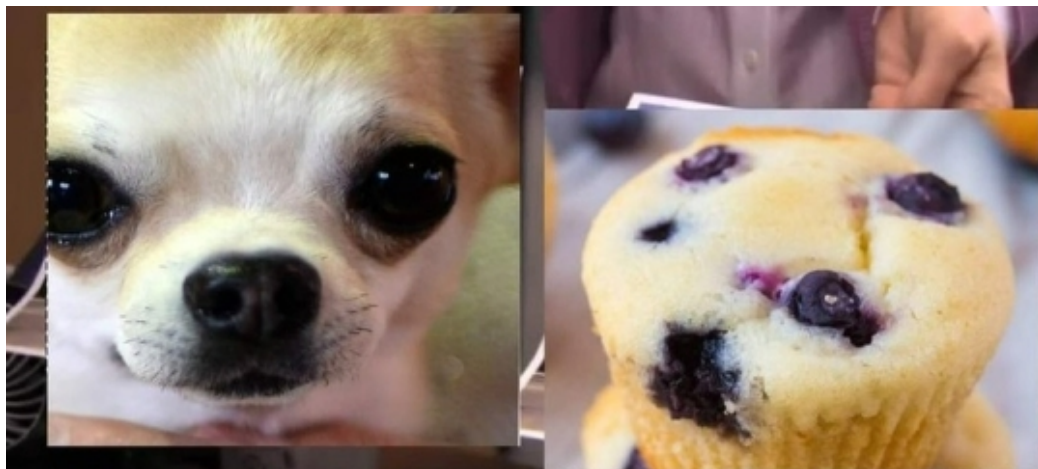
DL segmentation



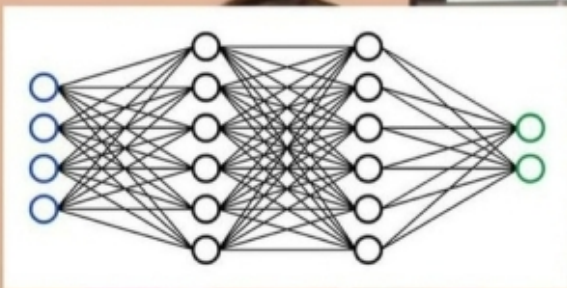
Overlay of voxel intensity with phase assignment demonstrates DL does a non-trivial segmentation



# Image segmentation uncertainty



Corporate needs you to find the difference between this picture and this picture

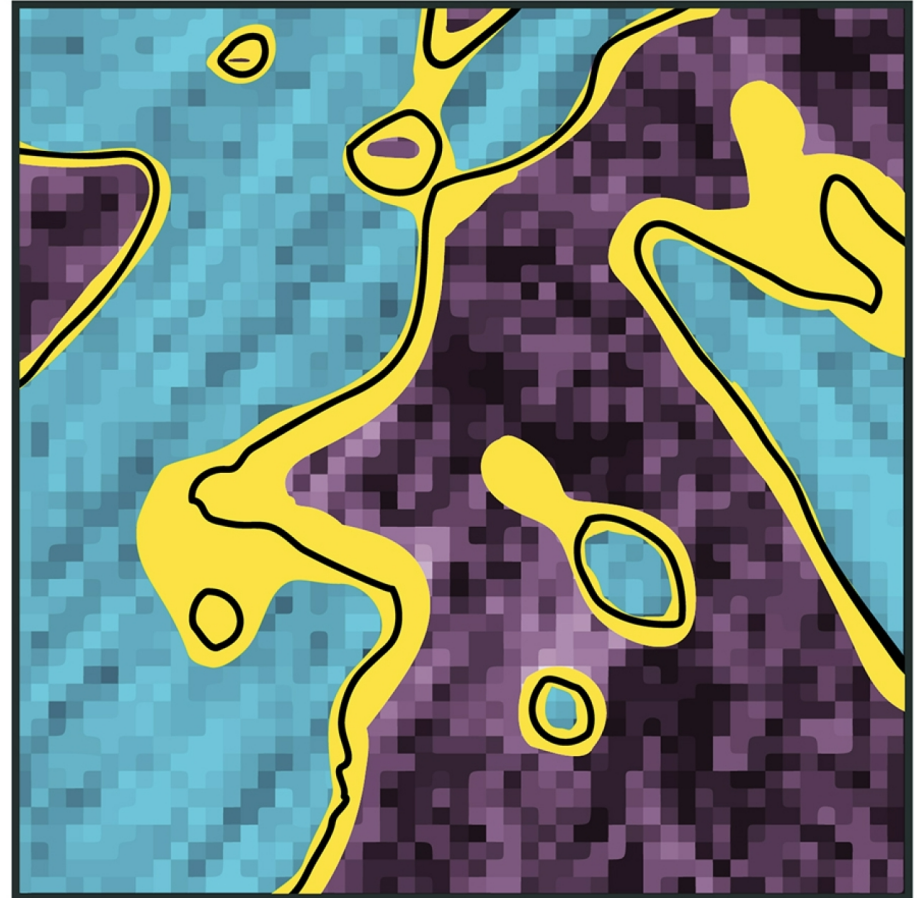
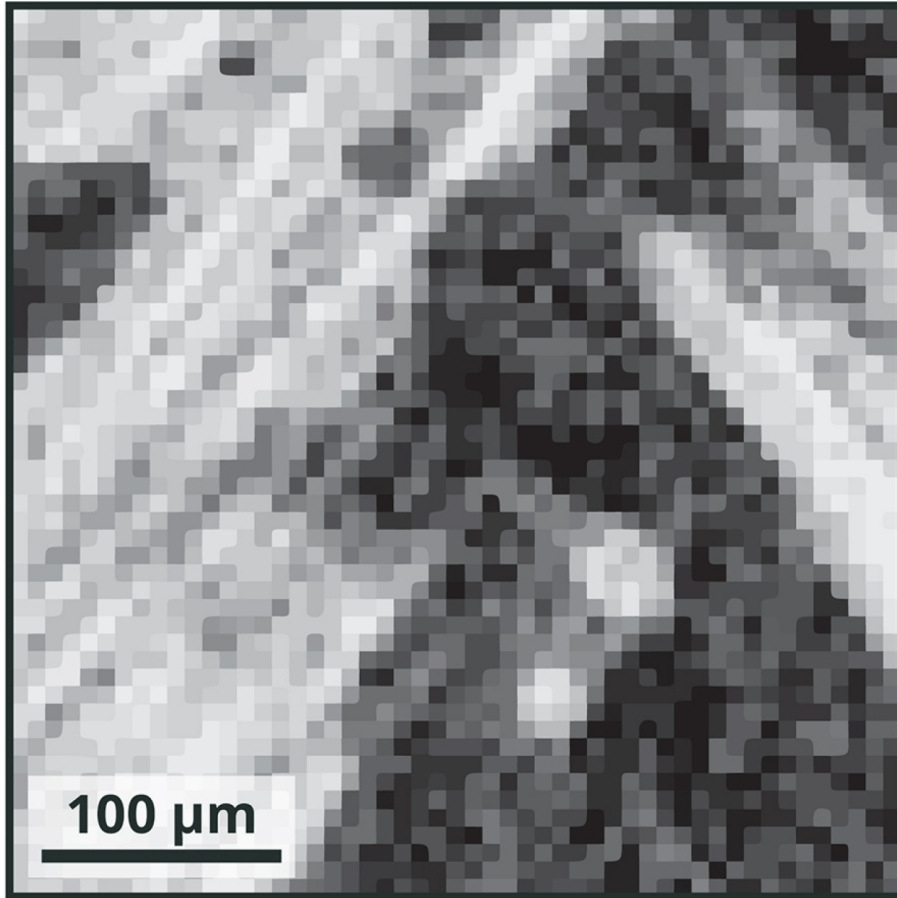


