Semi-Supervised Segmentation of Carbon Fiber Weaves in Micro Computed Tomography

Michael MacNeil[1], Dani Ushizima[1,2], Francesco Panerai[3], Harold Barnard[4], Dula Parkinson[4]

[1]Computational Research Division - LBNL, [2]University of California Berkeley, [3]NASA Ames, [4]Advanced Light Source - LBNL

Summary

- Increasingly large and complex image datasets from microCT **confound existing software tools.**
- Scientific analysis of observational DOE data requires **significant advances in methods.**
- Target of this research is quantitative analysis of complex 3D shapes in a large and noisy 3D image dataset.
- Our results **replace a process requiring months of manual effort with one that takes only a day**.
- **Outperformed existing classification software by 10% in F1 score.**

Approach

Semi-supervised segmentation for MicroCT has three modular sub routines:

(1) **Feature extraction**. Features are based on **Wavelets** for texture cross-section characterization;

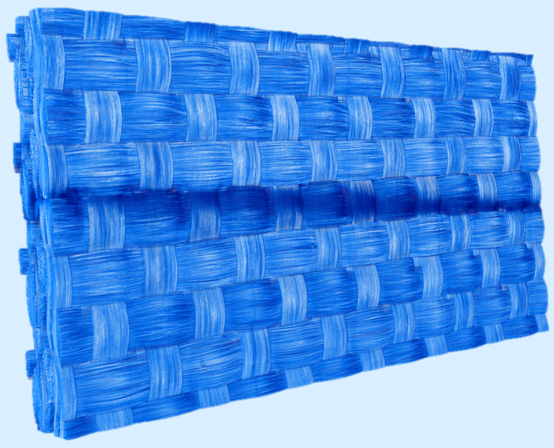
(2) **Classification.** Using user-labelled pixels as input, artificial **Neural Networks** were ensembled to classify the remaining pixels.;

(3) **Spatial Regularization.** Based on a convex relaxation of Fully Connected Conditional Random Fields, we derive Nonlocal Means as an memory efficient, one pass algorithm to add spatial context. That is, pixels with similar features are classified to similar labels.

$$\min_{U_l \in \mathbb{R}^n} \sum_{l \in \mathcal{L}} -\langle P_l, U_l \rangle + \langle U_l, DU_l \rangle$$
$$\sum_{l \in L} U_l = 1,\ U \succeq 0.$$

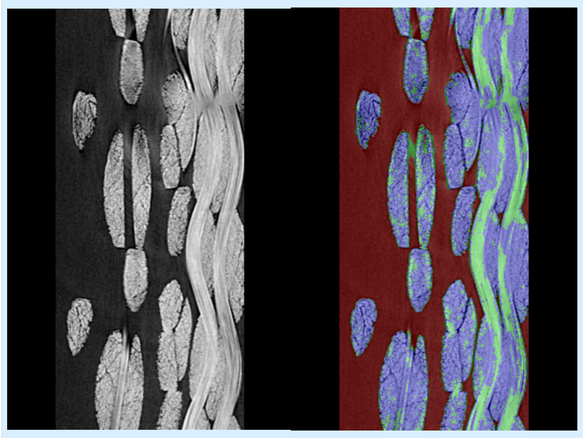
Results

1. Segmentation Task



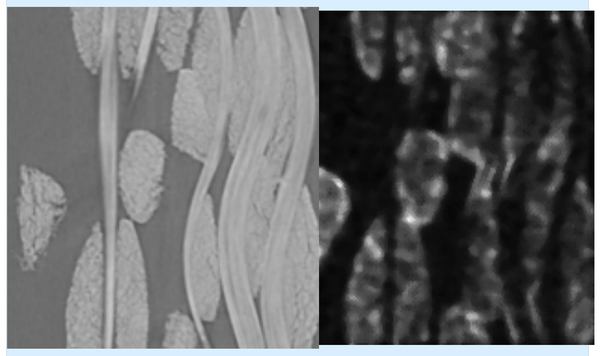
- Separate carbon fiber bundles running vertically from those running horizontally across the volumetric image volume;

2. Failure of Standard Tools.



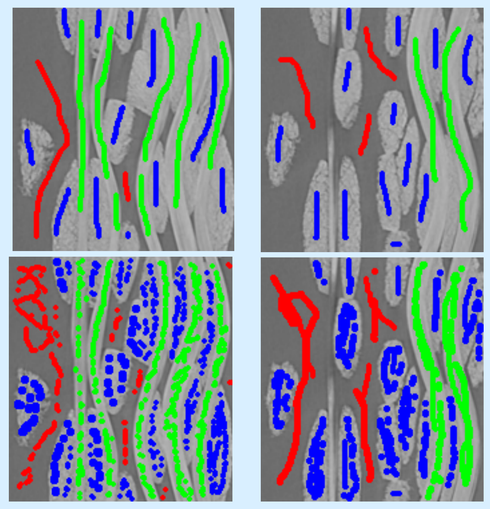
- Experiments using *Trainable Weka Segmentation* showed that even with strong features, classification precision remained at 75% in F1.

