Particle Distribution Analysis of Electron Microscopy images using deep learning in material science.

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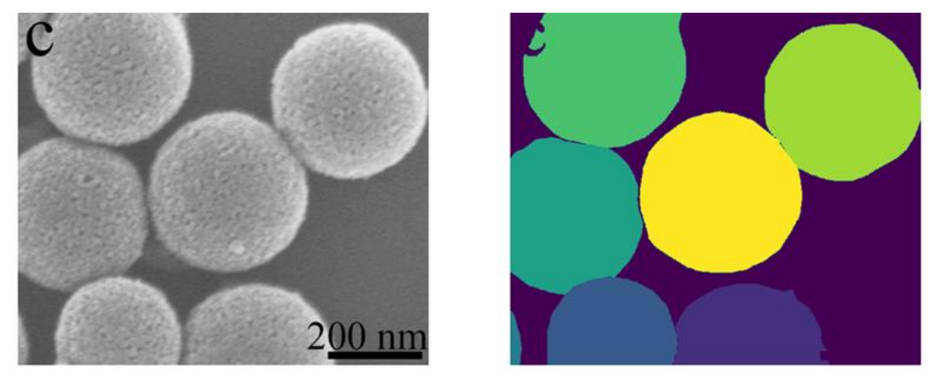
Abstract

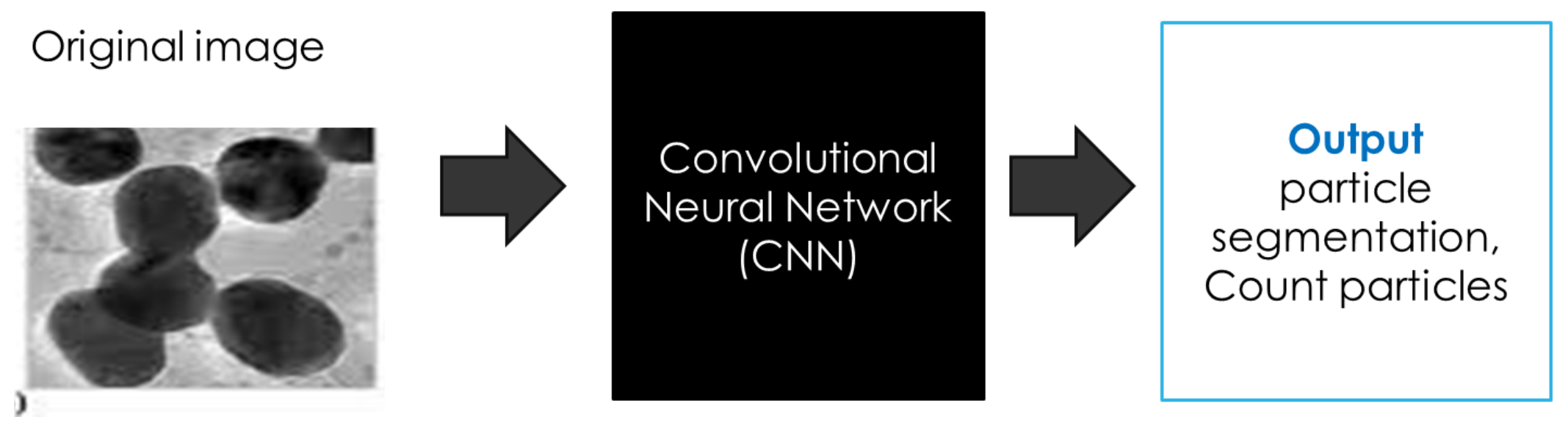
This research aims to develop an automated deep learning-based methodology for particle segmentation and counting in electron microscopy (EM) images, which are widely used in material science for understanding particle distribution. Traditional manual analysis methods are time-consuming and prone to subjectivity. To overcome these challenges, we applied the DeepLabV3 architecture, pretrained on ResNet-50, to segment particles with high precision. The dataset consists of 465 electron microscopy images with pixel-level segmentation. By incorporating data preprocessing techniques, such as augmentation and normalization, and postprocessing steps like thresholding and connected component labeling, we enhanced segmentation quality and particle counting accuracy. The results demonstrate the model's capability to automate and improve particle distribution analysis, offering significant advantages over manual methods.