They're the same picture



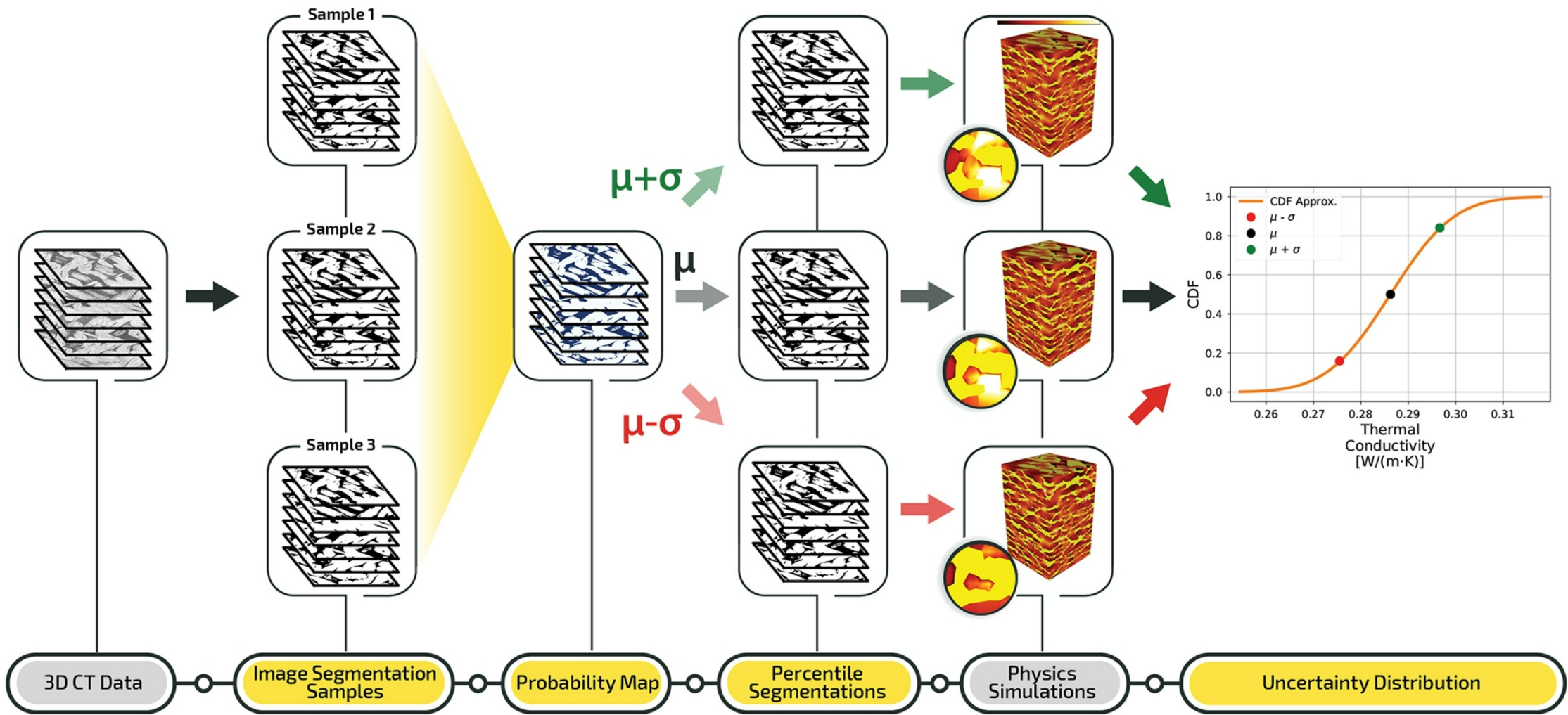


# Image segmentation uncertainty





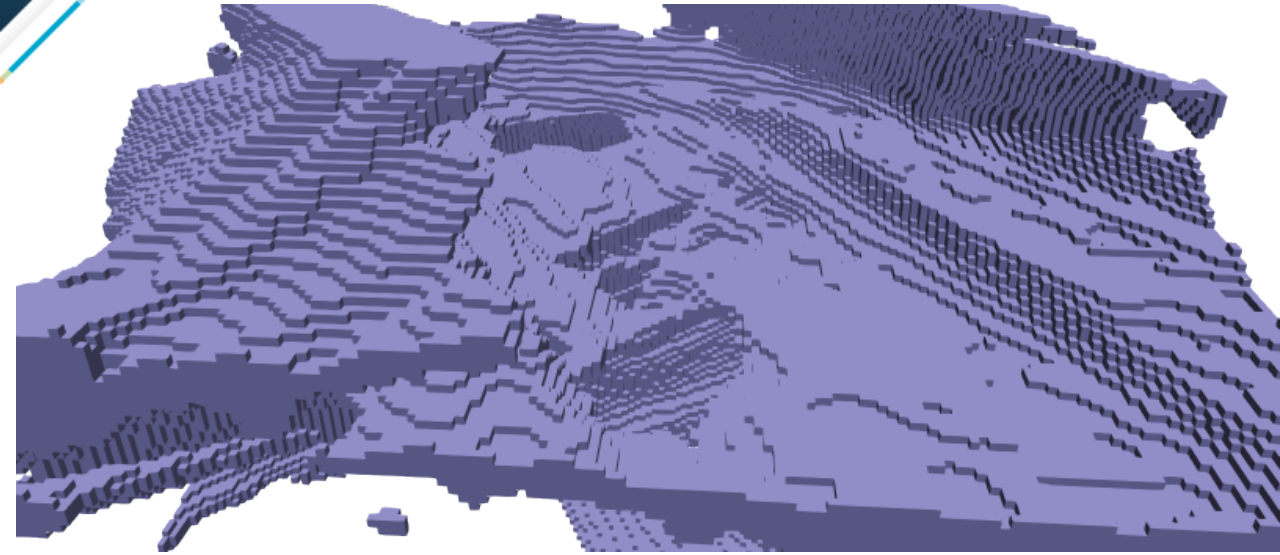
# Efficient Quantification of Uncertainty in Image-based Physics Simulations (EQUIPS)



