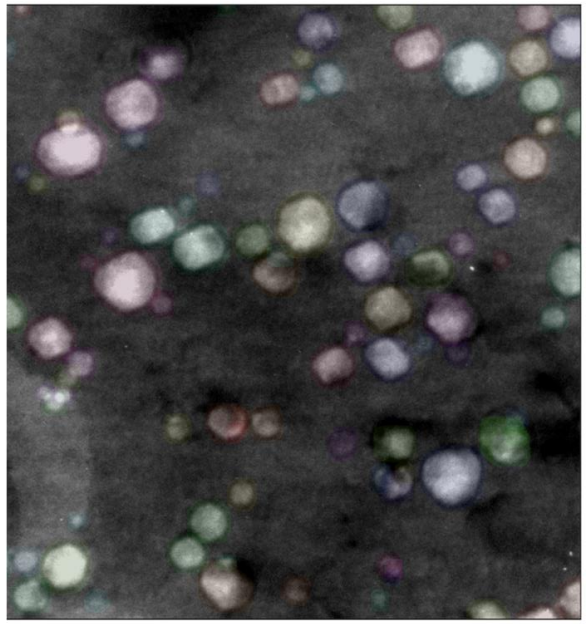
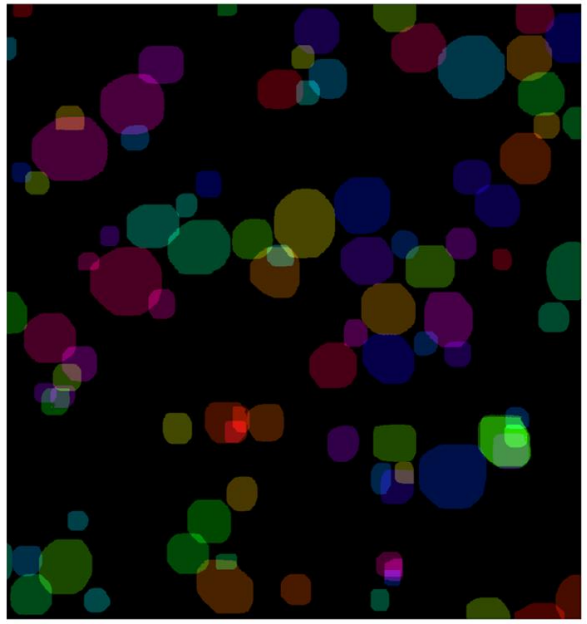
MSE 494/576

Lecture 30: Labeling for CNN Image Segmentation

Given by Tommy Wong

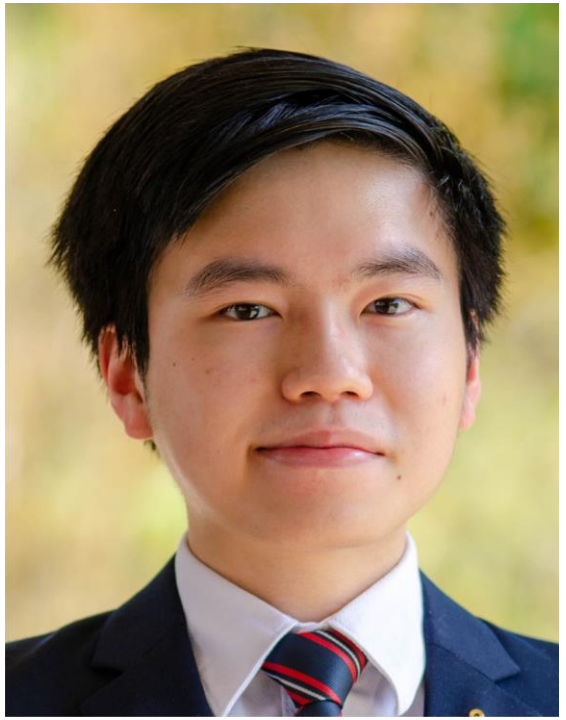
Instructor: Sergei V. Kalinin





Labeling this image took ~ 1 hr, DL prediction took < 1 min.

About me



Tommy (Chun Yin) Wong

Advisors: Dr. Sergei Kalinin, Dr. Maxim Ziatdinov

- Research interests: deep learning & computer vision, electron microscopy, radiation damage
- 4th year Ph.D. student in Energy Science & Engineering, Bredesen Center
- M.S. in Materials Science & Engineering ‘22, University of Tennessee
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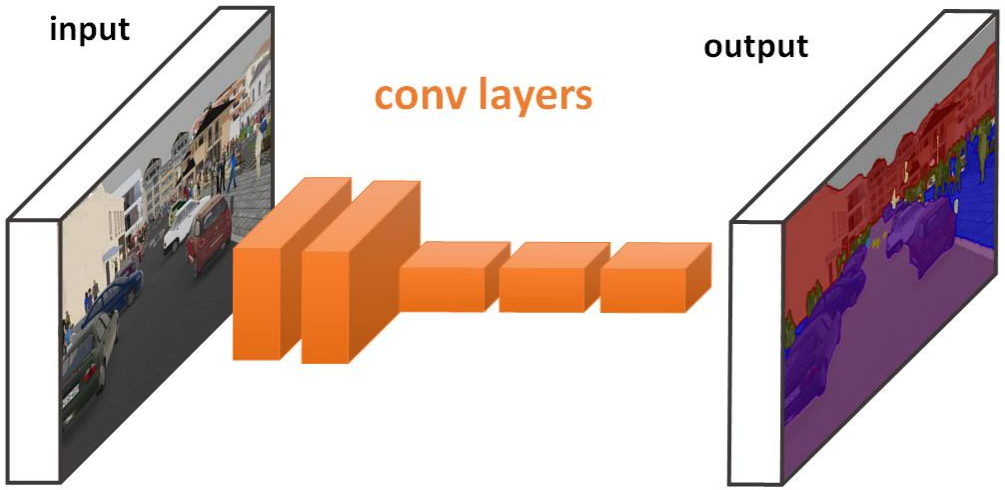
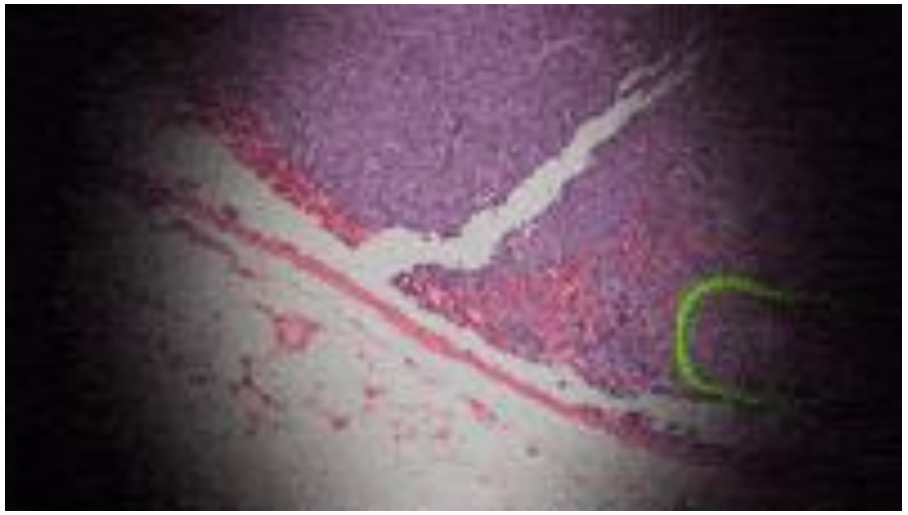
Segmentation is the process of separating objects or regions of interest from the background and identifying the boundaries between them *-ChatGPT*