Introduction

- **Particle distribution analysis** in material science refers to the process of characterizing and understanding the arrangement, size, shape, and spatial distribution of particles within a material or sample.
- **EM(Electron microscopy)** images are pictures taken using electron microscopes.



Objective



Original image

Convolutional Neural Network (CNN)

Output particle segmentation, Count particles

Dataset

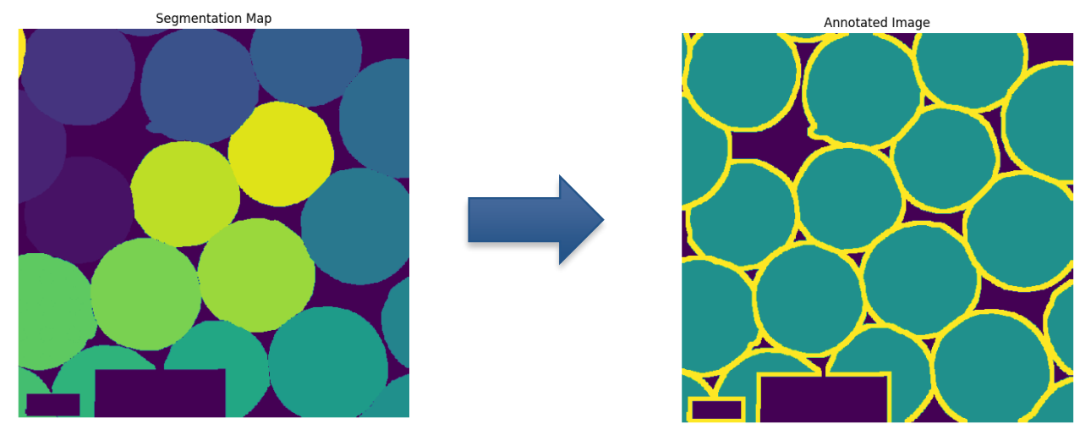
The dataset used for this research, "**Electron Microscopy Particle Segmentation"**[1], was obtained from Kaggle. It includes 465 electron microscopy images along with their corresponding pixel-level segmentations.

Annotate Segmentation Maps

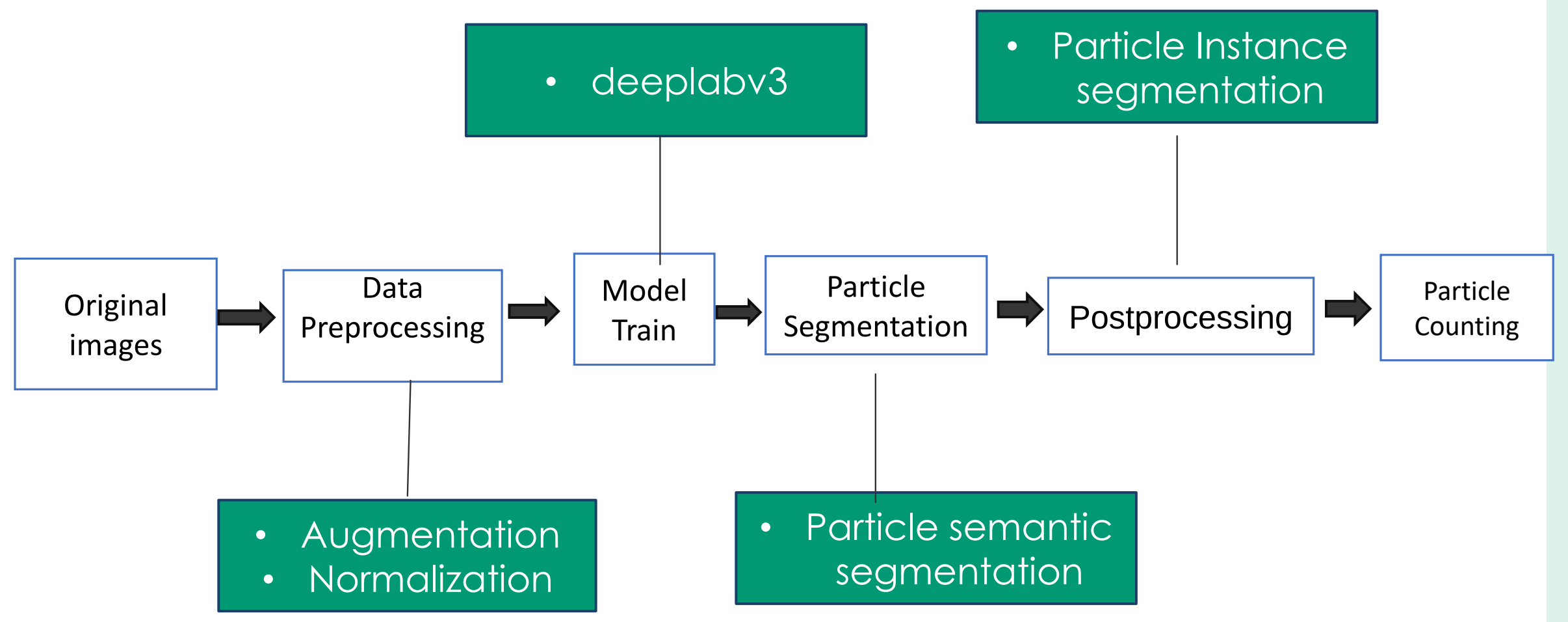
Annotate segmentation maps to label particles and their borders using morphological operations.