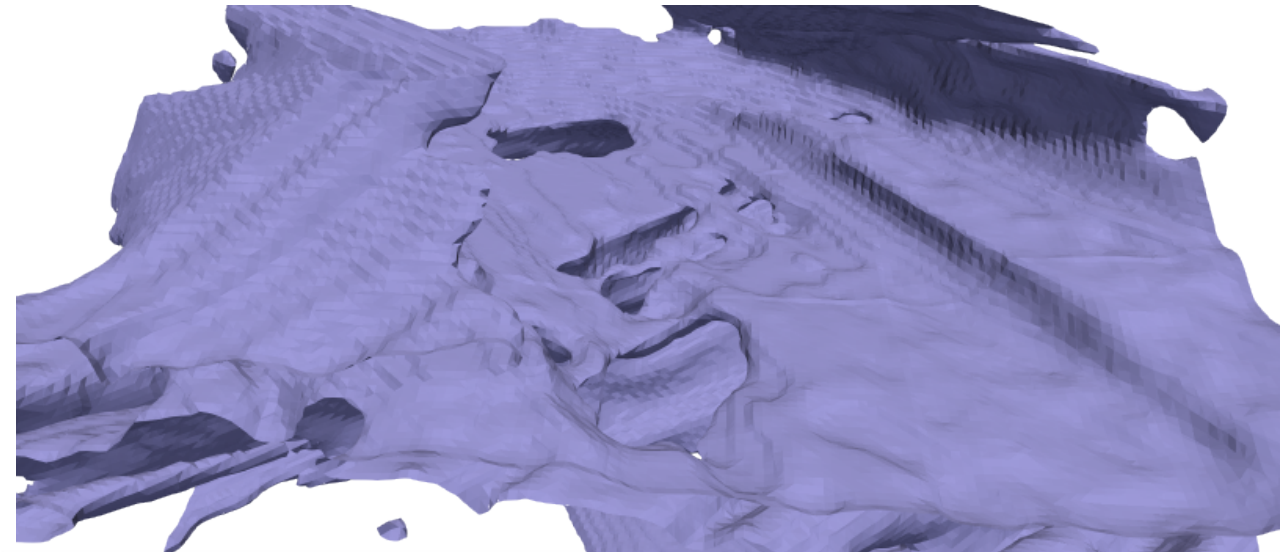


# Surface meshing

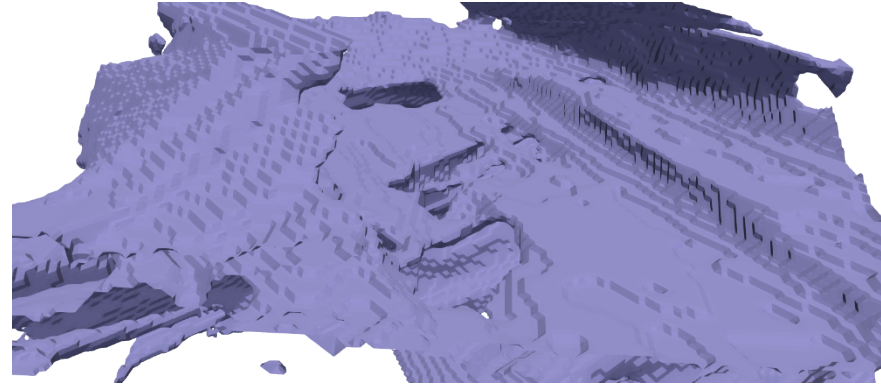
Surface mesh of binarized data



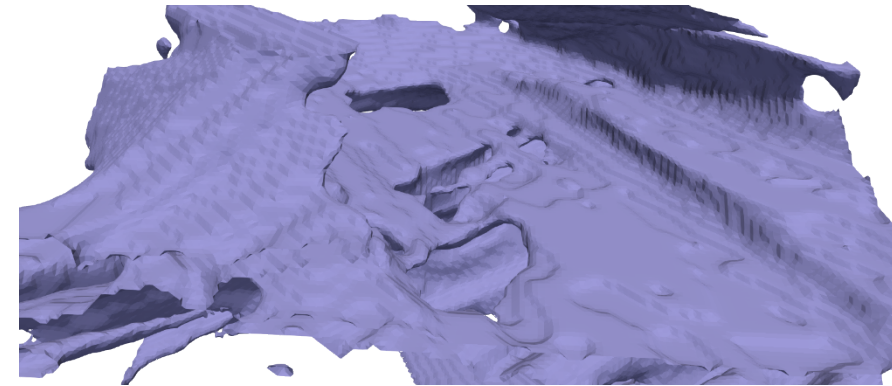
Marching cubes on probability map



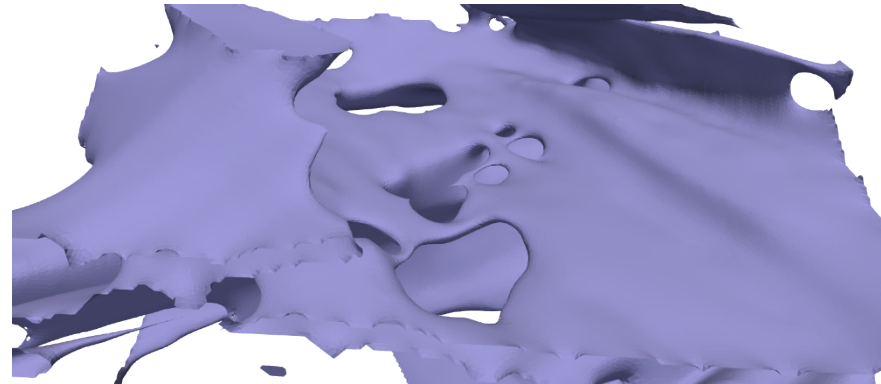
Smooth a little?



Smooth a bit more??



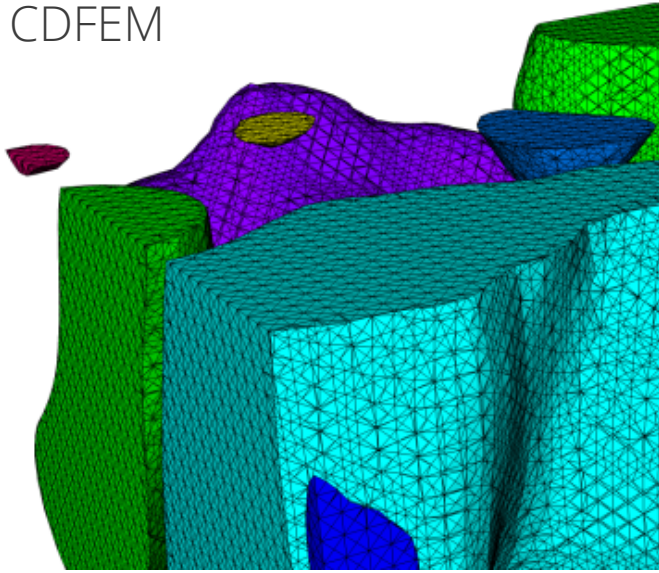
Smooth a lot???