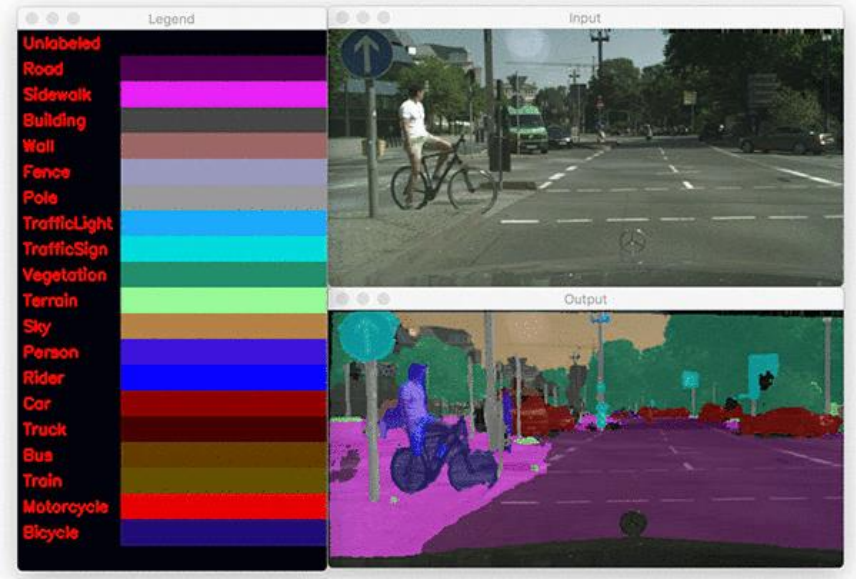
- Associating each pixel in an image with a class
- Traditional ML methods: thresholding, edge detection, decision trees, etc.
- DL methods using CNN:
  - Semantic segmentation
  - Instance segmentation



Semantic segmentation assigns class labels to each pixel



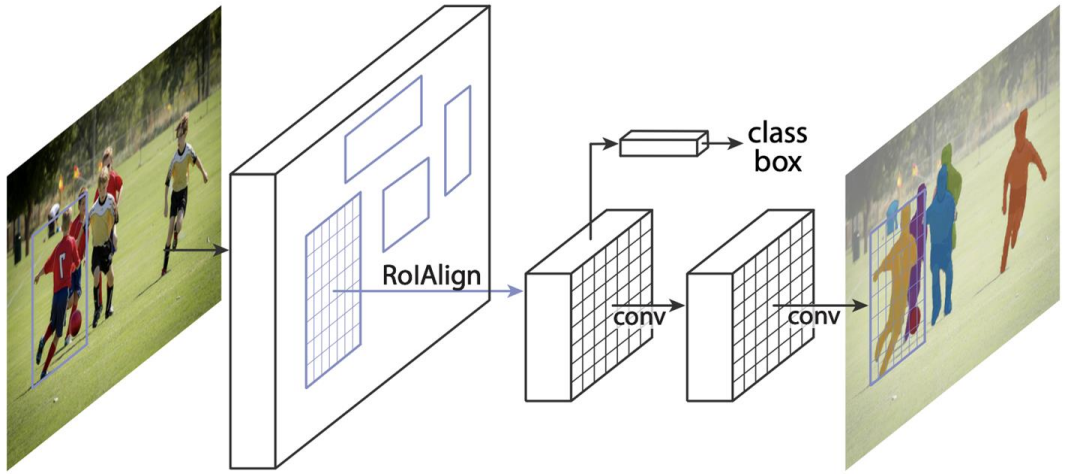
Augmented reality microscope *[3]*



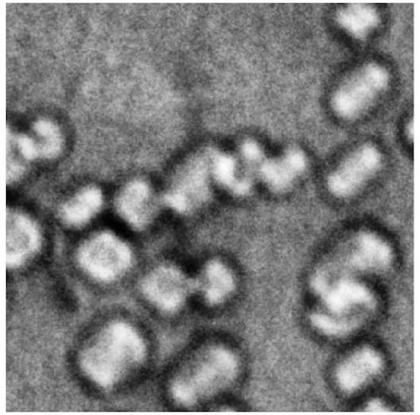
Semantic segmentation of street views *[1], [2]*

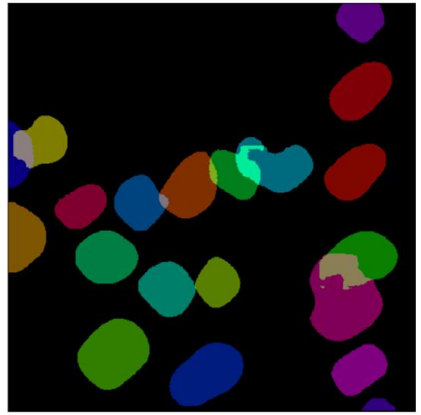
[1] G. Heinrich, “Image Segmentation Using DIGITS 5,” NVIDIA Developer Blog, Nov. 10, 2016. https://developer.nvidia.com/blog/image-segmentation-using-digits-5/ (accessed Feb. 25, 2021).
[2] M. Cordts et al., “The Cityscapes Dataset for Semantic Urban Scene Understanding,” in 2016 IEEE Conference on Computer Vision and Pattern Recognition (CVPR), Las Vegas, NV, USA, Jun. 2016, pp. 3213–3223, doi: 10.1109/CVPR.2016.350.
[3] P.-H. C. Chen et al., “Microscope 2.0: An Augmented Reality Microscope with Real-time Artificial Intelligence Integration,” arXiv:1812.00825 [cs], Dec. 2018, doi: 10.1038/s41591-019-0539-7.

Instance segmentation w/ Mask R-CNN



Mask R-CNN



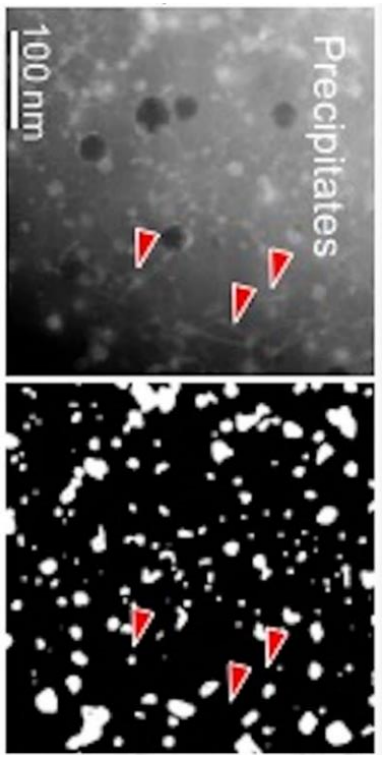


$$Loss = L_{class} + L_{box} + L_{mask}$$

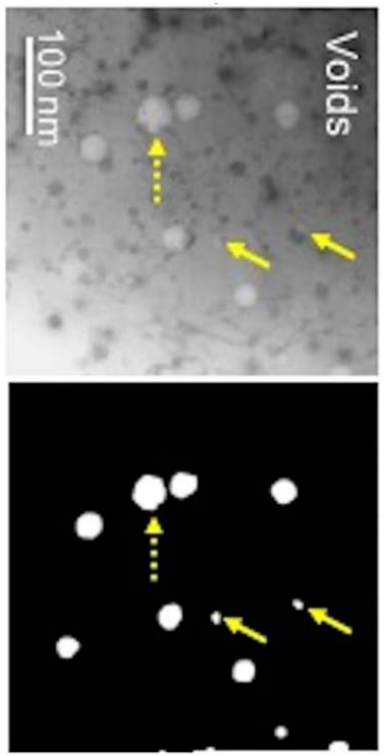
Adapted from Girschick (2015) https://arxiv.org/abs/1504.08083, He et al. (2018) https://arxiv.org/abs/1703.06870v3

