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Defect detection in ReBCO layers using Machine Learning

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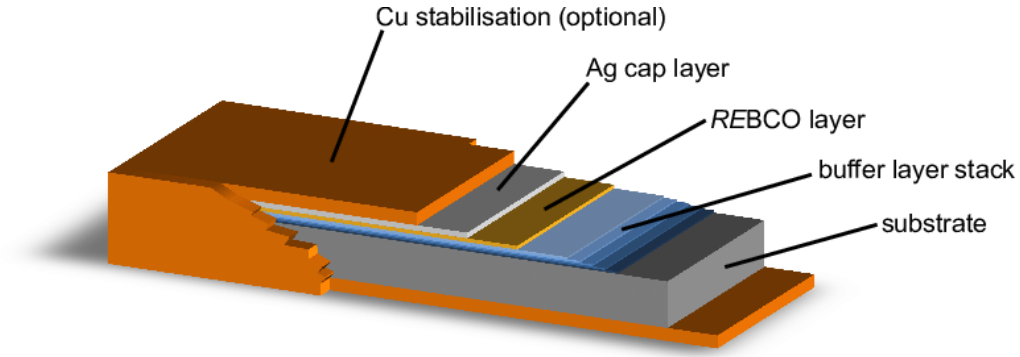
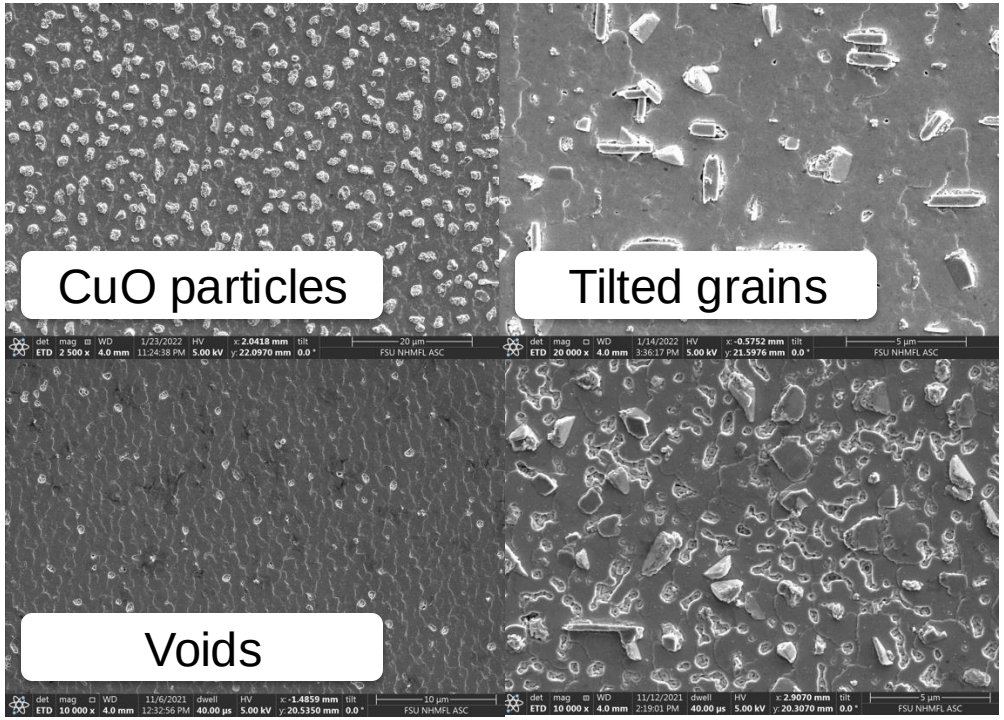
Table of contents

Larger goal

- Correlating transport and mechanical properties to microstructure
- Characterization of ReBCO conductors of varying thickness between 0.6 – 1.9 μm
- SEM of top layer after etching out Cu and Ag layers to reveal ReBCO layer
- Defects: voids, CuO particles, and a-axis grains



C Barth *et al* 2015 *Supercond. Sci. Technol.*

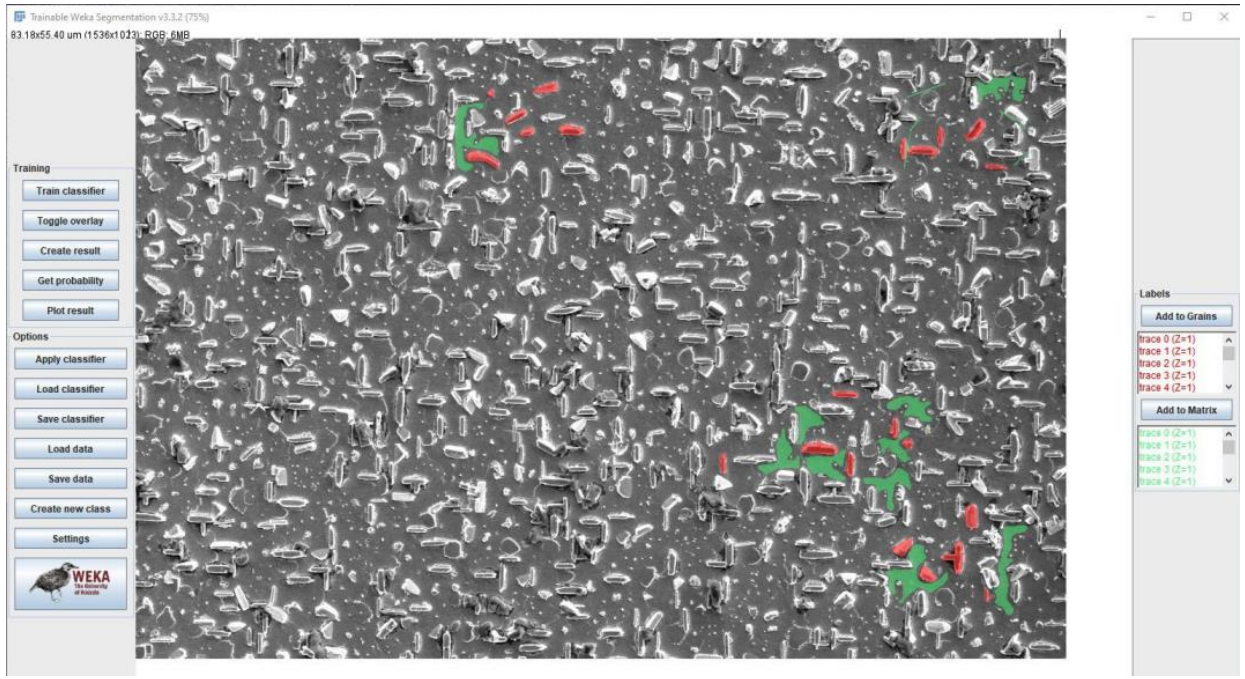


Imaging and etching done at FSU by D. Abraimov et al.

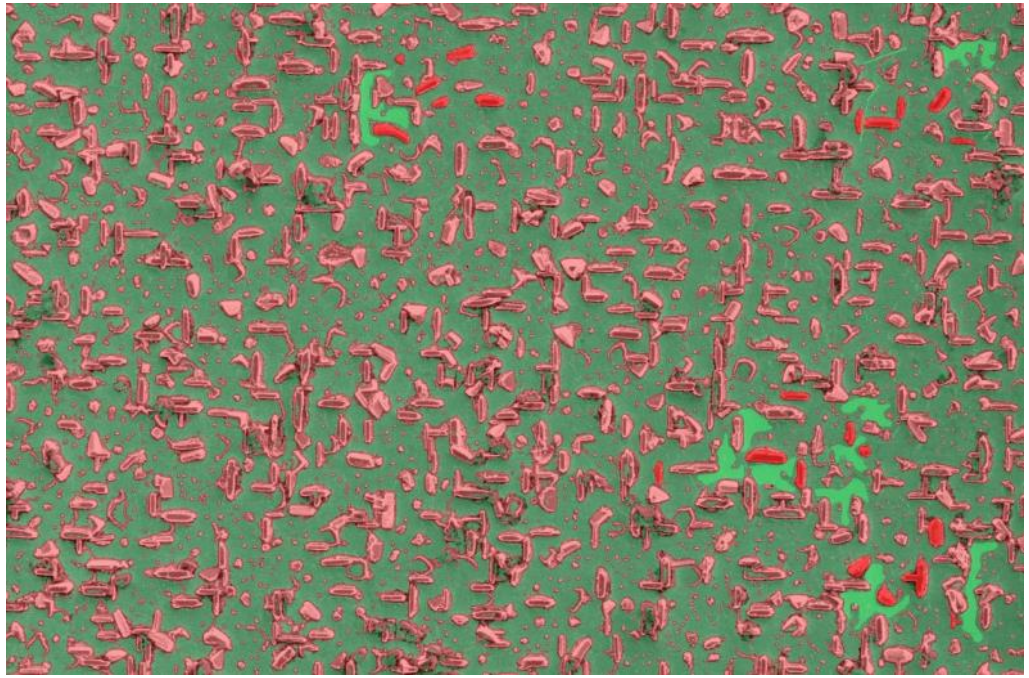
Defect detection

Existing methodologies

- Counting defects manually
- Built-in ML techniques within image analysis software (ImageJ)