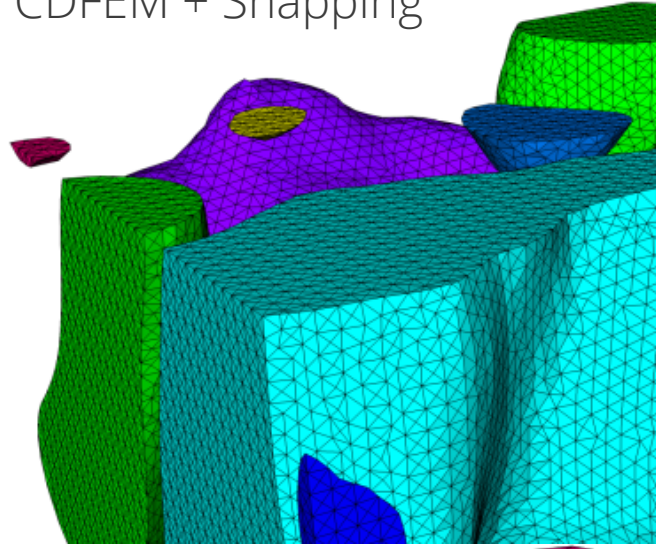


# Volume meshing – Krino + Emend

CDFEM

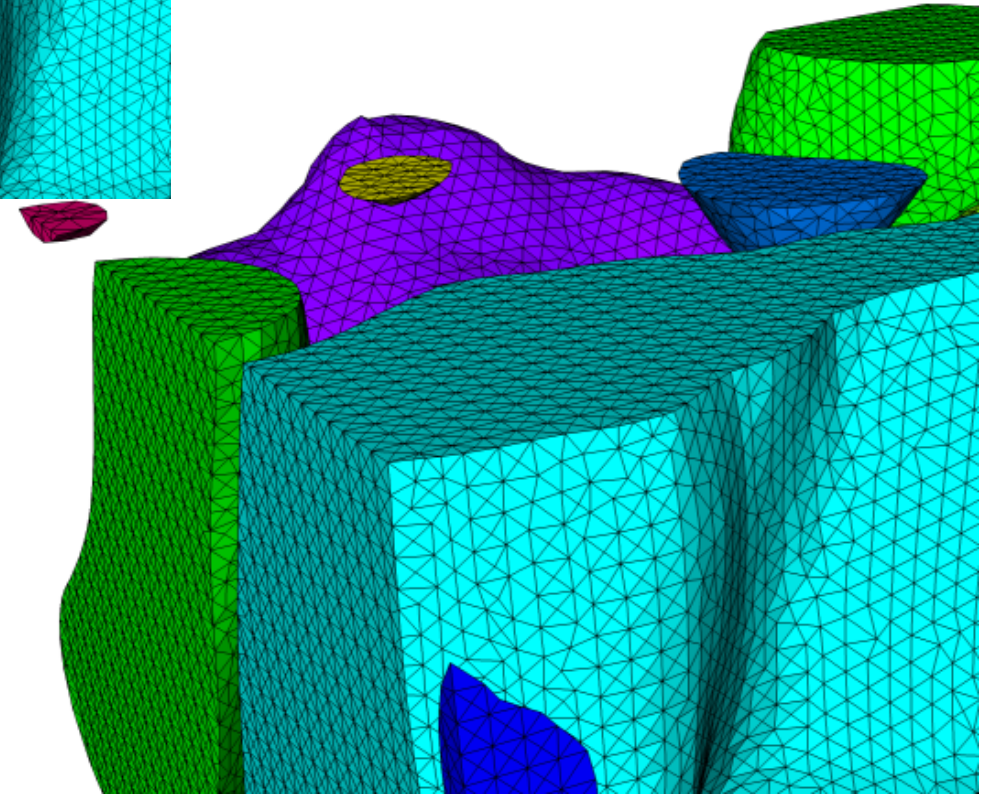
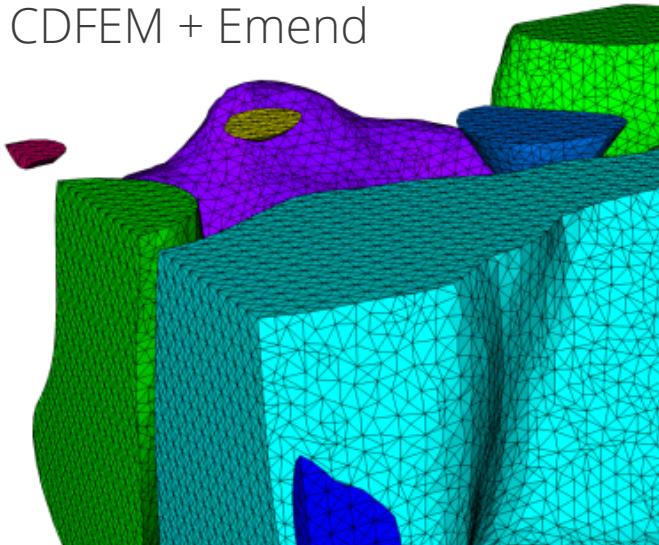


CDFEM + Snapping