Microstructural defects can be labeled for pixel-wise segmentation

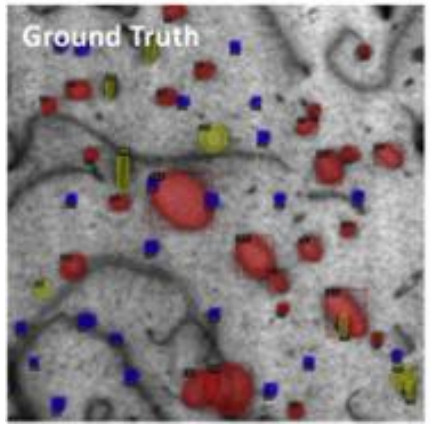
- Segmentation: associating each pixel in an image with a class



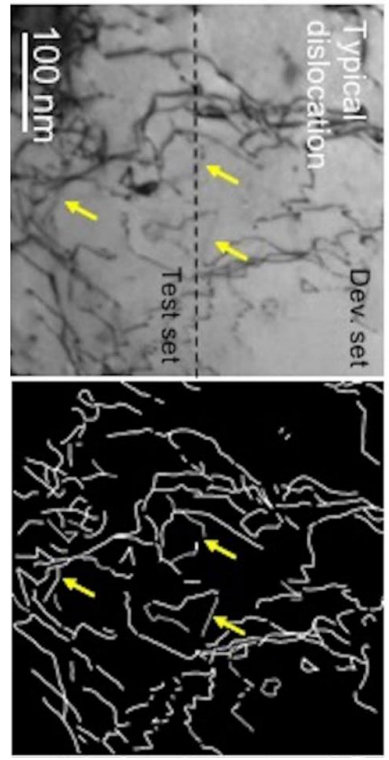
Cavities (bubbles & voids)



Precipitates



Dislocation loops

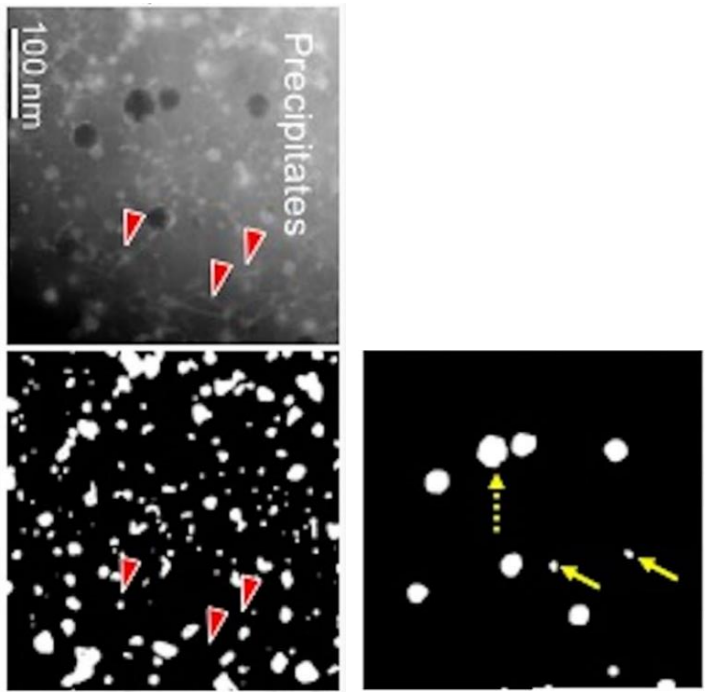


Dislocation lines

Adapted from Roberts et al. 2019 10.1038/s41598-019-49105-0, Jacobs et al. 2022 10.1016/j.xcrp.2022.100876

Different labeling systems are required for different segmentation algorithms

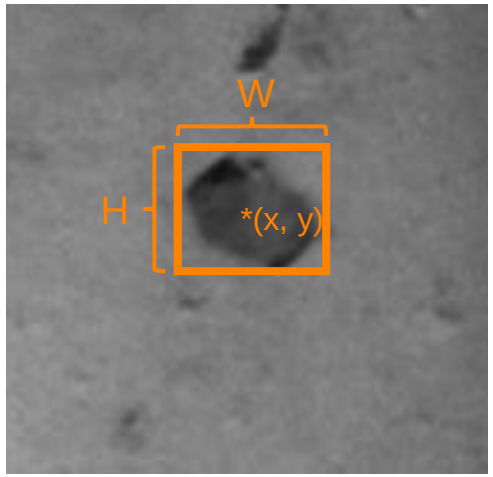
- **Important: labels are usually either 0 or 1**



Precipitates

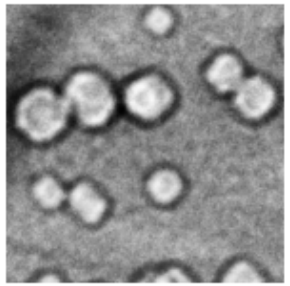
Voids

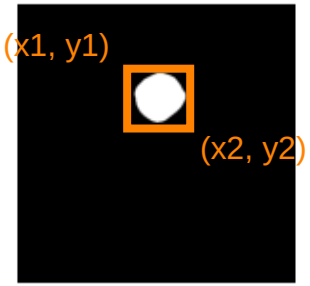
Semantic segmentation: one-hot encoding (U-Net)

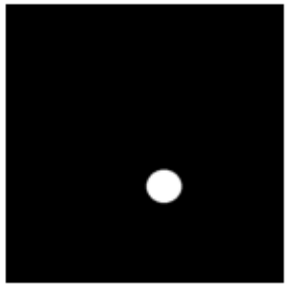


[Class x y W H]

Object identification: bounding box (YOLO)







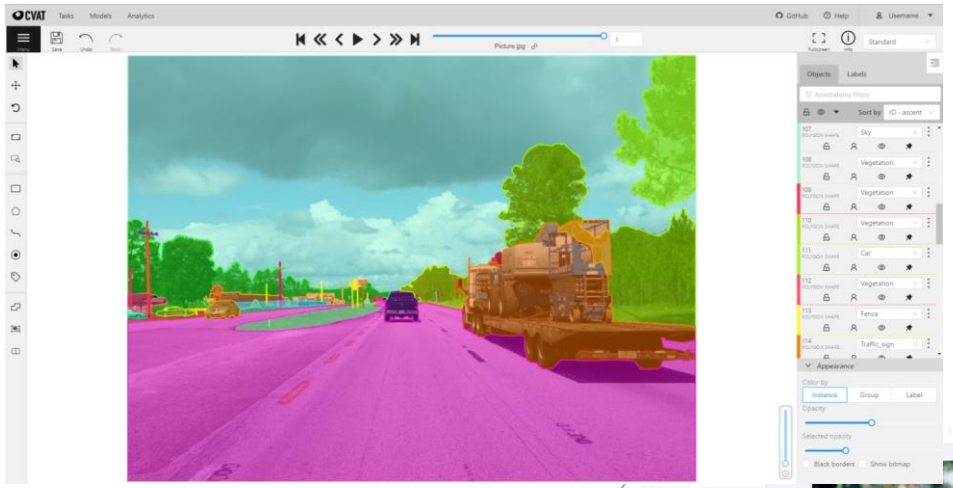
…

Dictionary{
'boxes': [x1 y1 x2 y2]
'labels': class
'masks': feature mask
}

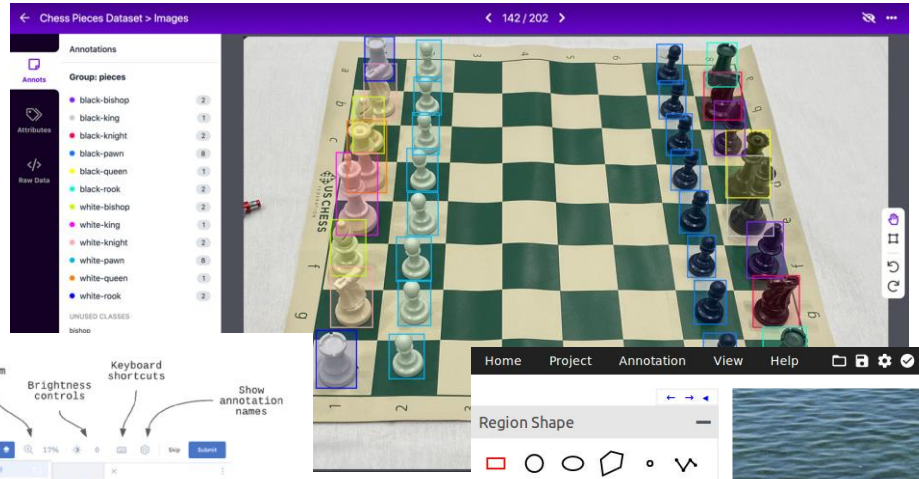
Instance segmentation: label encoding (Mask R-CNN)