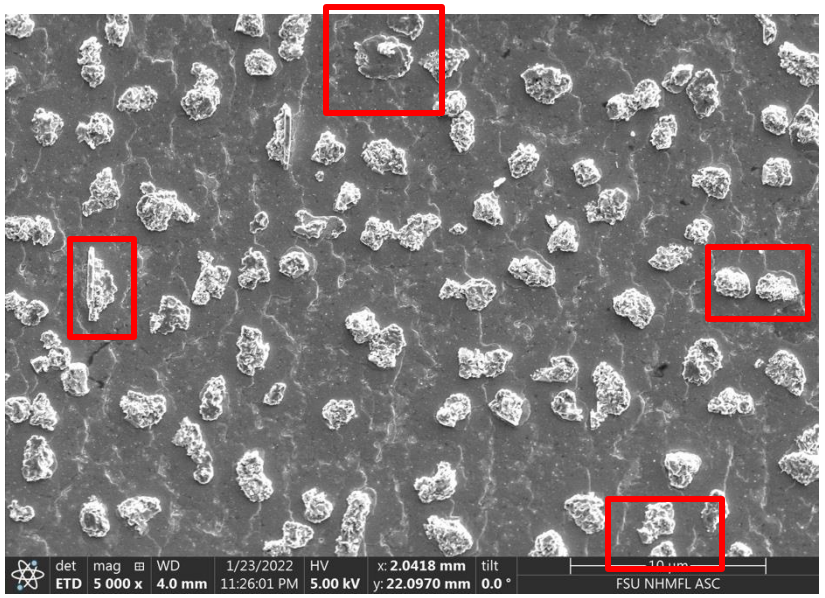
[Characterization of graded ReBCO conductors for the 40T superconducting magnet project]



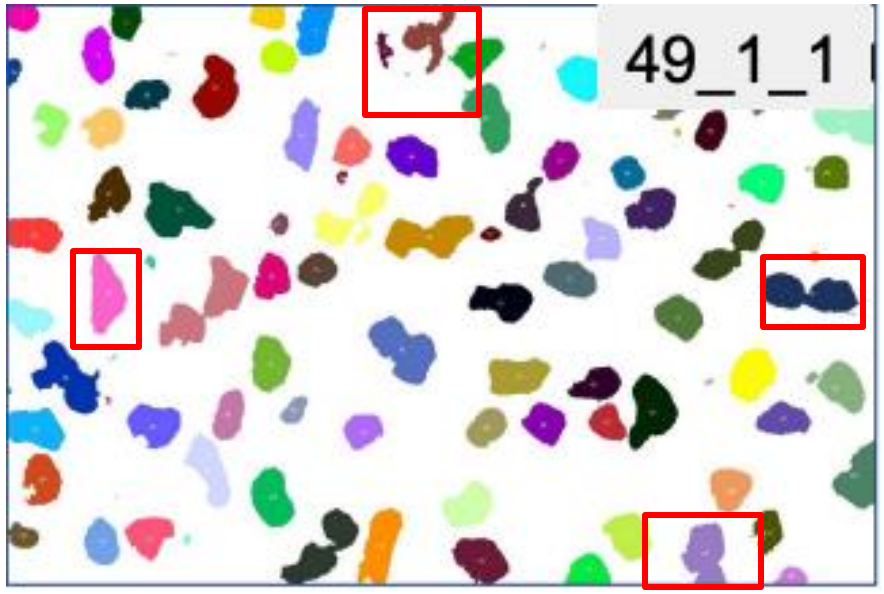
Fiji Trainable Weka Segmentation

Defect detection

Fiji Trainable Weka Segmentation



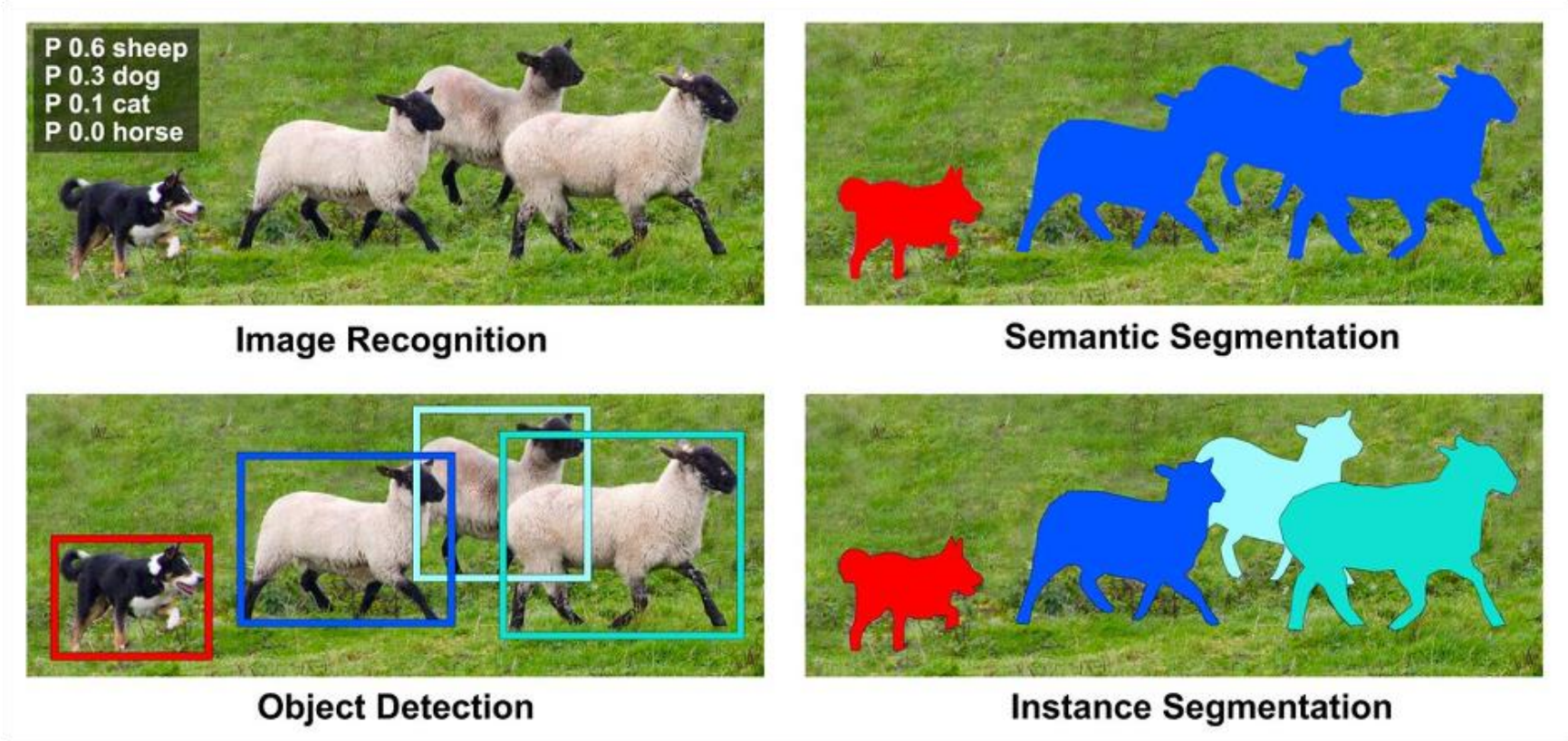
Origins of low-temperature in-field Jc variability in modern MOCVD ReBCO tapes