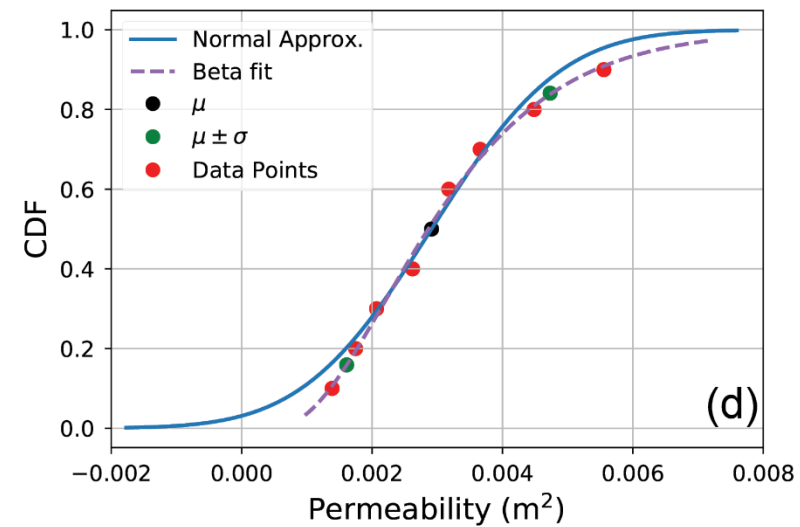
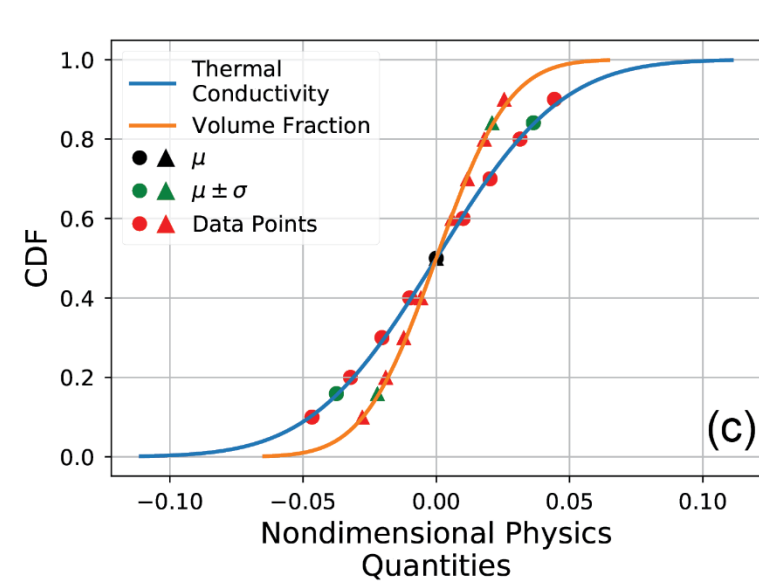
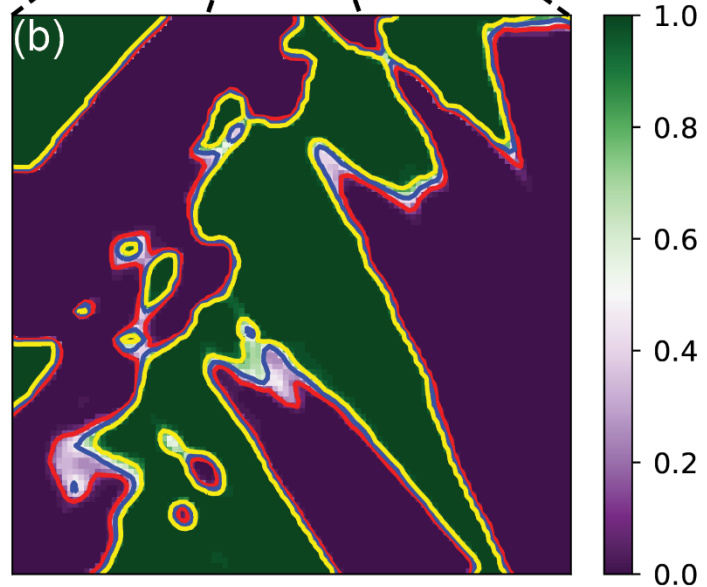
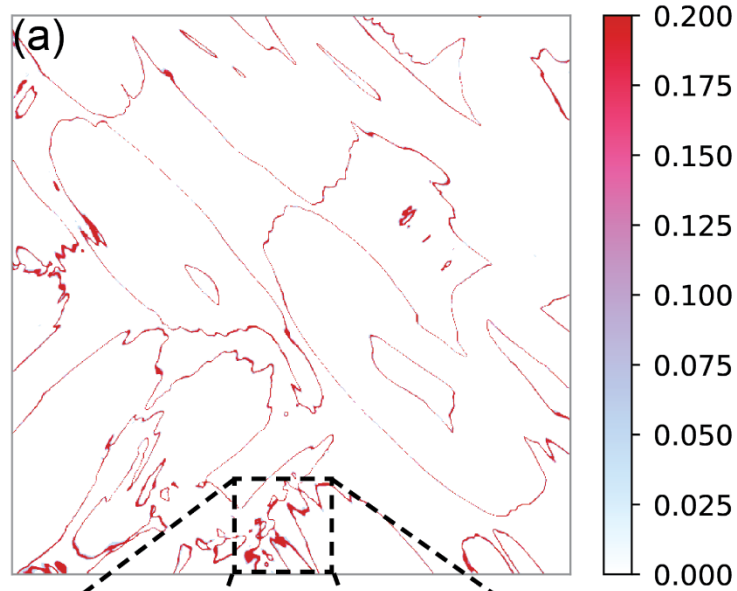
CDFEM + Snapping + Emend