Adapted from Roberts et al. 2019 10.1038/s41598-019-49105-0, Yang et al. 2011 10.1038/srep00190

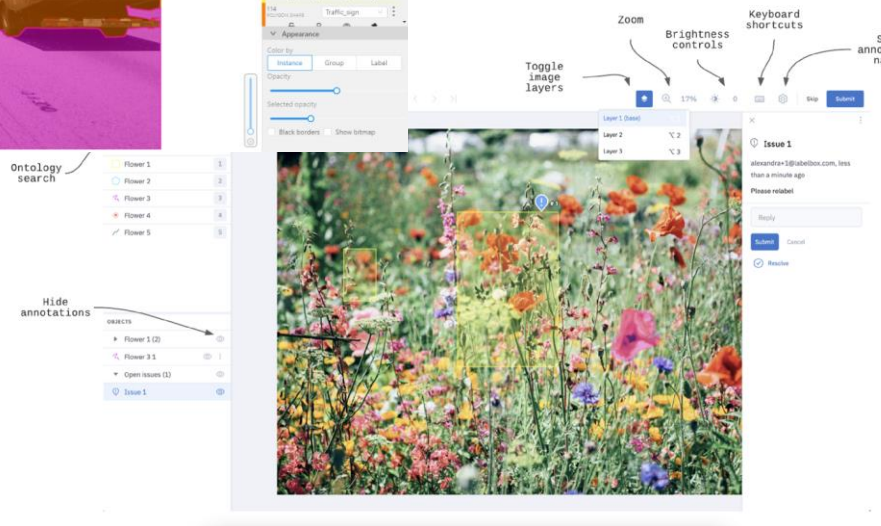
Web-based GUI tools are used for labeling



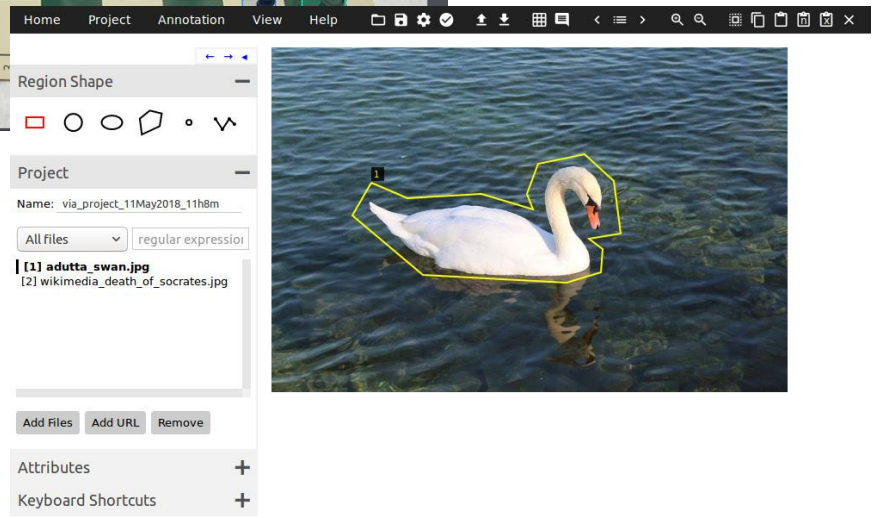
CVAT



Roboflow



Labelbox



VIA

Labeling using Computer Vision Annotation Tool (CVAT)

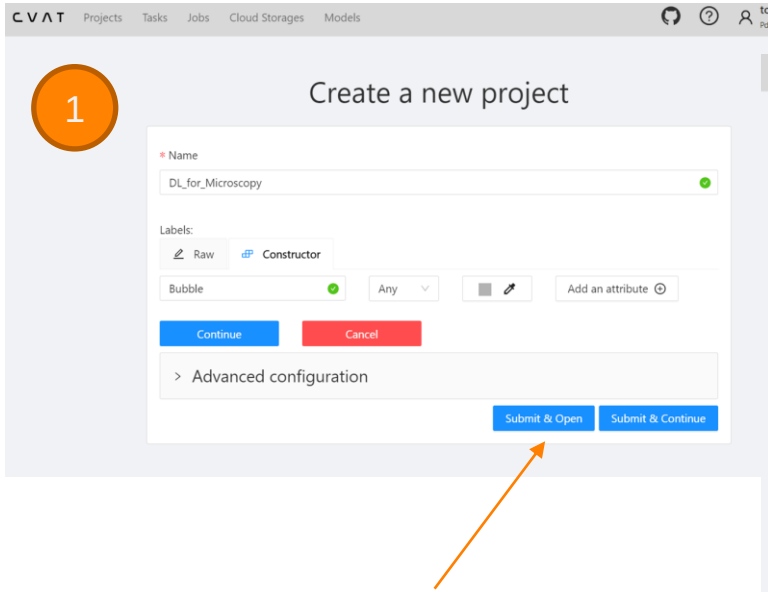
cvat.ai

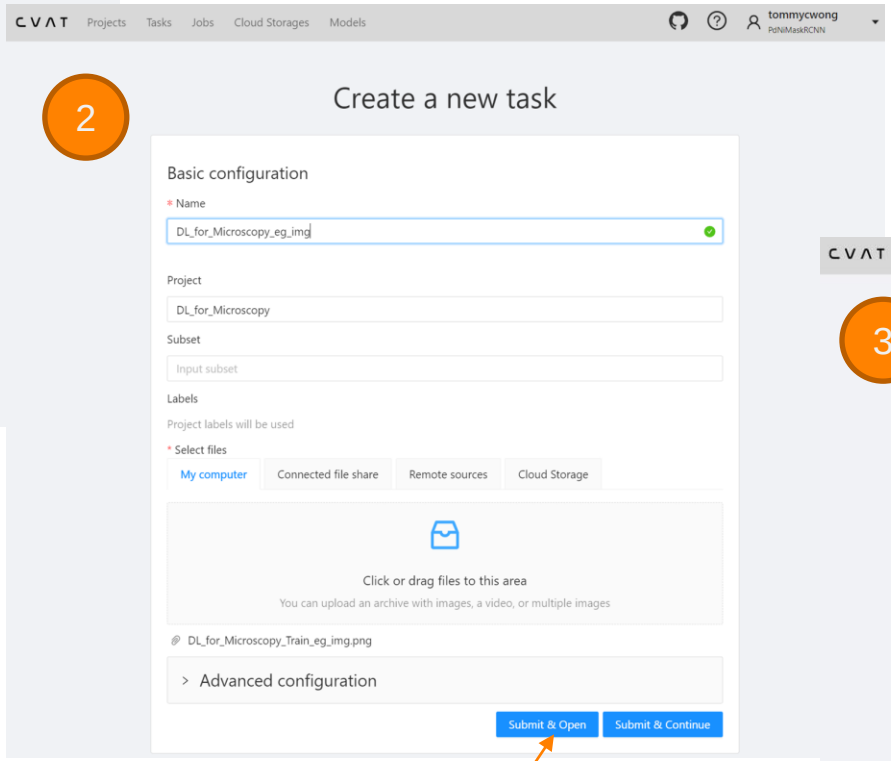
Documentation:
github.com/TaSeeMba/cvat/blob/master/cvat/apps/documentation/user_guide.md