3. Features



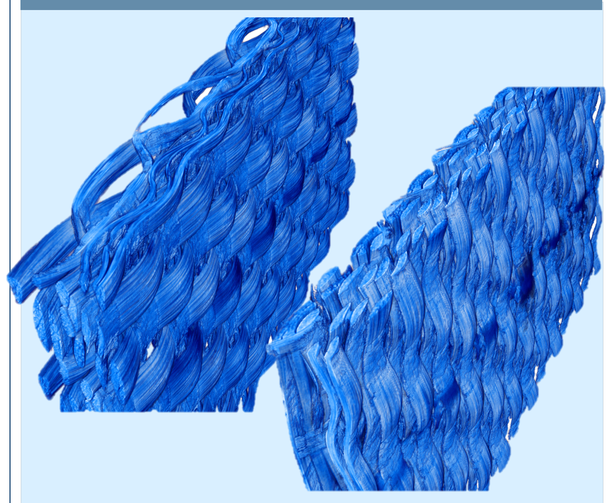
- Main cue is texture. Vertical tows are smoother, horizontal are rougher as observed in opposing directions.

4. Training and Validation



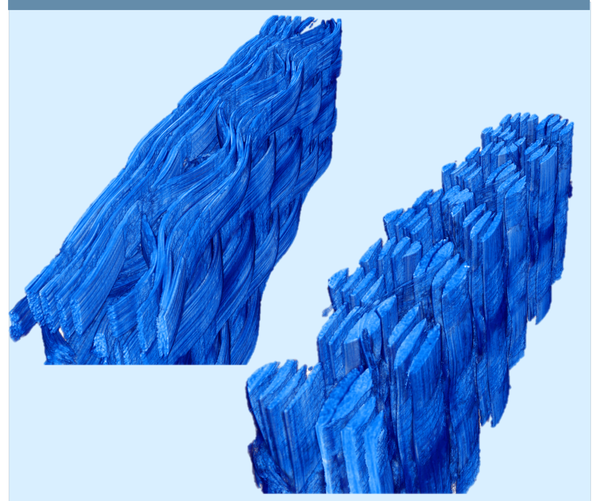
- **Images are labelled partially, instead of requiring an entire mask**. Significantly reduces labelling time.

5. Generalization



- **Trained on 10,000 pixels, generalizes well to 400 million. On Validation and Test Sets, average F1 Score of 0.93.**

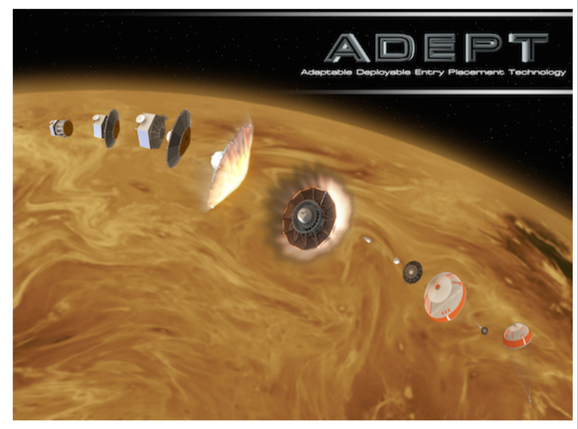
6. Transfer

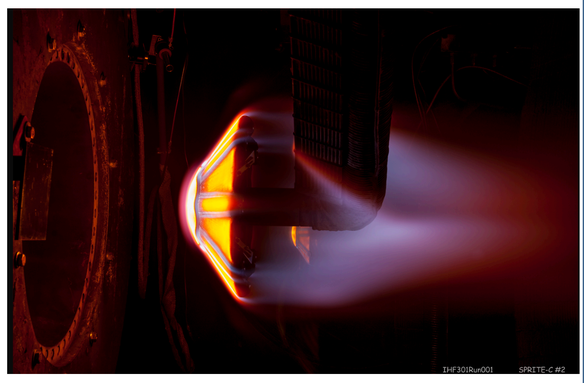


- **On transfer sets, generalization averaged F1 score of 0.9, without fine tuning or transfer learning.**

Science Impact

- **NASA** is replicating the conditions of Mars atmosphere re-entry at the Advanced Light Source to study next generation materials for atmospheric entry systems, such as the ADEPT system, pictured below;





- **LBNL ALS Beamline 8.3.2** can perform micro-tomography analysis which can be heated to temperatures up to **>1200C with mechanical and chemical stresses, in-situ, to model extreme environments experienced during atmospheric entry**;
- The **3D microCT** specimens to the left enable study of microstructure of woven carbon fibers (WCF) for heat shields, as pictured above.
- **Segmentation is a crucial step** and this work demonstrates strong proof of concept for **semi-supervised machine learning algorithms**.

Acknowledgements

Special thanks to Burlen Loring for advice on Paraview. This work was supported by the Director, Office of Science, Office of Advanced Scientific Computing Research of the U.S. Department of Energy under Contract No. DE-AC02-05CH11231, through the grants: **DOE Early Career Research Program**. This works has also the financial support of Sloan Moore Foundation through UCB.