CDFEM + Emend



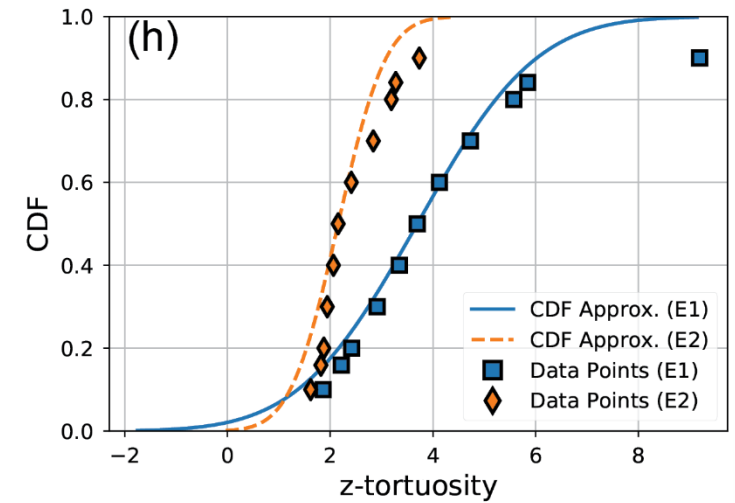
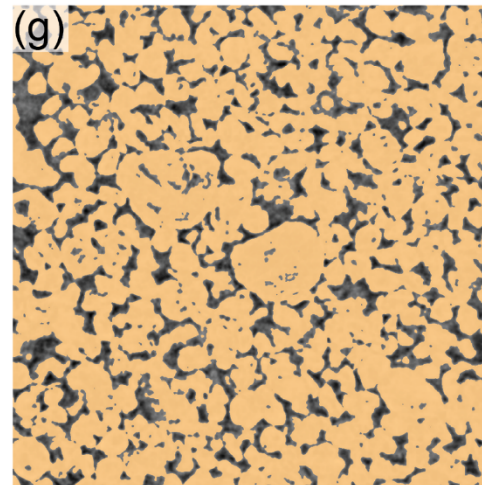
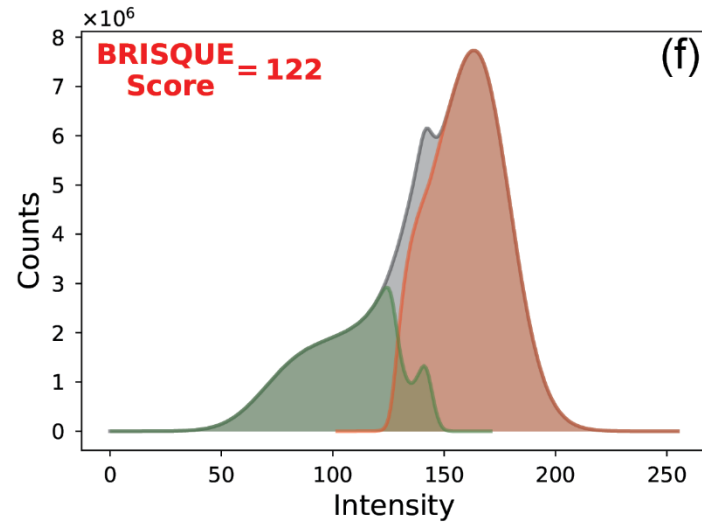
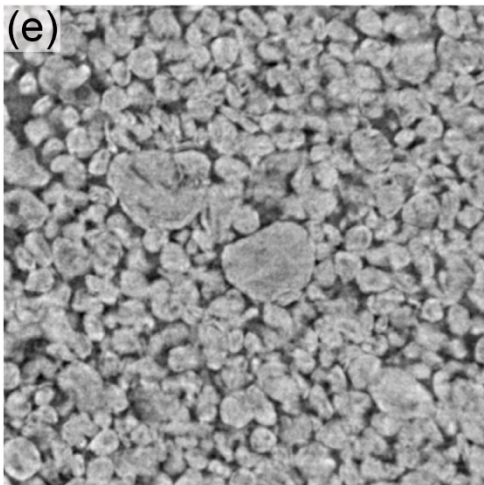