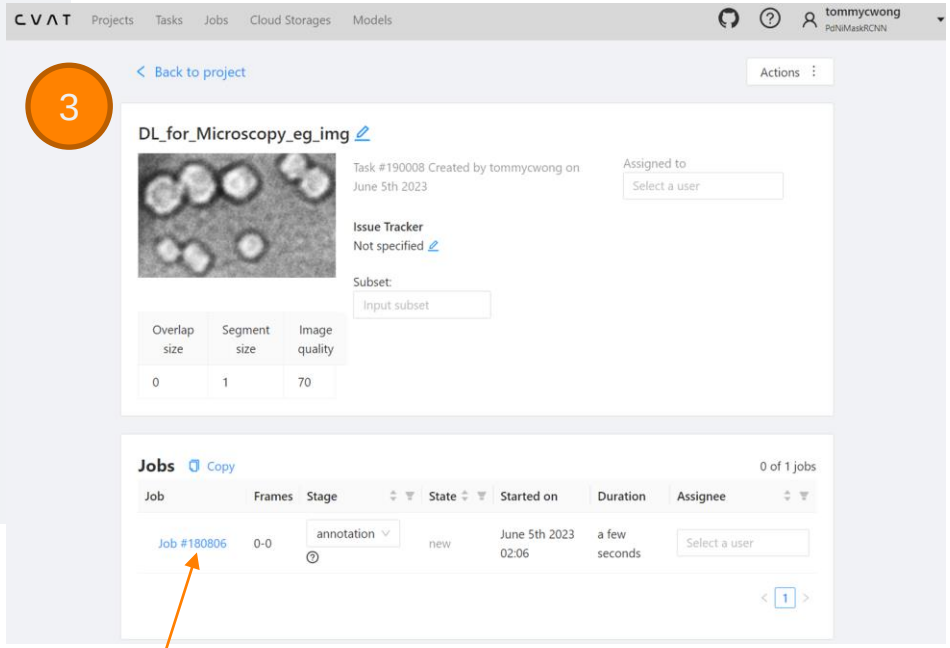
CVAT labeling workflow

Important: before labeling, ensure all image data have the same dimensions e.g. 1024x1024

Creating a project and labeling tasks





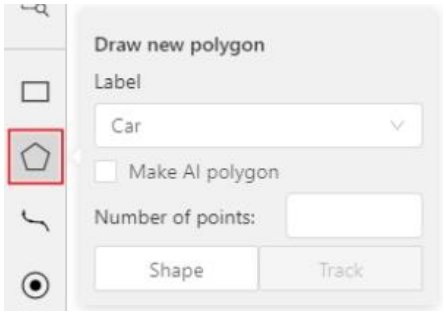


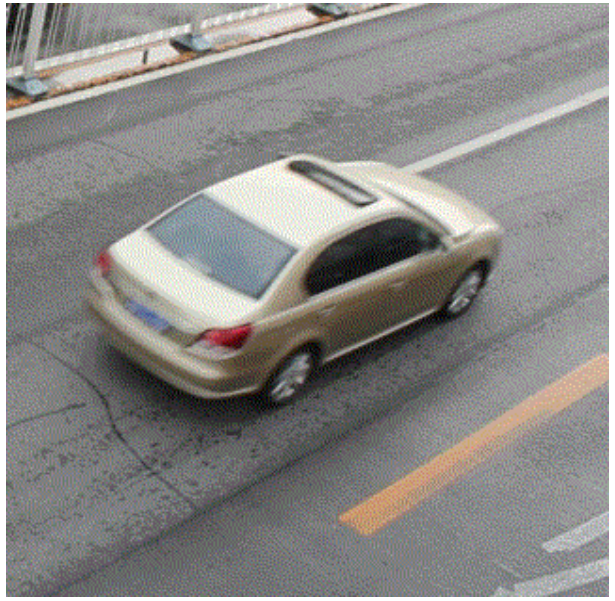
Labeling using polygon and ellipse tools

Remember to click **Save**

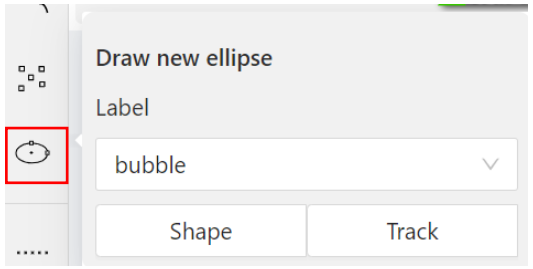
Polygon tool (preferred)

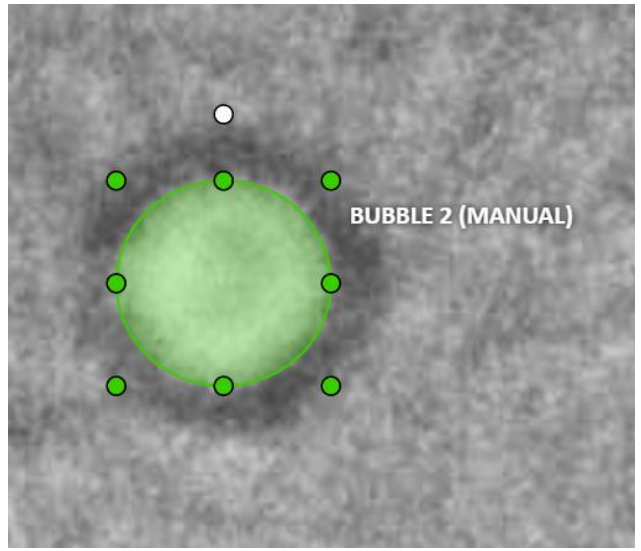
- Hold **Shift** to draw





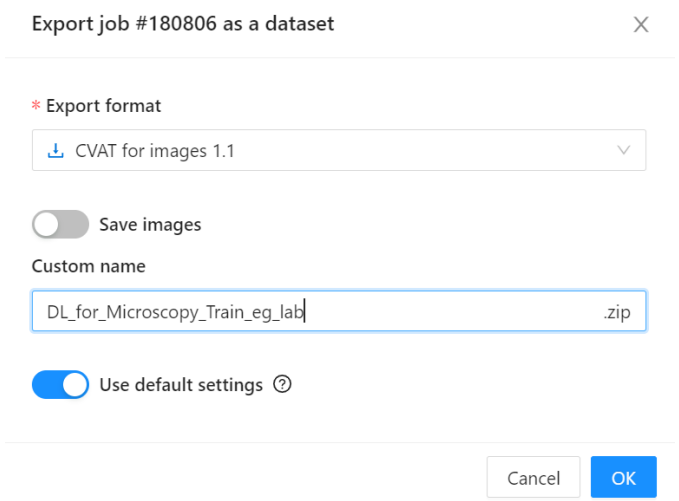
Ellipse tool





Exporting and parsing labels

Export as .xml



Parsing labels using Python

```
get_imgs(train_img_names)

parse_anno_file(xml, train_img_filename)

get_unet_mask(annos)

get_maskrcnn_mask(annos)

get_maskrcnn_dataset(images=train_imgs,
labels=maskRcnn_masks)
```