Value Labels:

0: Background region
1: Particle region
2: Border of the particle



Methodology



Original images → Data Preprocessing → Model Train → Particle Segmentation → Postprocessing → Particle Counting

- Augmentation
- Normalization

- deeplabv3

- Particle semantic segmentation

- Particle Instance segmentation

Step 1. Image Preprocessing

Image Augmentation

Image Transformations:

- Resize
- Flipping
- Random Cropping
- Random Rotations

Distortion Techniques:

- Elastic Transform
- Grid Distortion
- Optical Distortion

Color Augmentations:

- Brightness and Contrast Adjustments
- Gamma Adjustments

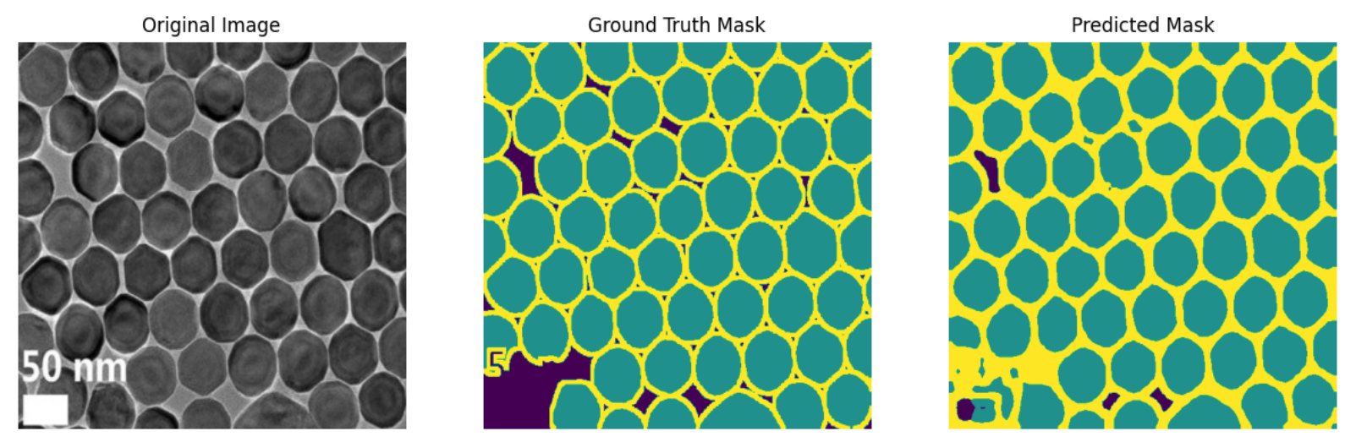
Normalization

Images normalized using mean (0.4773) and standard deviation (0.1719)