- Annotations need to be drawn
- Elementary ML models
- Features are not learned but user-defined
- Integration for analysis can be difficult
- Data wrangling

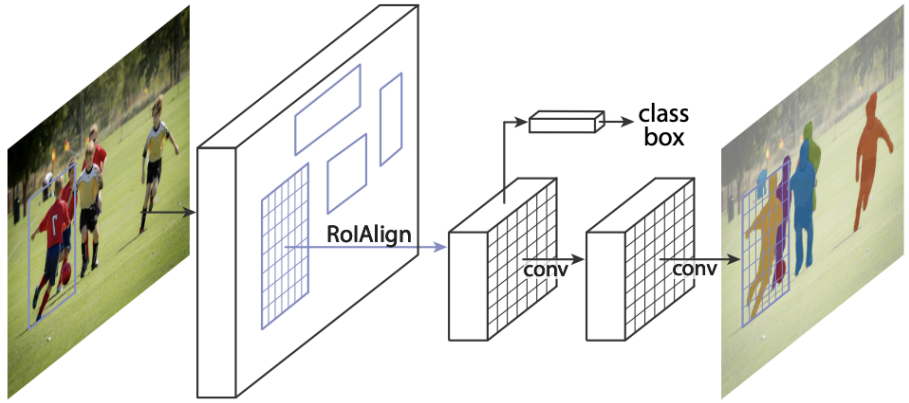
Convolution Neural Networks

- Image recognition (classification)
- Object detection
- Segmentation

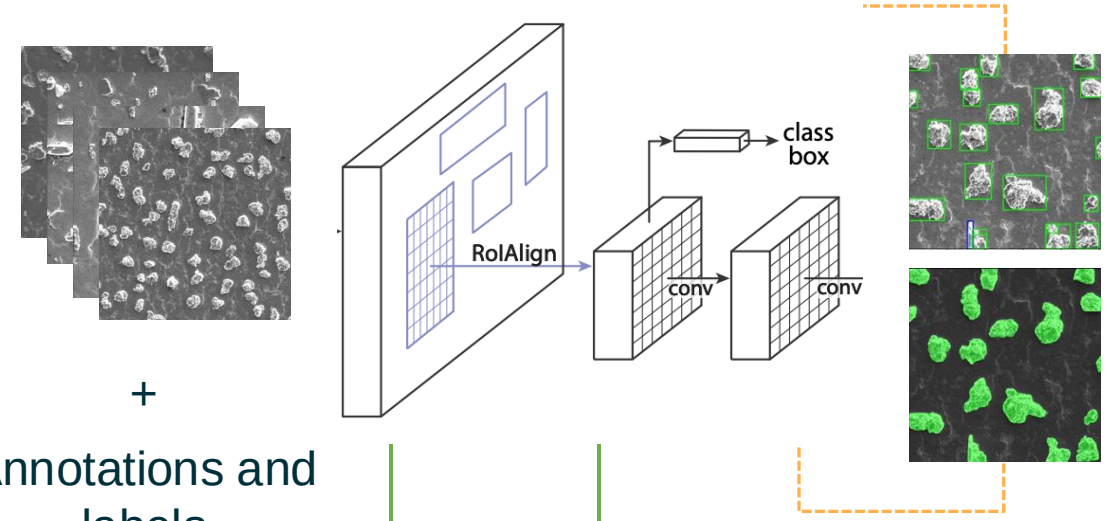


Reusing foundational models

1 Select pre-trained model (~118K images)



2 Training and Evaluation



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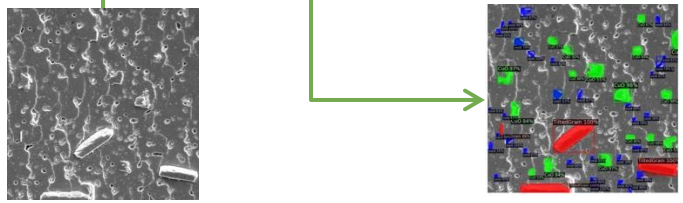
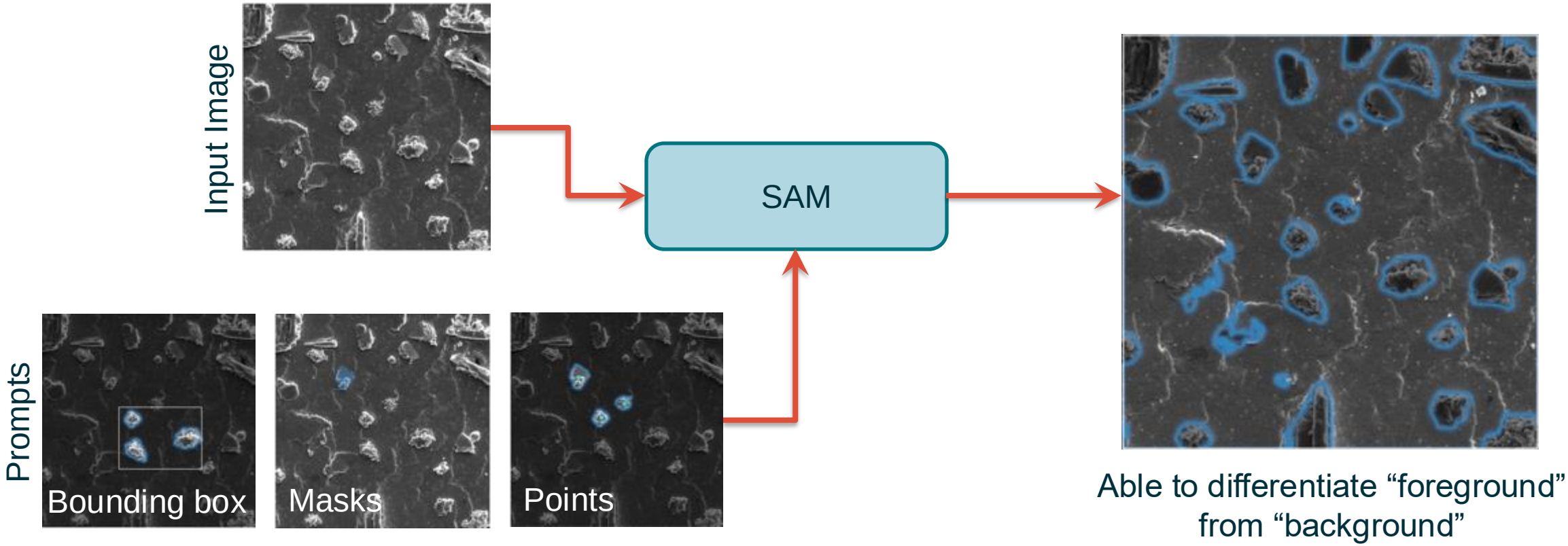
Annotations and labels

3 Final goal – test on unlabeled images



Segment Anything Model (SAM)

Prompts specifying what to segment in an image allows segmentation without the need for additional training