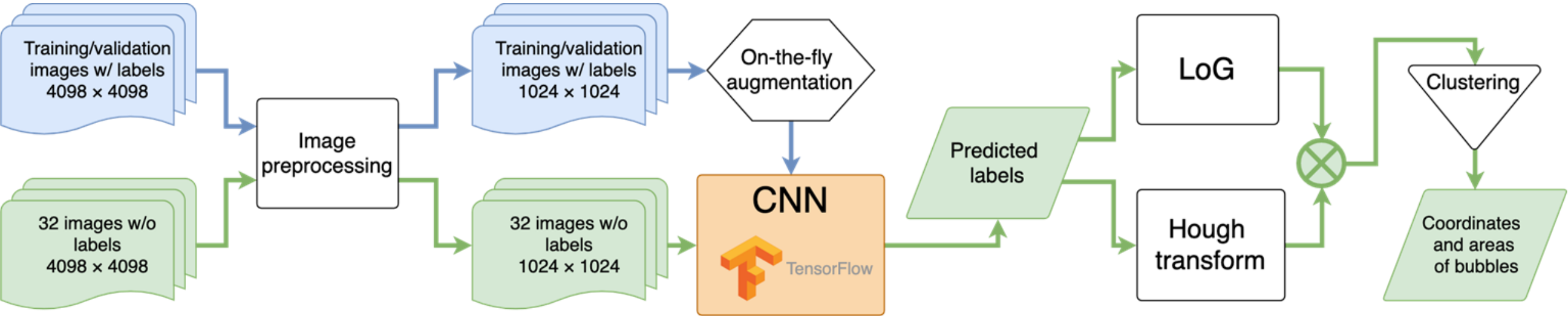
```
<image id="0" name="DL_for_Microscopy_Train_eg_img.png" width="512" height="512">
  <ellipse label="Bubble" source="manual" occluded="0" cx="291.95" cy="334.99" rx="32.35" ry="30.94" z_order="0">
  </ellipse>
  <polygon label="Bubble" source="manual" occluded="0" points="282.22,131.08;289.47,135.54;295.61,142.23;300.07,1
  </polygon>
```

Additional notes on labeling

- Features typically should have a convex mask
  - Concave masks are likely occluded convex masks
- Don’t leave holes between multiple overlapping masks
- Keep in mind output files: different parsing scripts needed for .xml, .json, etc.

Example of CNN image segmentation: Detecting He bubbles w/ U-net

Training & Classification Workflows



1 IMAGE PROCESSING

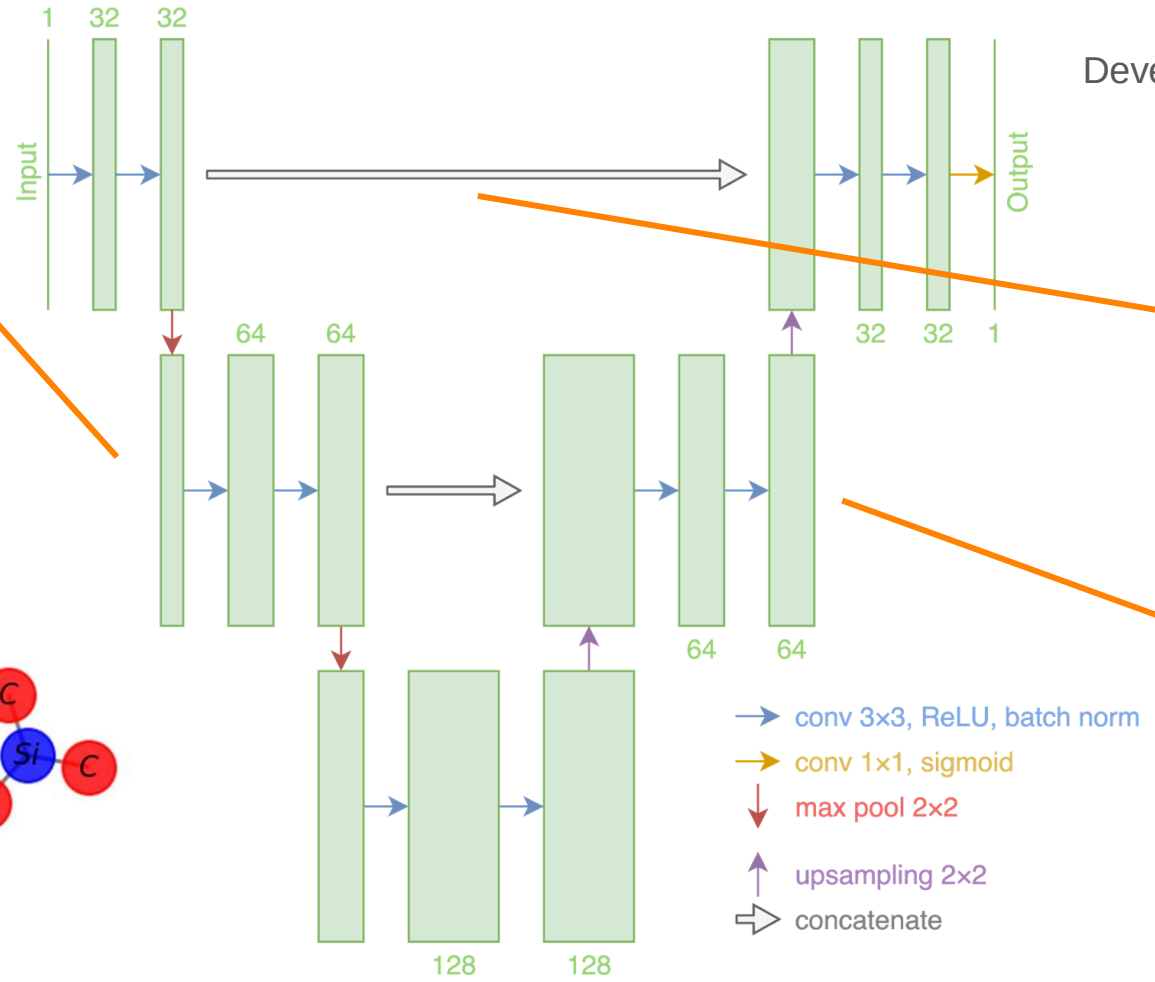
2 DEEP LEARNING

3 POST PROCESSING

Semantic segmentation w/ U-Net

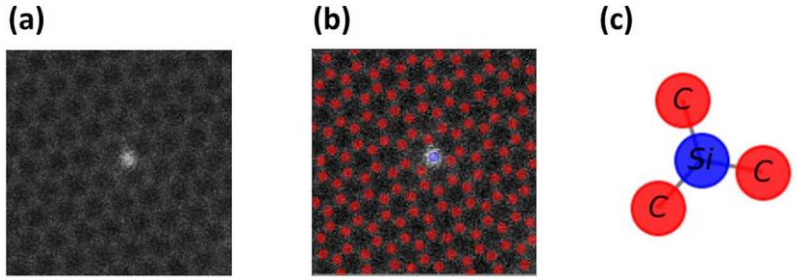
Look for salient features

Developed by Ronneberger et al. (2015) [11]



Preserve “big picture”

Expand back to original size

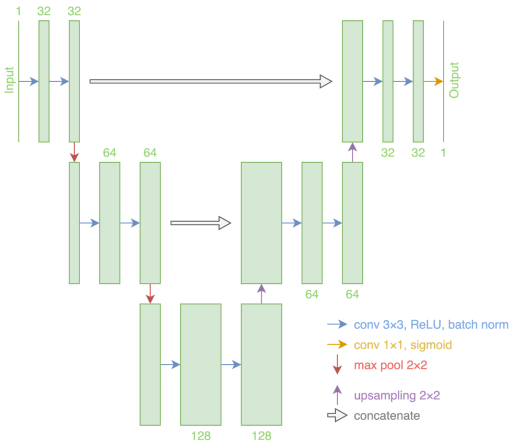


Ziatdinov et al. (2017) [12]

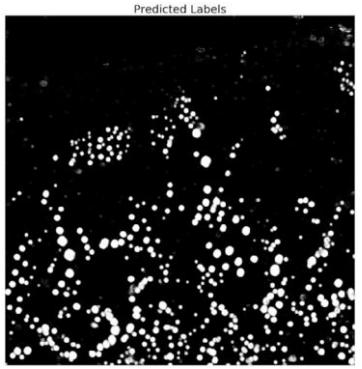
[12] M. Ziatdinov *et al.*, “Deep Learning of Atomically Resolved Scanning Transmission Electron Microscopy Images: Chemical Identification and Tracking Local Transformations,” *ACS Nano*, vol. 11, no. 12, pp. 12742–12752, Dec. 2017, doi: 10.1021/acsnano.7b07504.