Step 02. Model Training

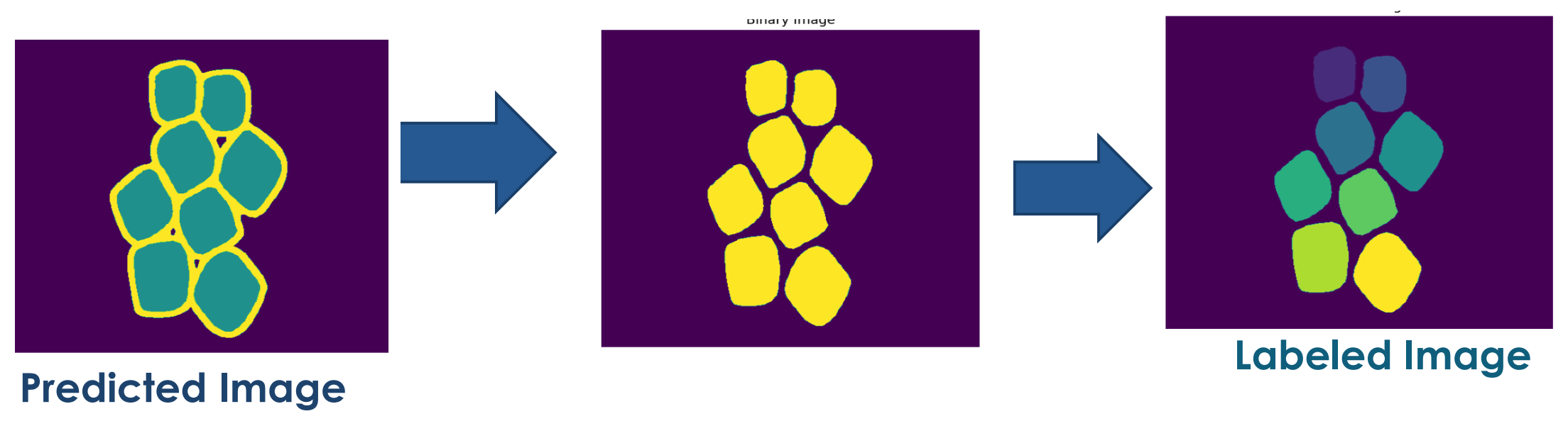
1. **Model Architecture**:
   - Utilize the **DeepLabV3** architecture with a modified classifier for 3 output classes.
   - Pretrained on ResNet-50 for feature extraction.
2. **Loss Function and Optimization**:
   - Use **weighted cross-entropy** loss to handle class imbalance.
   - Adam optimizer with an initial learning rate of 1e-3.
   - Cosine annealing scheduler for dynamic learning rate adjustments.
3. **Training Setup:**
   - Number of Epochs:50 epochs
   - Batch Size:8

Step 03.Particle Semantic Segmentation



Step 04.Postprocessing

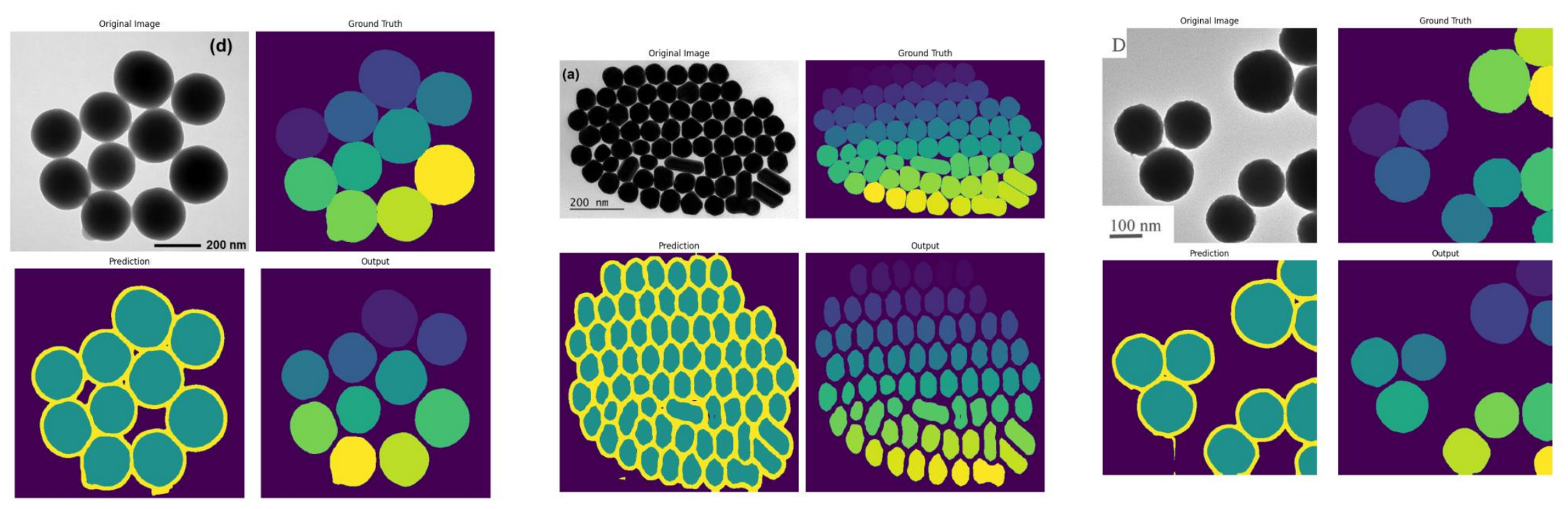
- Convert border pixels to background
- Threshold the image to create a binary image
- Label connected components in the binary image