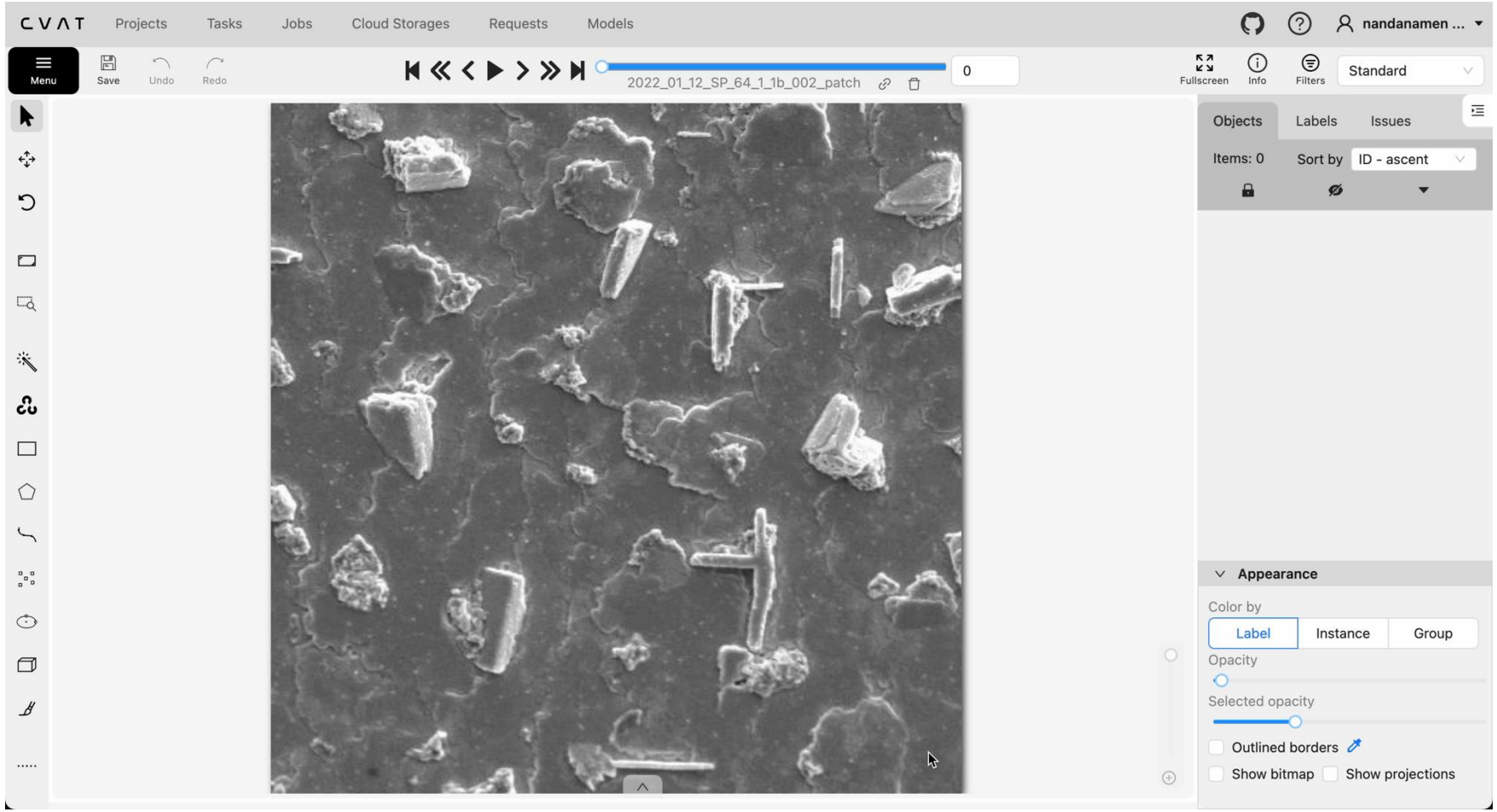


Able to differentiate “foreground” from “background”

Backend SAM for annotation

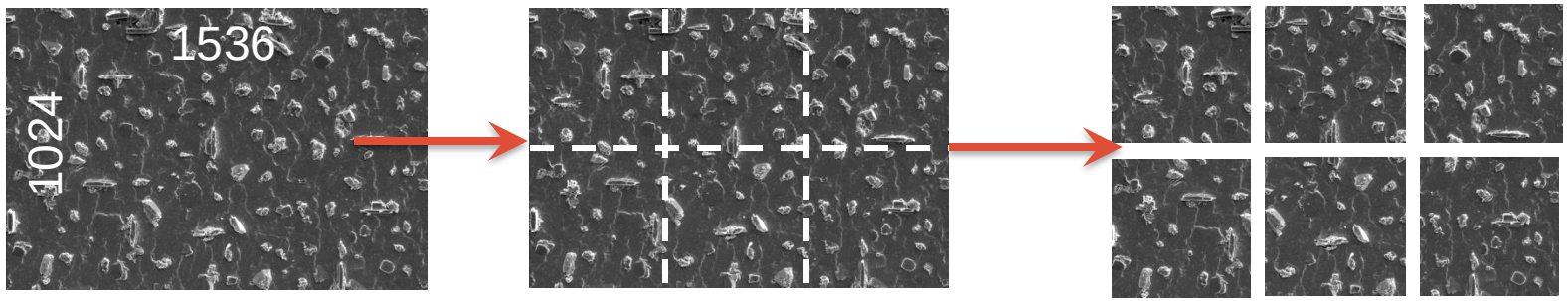
Zero-shot learning allows for interactive segmentation

cvat.ai



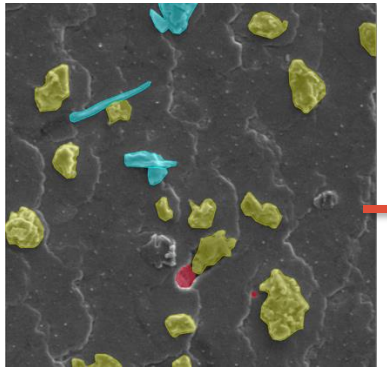
Data preparation

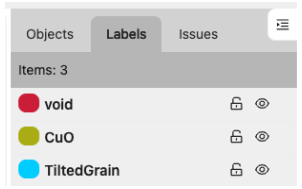
1 Patch images



Images cropped to 512x512

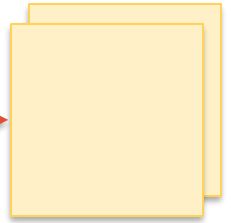
2 Annotating





Annotations saved as JSON

45 patches

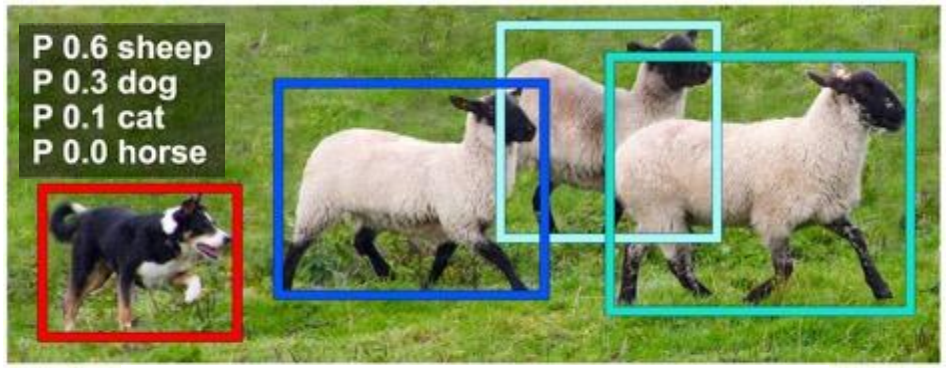


12 patches

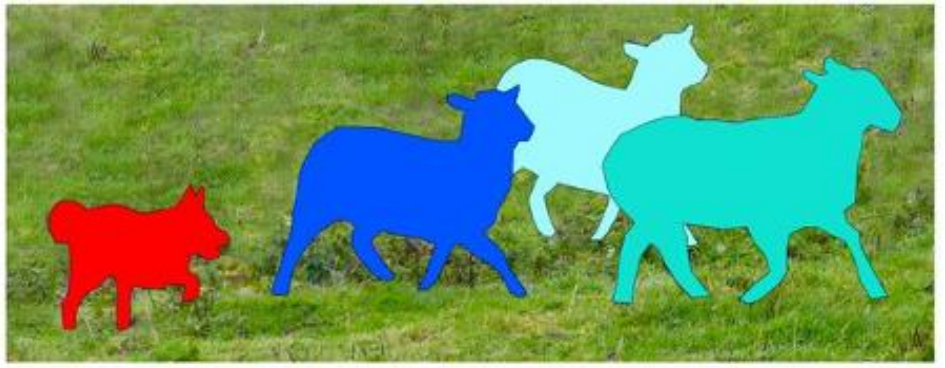
80%-20% train-validation random split

Detectron2: Mask R-CNN

- Rapid implementation of Mask Region-based Convolutional Neural Network (R-CNN)
- 2 step-models
  - 1. Region proposals to determine regions with objects
  - 2. Bounding box refinement and classification, Instance segmentation using a CNN in region proposal
- Outputs: Masks, Bounding boxes, Classes, Scores