Ensemble learning improves accuracy

random(weights) ×12



×12



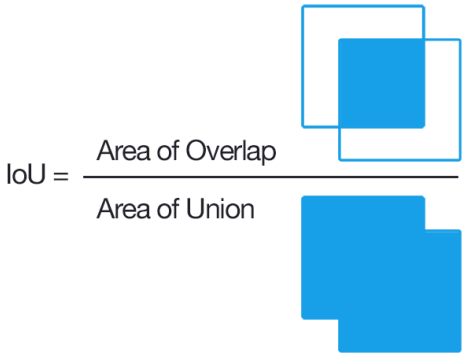
12

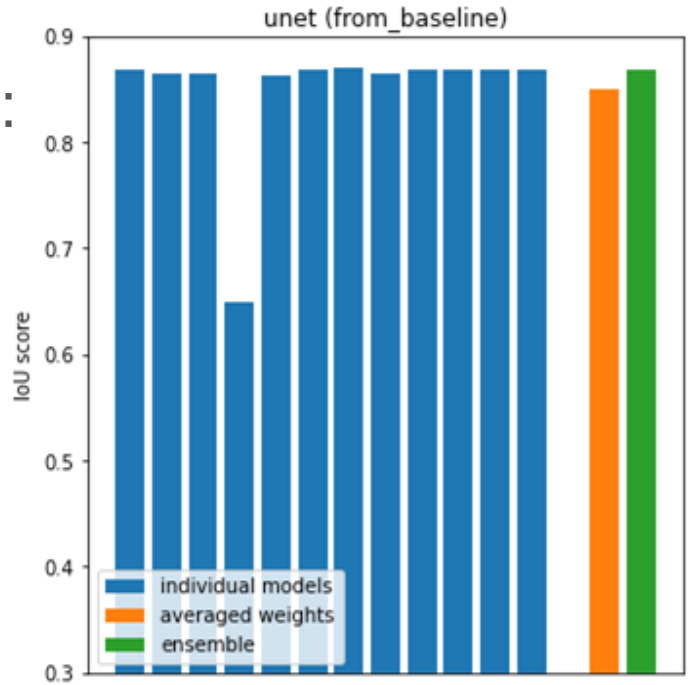
- **Aim**: to identify He bubbles in TEM images
- Based on Pycroscopy AtomAI (github.com/pycroscopy/atomai) [13]
- Trained using open-source package via Google Colab

[13] M. Ziatdinov, A. Ghosh, T. Wong, and S. V. Kalinin, "AtomAI: A Deep Learning Framework for Analysis of Image and Spectroscopy Data in (Scanning) Transmission Electron Microscopy and Beyond," *ArXiv210507485 Cond-Mat Physicsphysics*, May 2021, Accessed: May 12, 2022. [Online]. Available: http://arxiv.org/abs/2105.07485

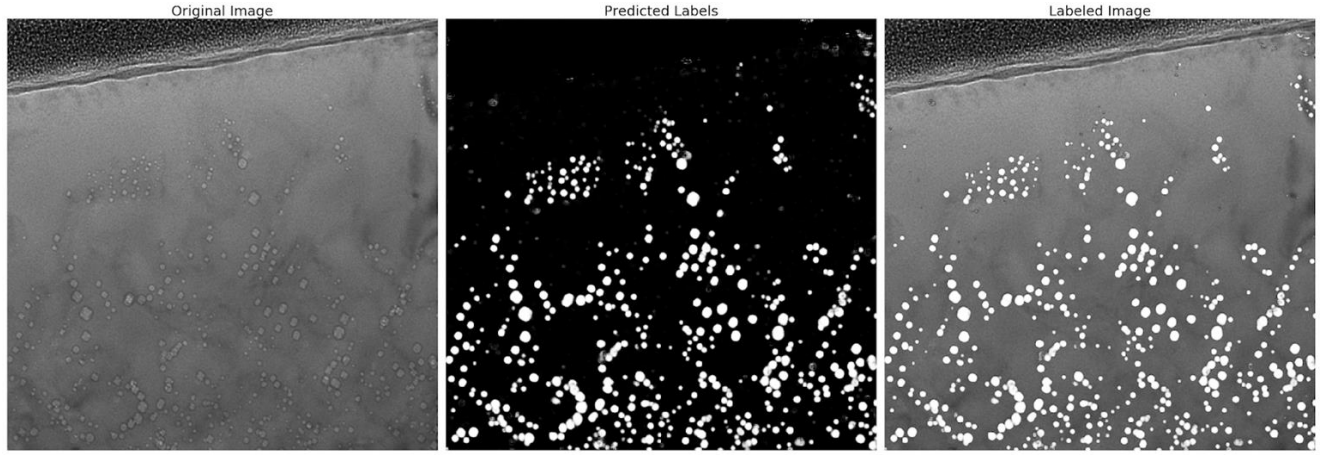
Results from CNN

- Overall px acc: 0.98
- Average per class px acc: 0.95
- IoU: 0.85
- F1: 0.91

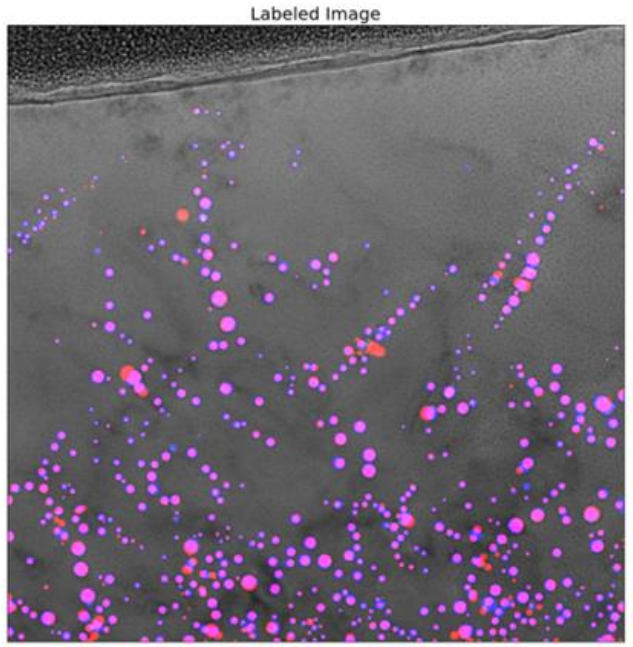




Individual & ensemble IoUs [14]



Sample CNN labels [15]



CNN

Both

Manual

Comparing CNN to manual labels

pyimagesearch.com/2016/11/07/intersection-over-union-iou-for-object-detection

[14] C. Y. Wong, X. Wang, Z. Fan, K. More, S. Kalinin, and M. Ziatdinov, "Deep Learning–Based Workflow for Analyzing Helium Bubbles in Transmission Electron Microscopy Images," *Microsc. Microanal.*, vol. 27, no. S1, pp. 2132–2133, Aug. 2021, doi: 10.1017/S1431927621007686.

[15] X. Wang *et al.*, "Understanding effects of chemical complexity on helium bubble formation in Ni-based concentrated solid solution alloys based on elemental segregation measurements," *J. Nucl. Mater.*, vol. 569, p. 153902, Oct. 2022, doi: 10.1016/j.jnucmat.2022.153902.