Result

- The **accuracy** values range from around **0.58 to 0.98** across different images.**IoU scores** range from approximately 0.30 to 0.89.**Dice scores** range from about 0.44 to 0.93

Easy Case



[Above 3 images, the model accurately segmented well-separated particles with regular shapes and sizes, demonstrating strong boundary detection]

Difficult Case

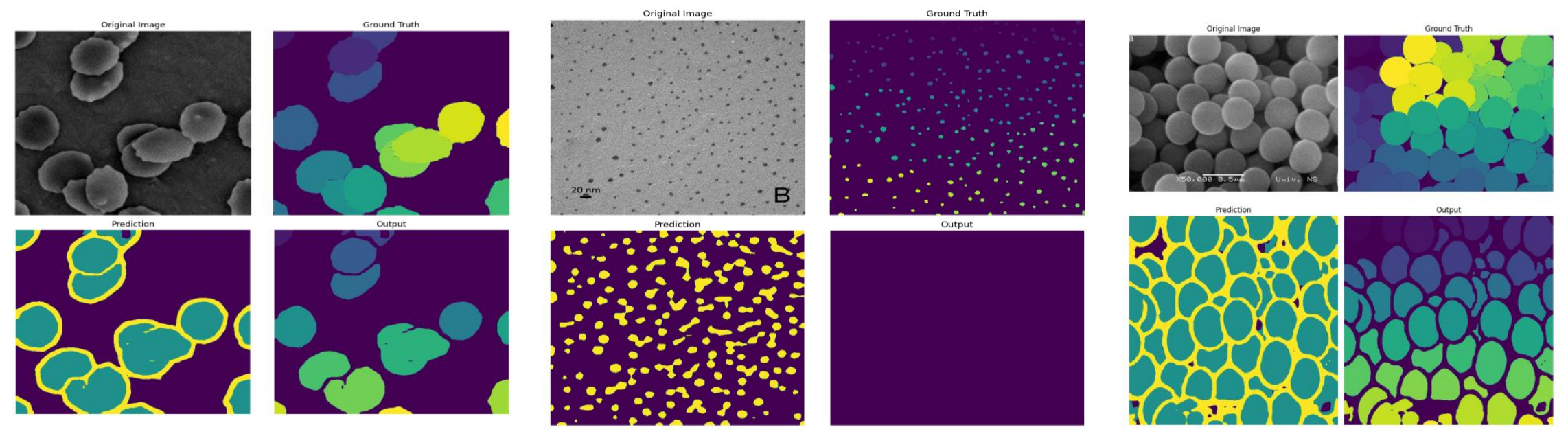


Figure1 Figure2 Figure3

[Figure1-The model merged overlapping particles into a single entity, resulting in under-segmentation.**Figure2-** Small particles near the resolution limit were frequently missed or misclassified as background.**Figure3-** In high-density regions, where many particles are packed closely together, the model has difficulty identifying and separating each particle]

Conclusion

- Our customized DeepLabV3 model effectively recognizes nanoparticles in electron microscopy images.
- We recommend exploring other deep learning models and combining this dataset with additional data for further improvements.

References

1. Yildirim, Batuhan, and Jacqueline M. Cole. "Bayesian particle instance segmentation for electron microscopy image quantification." *Journal of Chemical Information and Modeling* 61.3 (2021): 1136-1149..
2. Liz, Mikhail F., et al. "Using computer vision and deep learning for nanoparticle recognition on scanning probe microscopy images: modified U-net approach." *2020 Science and Artificial Intelligence conference (SAI ence)*. IEEE, 2020.
3. Horwath, James P., et al. "Understanding important features of deep learning models for segmentation of high-resolution transmission electron microscopy images." npj Computational Materials 6.1 (2020): 108.