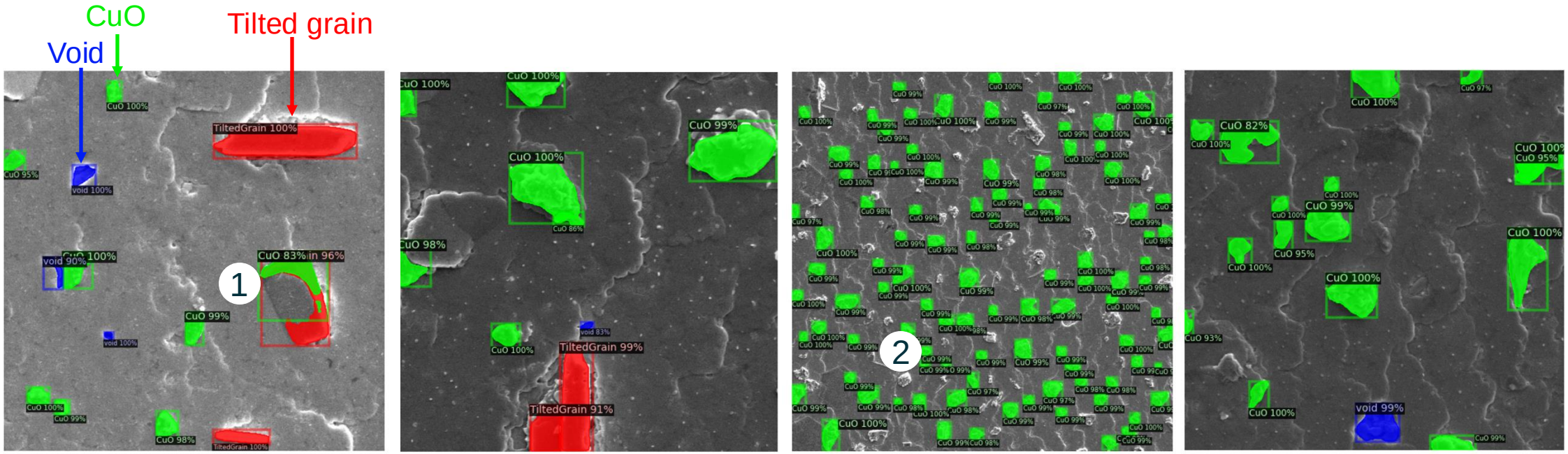
Object detection + Classification



Instance Segmentation

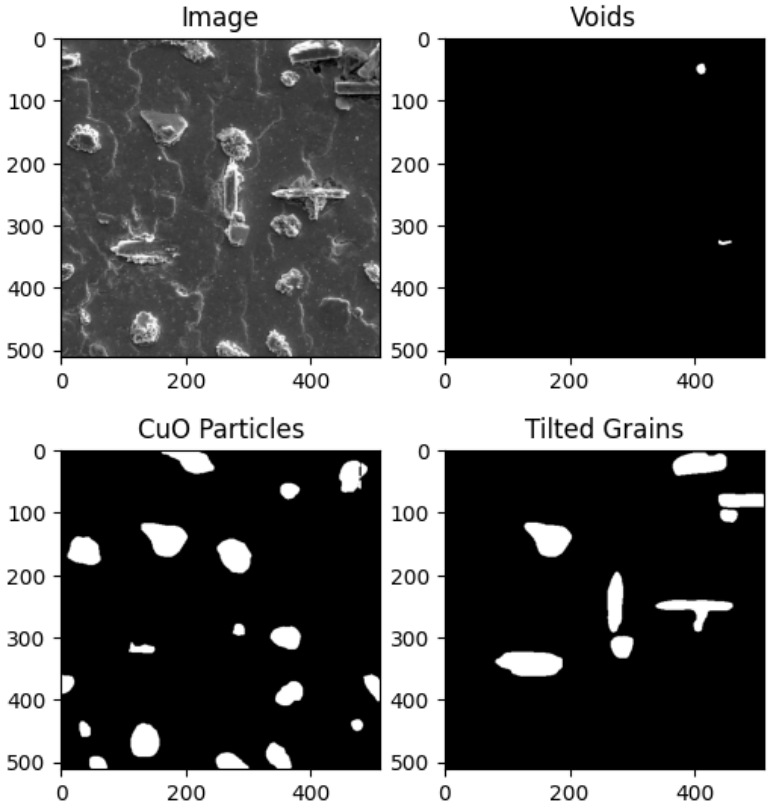
Validation results: Visualized

- ~ 15 mins to train for 5000 iterations on 1 GPU, 12.3 secs inference on CPU
- Some cases of partial masks (1) and missing instances (2)