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Workflow Can Be Generalized to Other Material Systems

- The algorithm was not altered at all—✕ new training images
- Only resized images ⇨ bubbles are similar in size to those in training images

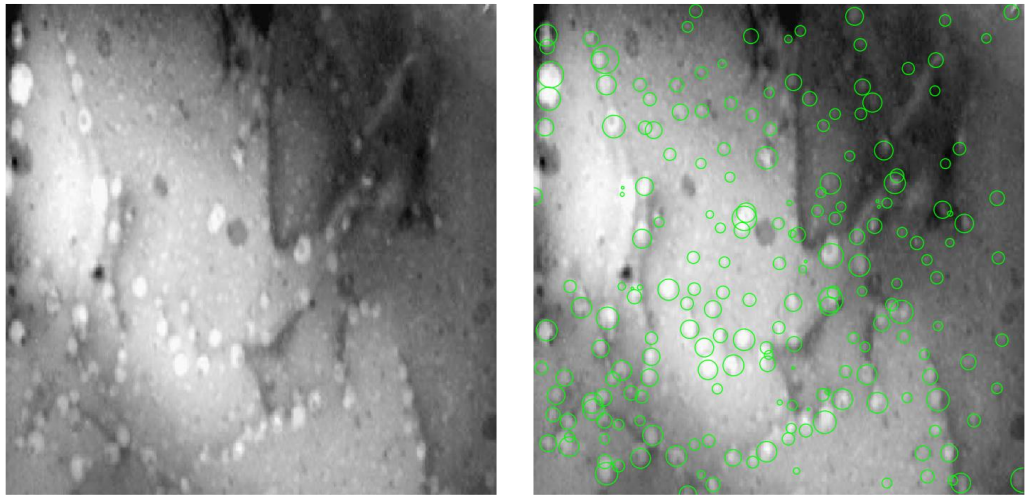


Fig. 19. Fission gas bubbles in UO_2 nuclear fuel *adapted from [10]*

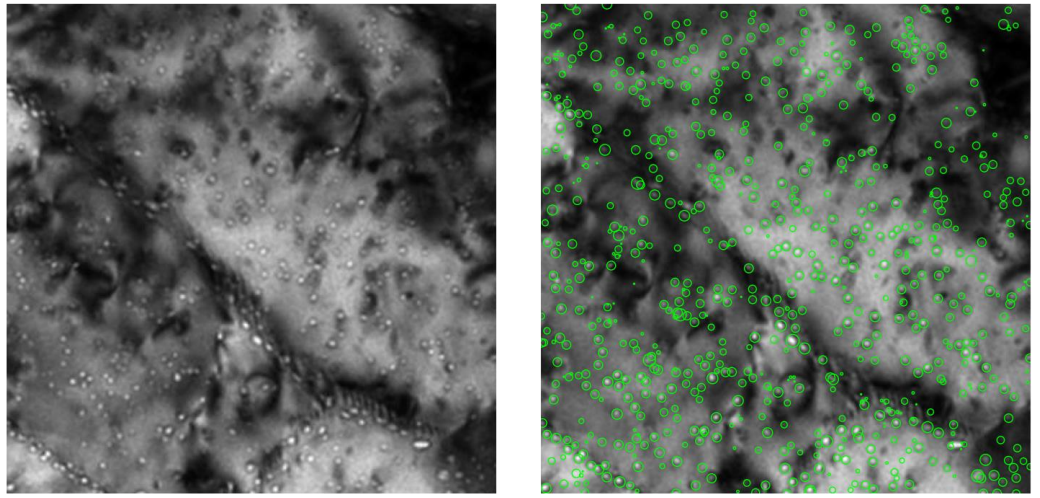
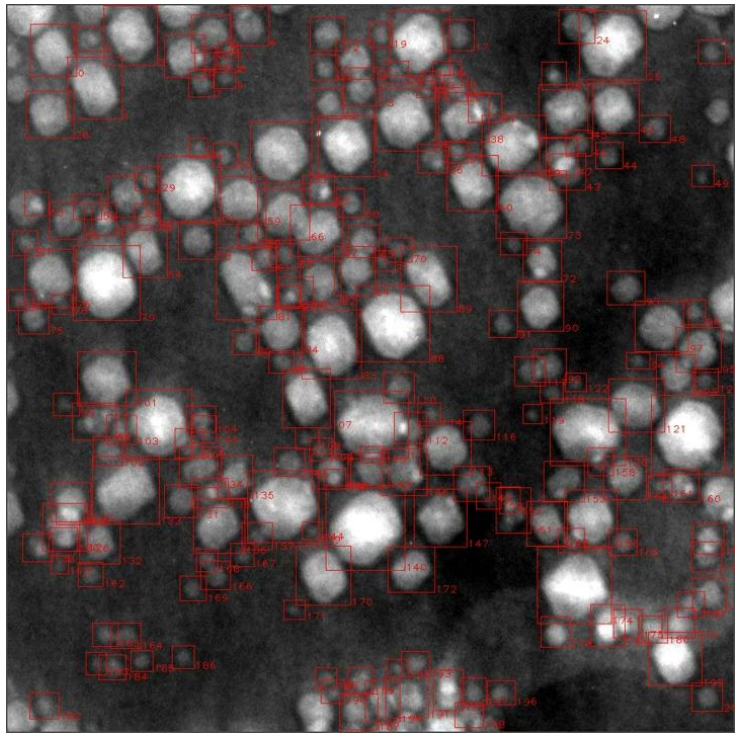


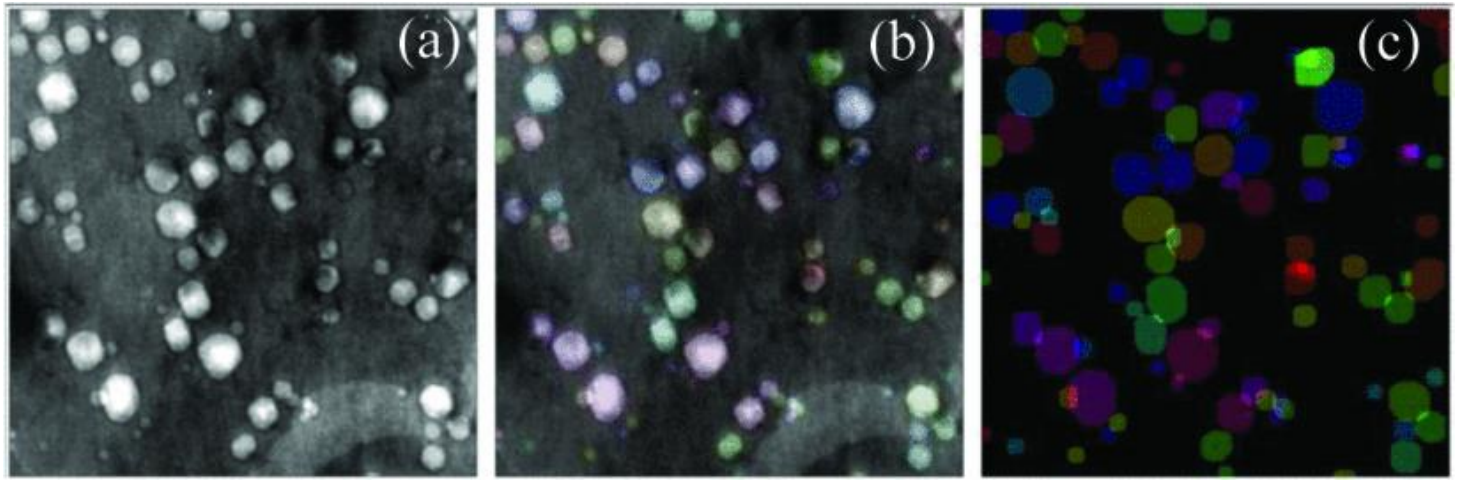
Fig. 20. He bubbles in W plasma-facing material *adapted from [11]*

[10] C. Ronchi, "Thermophysical properties affecting safety and performance of nuclear fuel," High Temp, vol. 45, no. 4, pp. 552–571, Aug. 2007, doi: 10.1134/S0018151X07040177.
[11] F. Luo et al., "TEM observation of bubbles induced by single and sequential He/H irradiation in tungsten," Fusion Engineering and Design, vol. 125, pp. 463–467, Dec. 2017, doi: 10.1016/j.fusengdes.2017.04.014.

Example of CNN image segmentation: Tracking He bubbles w/ Mask R-CNN

He bubbles in PdNi sample are tracked individually





Agarwal et al. (2023) https://doi.org/10.1109/ICECCME57830.2023.10252280