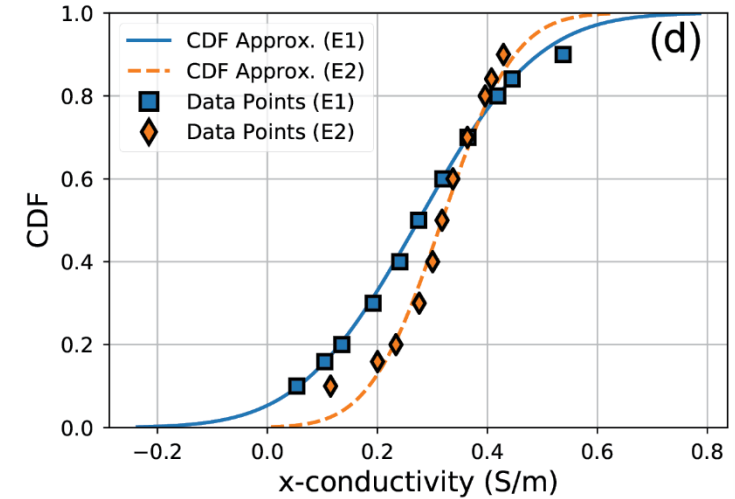
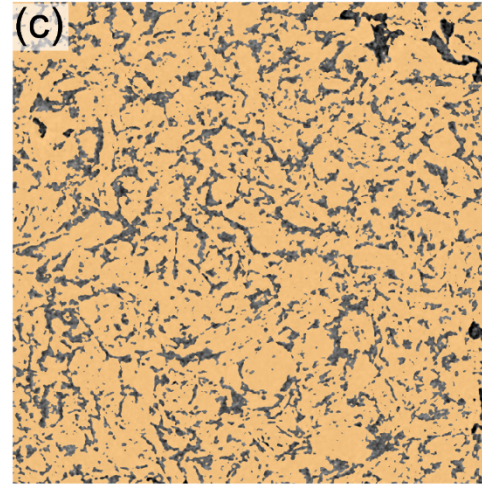
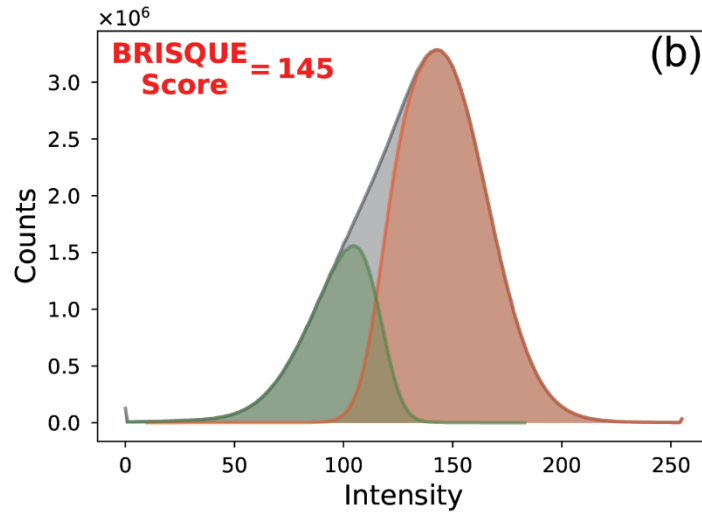
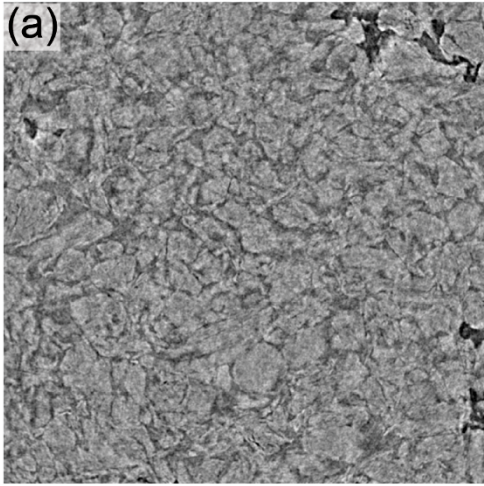