Validation results: Visualized

Statistics from single image

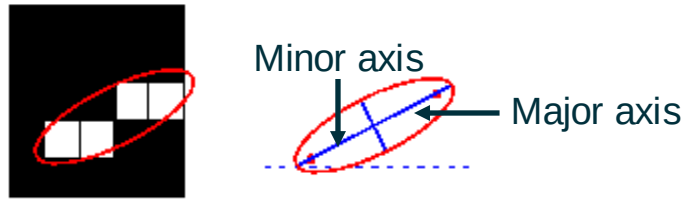


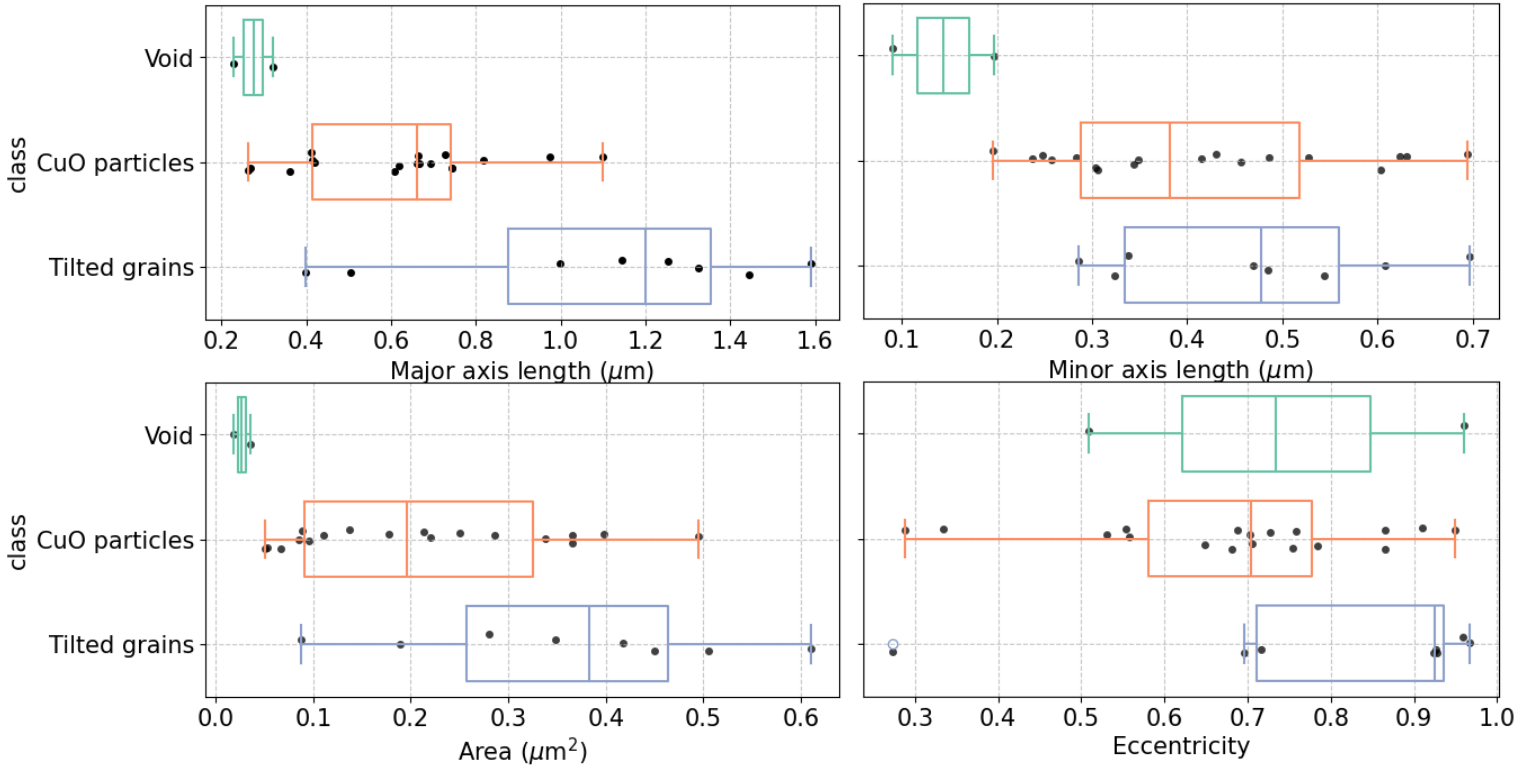
Void = 2

CuO particles = 18

Tilted grains = 8

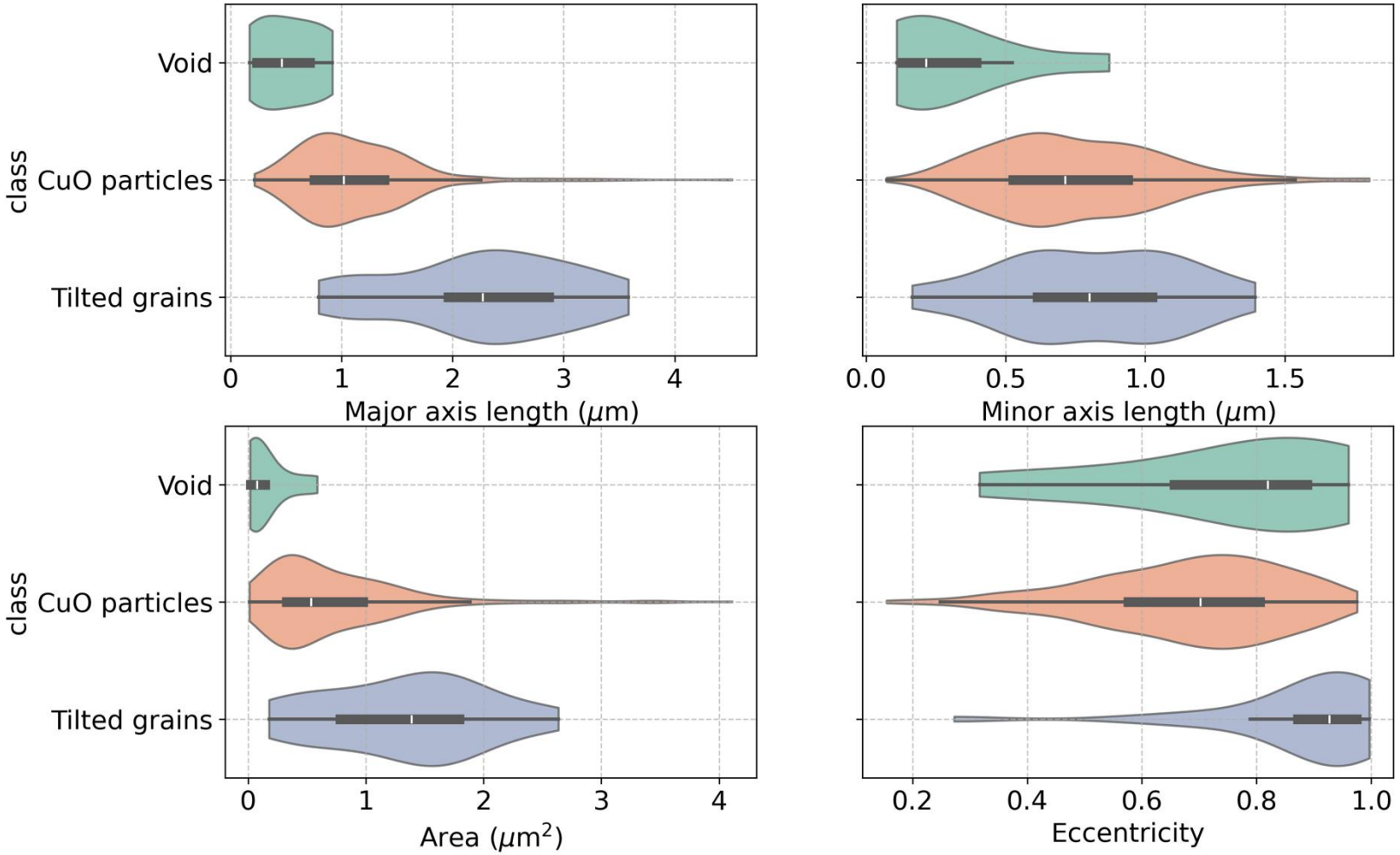
Fitted ellipse:





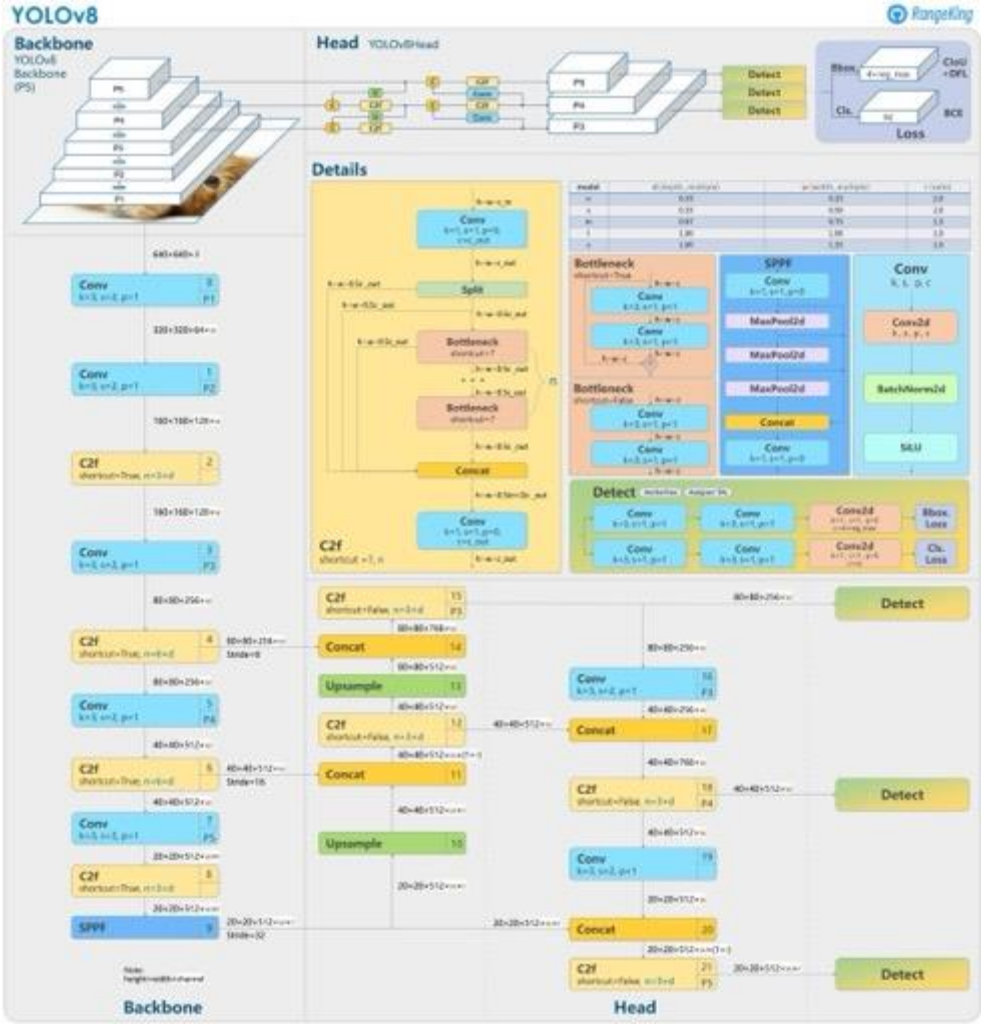
Validation results: Visualized

Statistics from all images



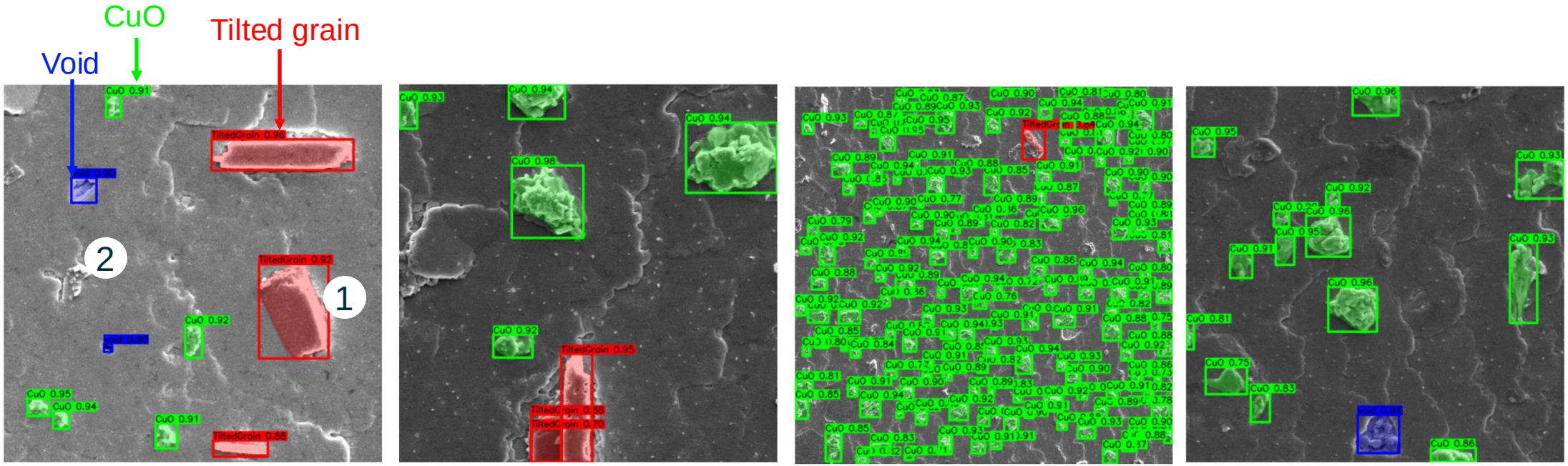
YOLOv8

- **Y**ou **O**nly **L**ook **O**nce: Single-step detection and segmentation
- Relatively larger model size
- Faster inference → better for real-time detection



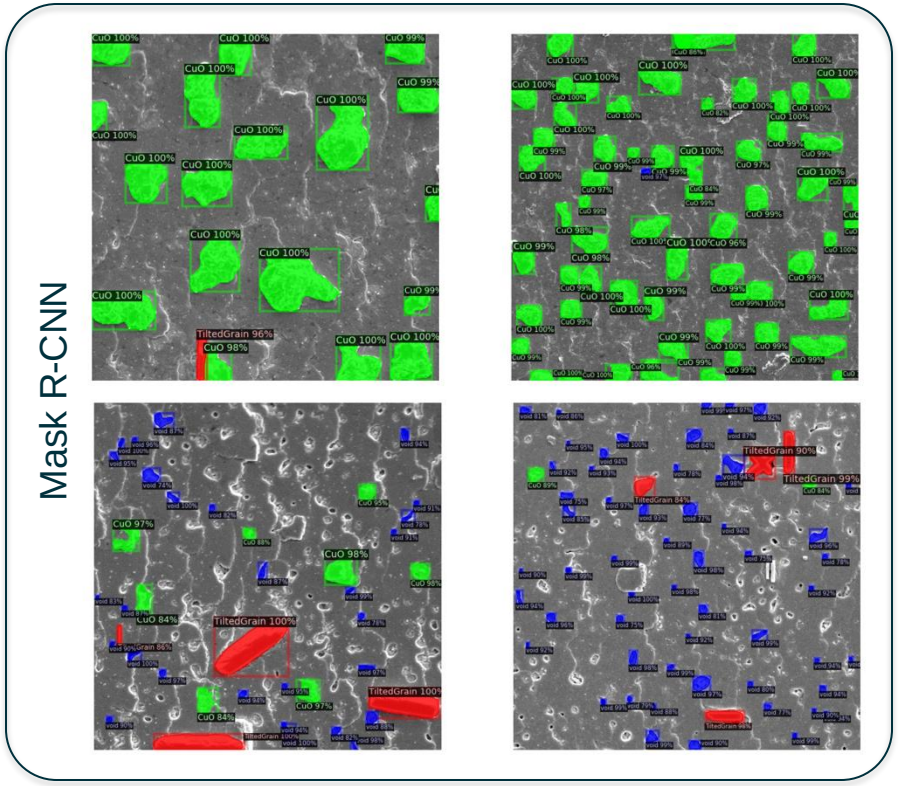
Validation results: Visualized

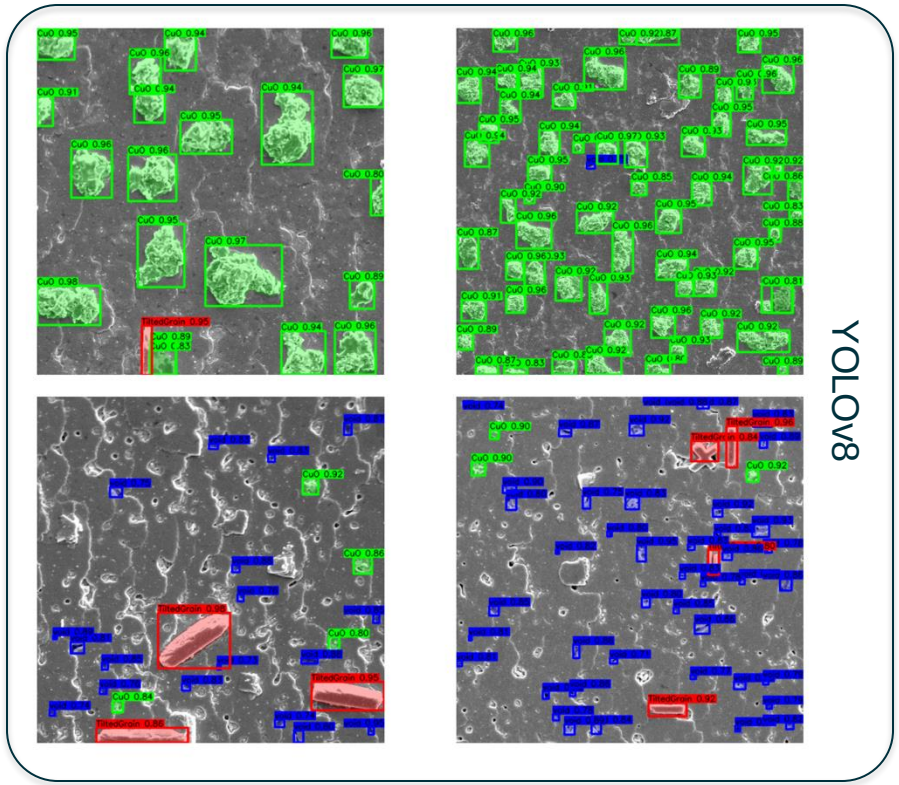
- ~ 3 hrs. to train for 5000 iterations on 1 GPU, 3.2 secs inference on CPU
- No partial masks like Mask R-CNN (1)
- Some cases of obvious instances not being detected (2)