# Exemplar: Thermal protection system (TPS) materials



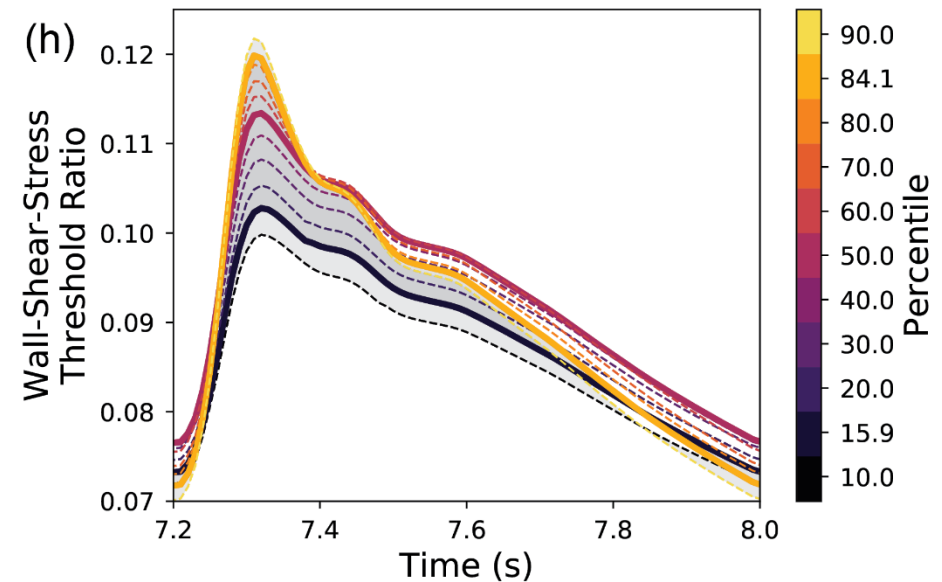
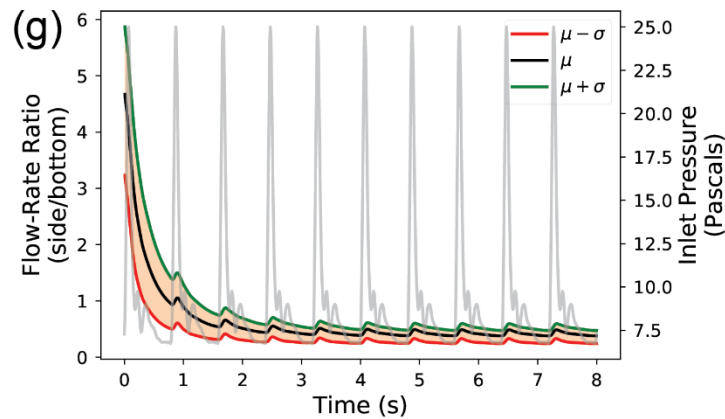
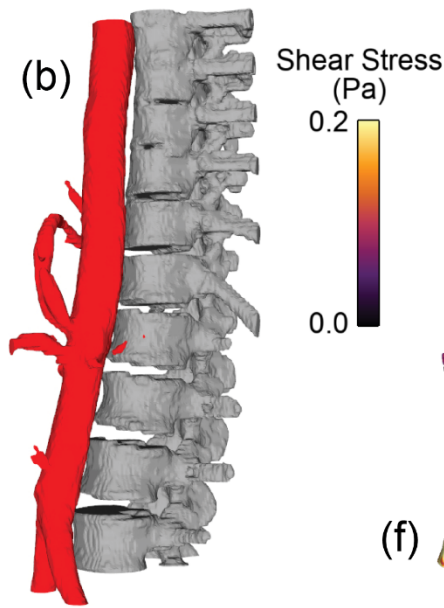
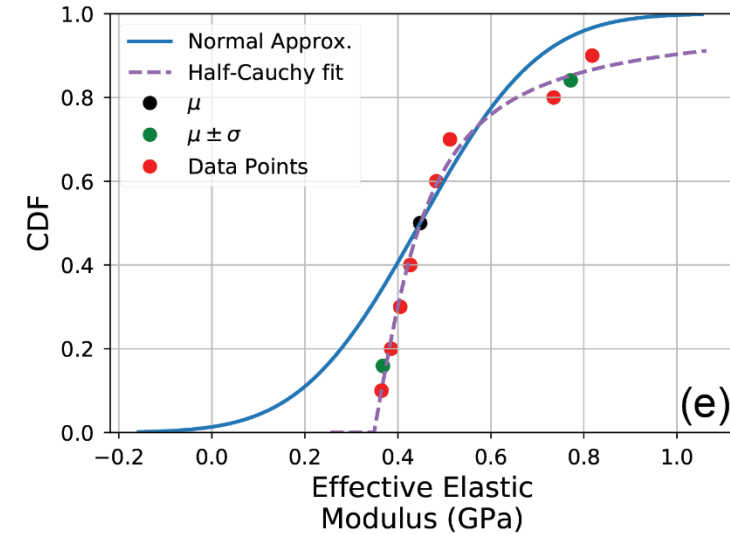
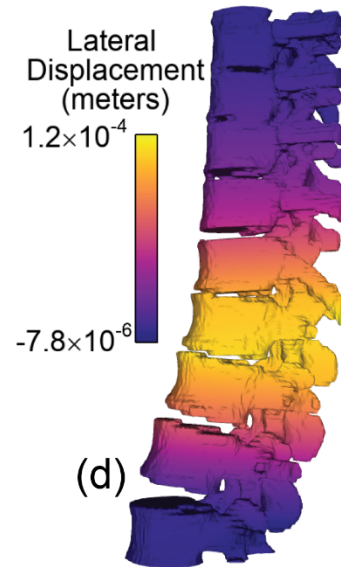
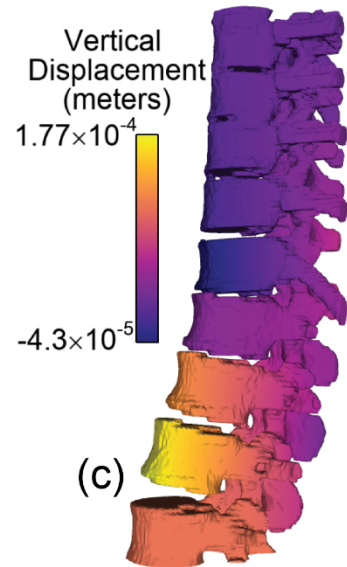
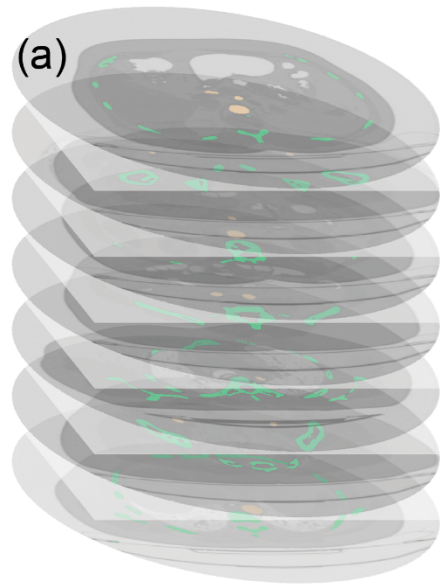


# Exemplar: Graphite battery electrodes





# Exemplar: Medical imaging of human tissue





## Real-world application: web/cloud-based EBW simulations





## Summary

- Image-based simulation is becoming a reality for materials and components. Enablers:
  - Machine learning based image segmentation
  - Automated, high quality mesh generation
  - Scalable physics simulation codes
- Credibility of image-based simulation requires uncertainty quantification throughout process
  - Our workflow is generalizable to nearly all workflows
- Application areas: Detonators, neutron generators, foam encapsulants, thermal protection system materials, energy storage materials, thermal sprayed coatings, laser welded components, human tissues, etc., etc.
- Future insertion opportunities
  - Manufacturing inspection – acceptance based on performance rather than presence of “defects”
  - ICME – predict on a real part rather than simplified geometries
  - Surveillance – Non-destructive performance evaluation of aged/fielded objects

# THANK YOU!

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