Performance on test images

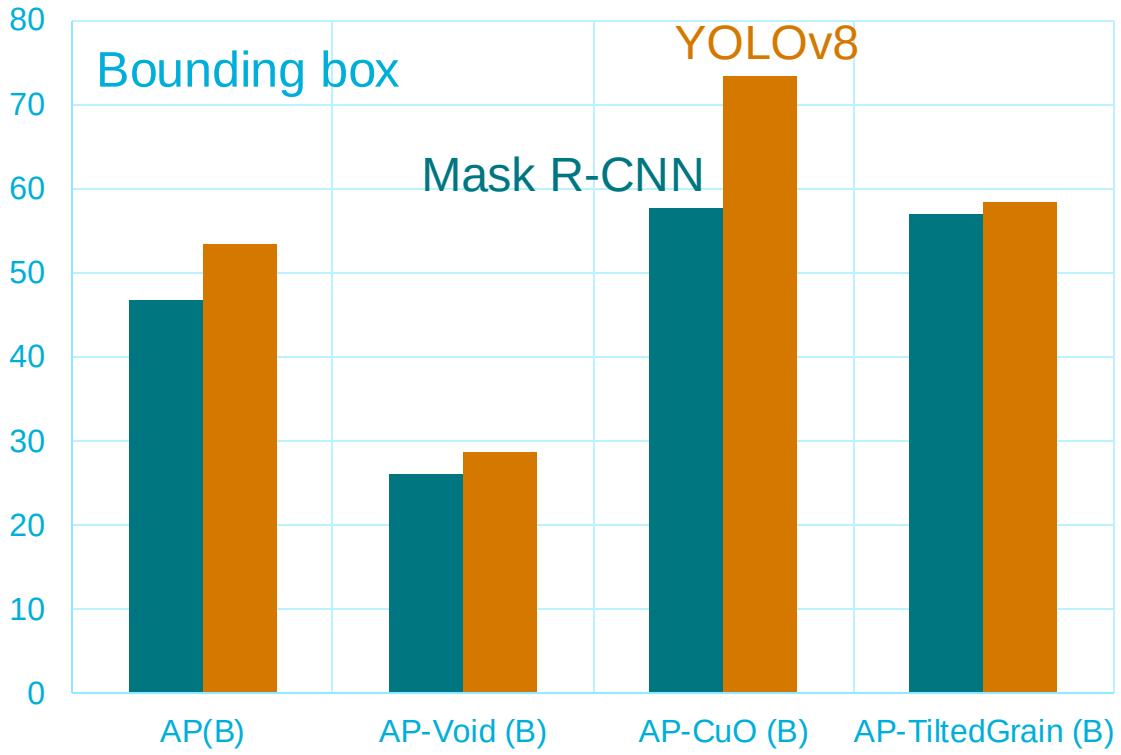
- Near perfect predictions on ‘clear’ images
- Issues with messy images (none used for train/validation) but still identifies the less ambiguous defects, especially voids



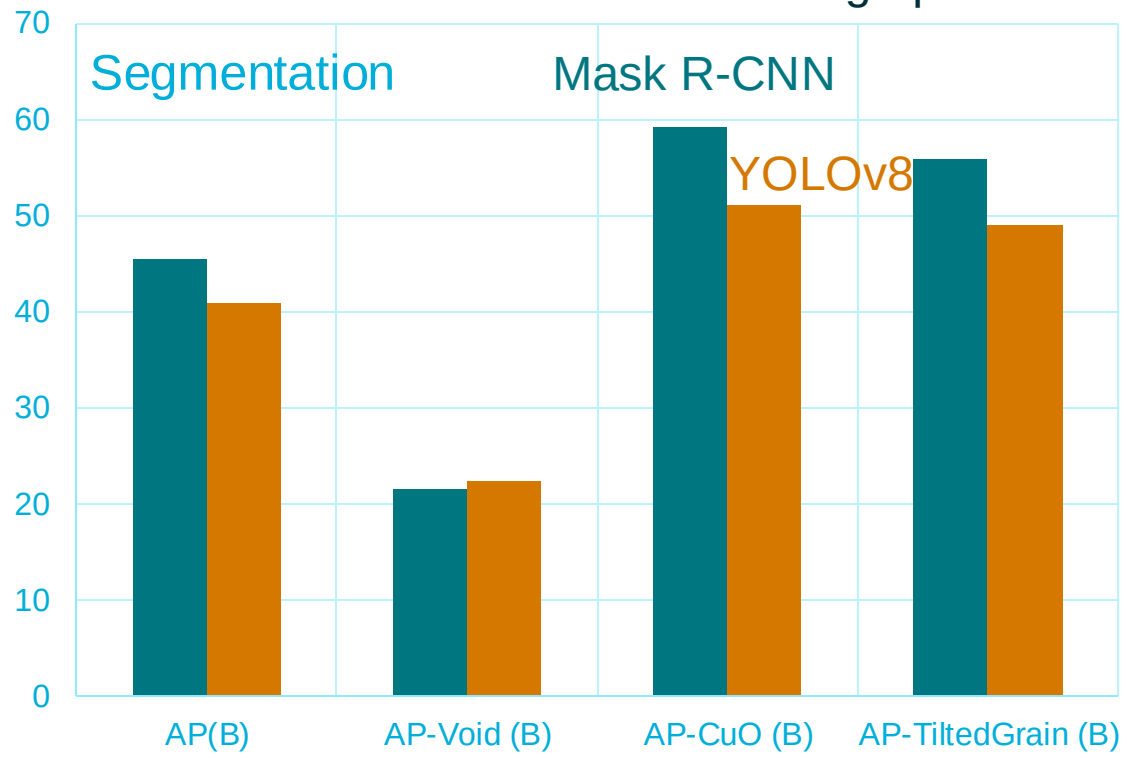


Comparison

Bounding box detection is better by YOLO while segmentation is better by Mask R-CNN

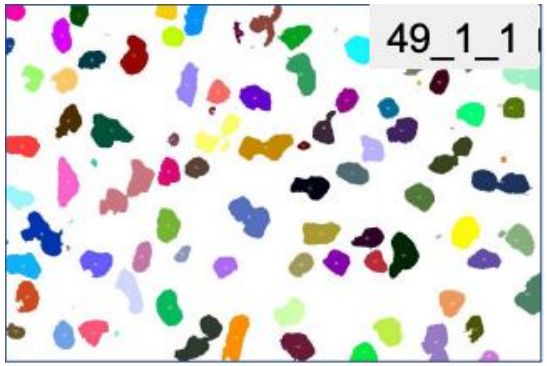


AP: Average precision

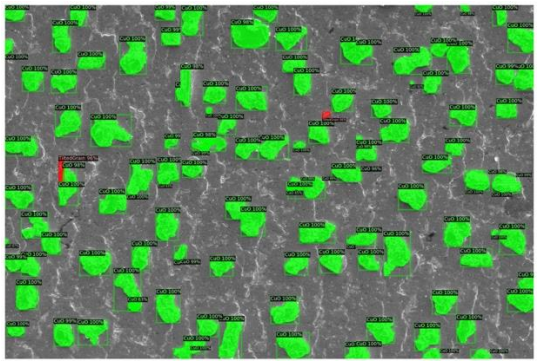


Concluding remarks

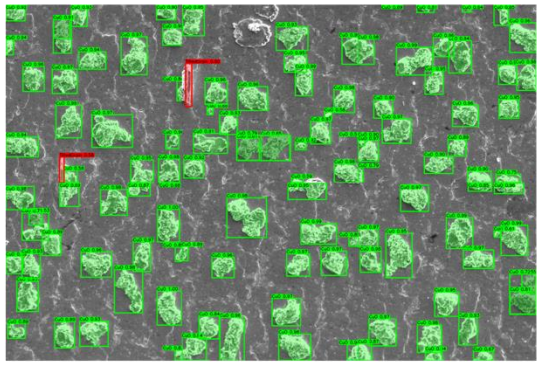
- Main takeaways:
  - SAM for annotation
  - Detectron2/ YOLO for object detection and instance segmentation
  - End-to-end solution for automating analyses
  - Models evolving by the day
- Next steps:
  - Models are only as good as labeled training data – train more to predict better
  - Correlate properties with the defects to find the origins of variation



Fiji Weka (ImageJ)



Mask R-CNN



YOLOv8

Thank You