DECOR: Deep Embedding Clustering with Orientation Robustness

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Motivation

- **Wafer defect analysis** is critical for yield and quality control, but real-world data is unlabeled, noisy, imbalanced, and often contains multiple defect types per wafer.
- Existing clustering methods require manual parameter tuning (number of clusters) and do not adapt well to changing defect distributions.
- Orientation variability (rotations and flips) causes identical defect patterns to be split into different clusters.
- We provide an **unsupervised, orientation-robust clustering framework** that is reliable for production-scale inspection.

Background

- Standard pipelines rely on learning embeddings (CAE, MoCo) followed by clustering (K-Means, DBSCAN, GMM).
- Parametric clustering assumes a fixed number of defect types, which is unrealistic in manufacturing.
- Most embeddings are orientation-sensitive, leading to fragmented clusters for rotated defects.
- **DECOR** addresses these issues by combining:
  - ➢ **Rotation- and flip-invariant embeddings** (RCAE)
  - ➢ **Non-parametric clustering** (DeepDPM)
  - ➢ **Cluster-aware outlier detection**

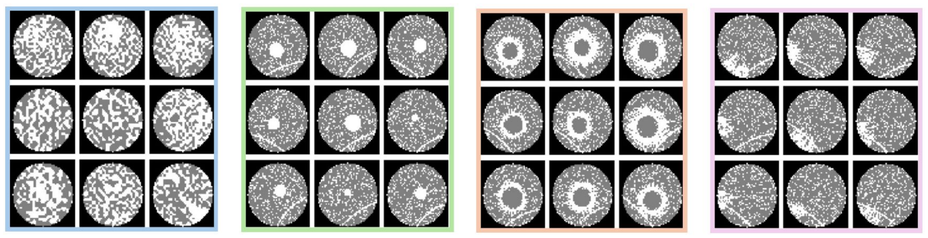
Dataset

- **MixedWM38** (38k+ wafer maps containing 1 non-defect, 8 single-defect and 29 mixed-defect patterns)
- **Multi-label ground truth** (mixed defects), so evaluation uses a cluster-aware dominant-label reduction for computing NMI/ARI.

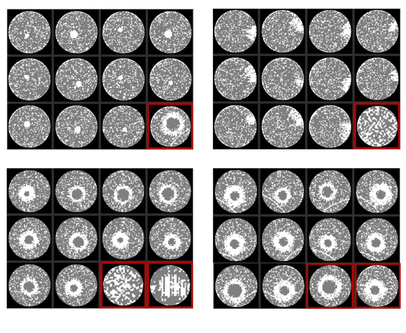
Experiments

- Evaluated on MixedWM38 (38k+ wafer maps) containing single and mixed defects.
- Extracted **128-D rotation-** and **flip-invariant embeddings**
- Applied non-parametric clustering and cluster-aware outlier detection.
- Assessed performance using **NMI** and **ARI** with dominant-label reduction for multi-label wafers.

Results



Same defect, different orientations → one cluster



Cluster-aware outlier detection

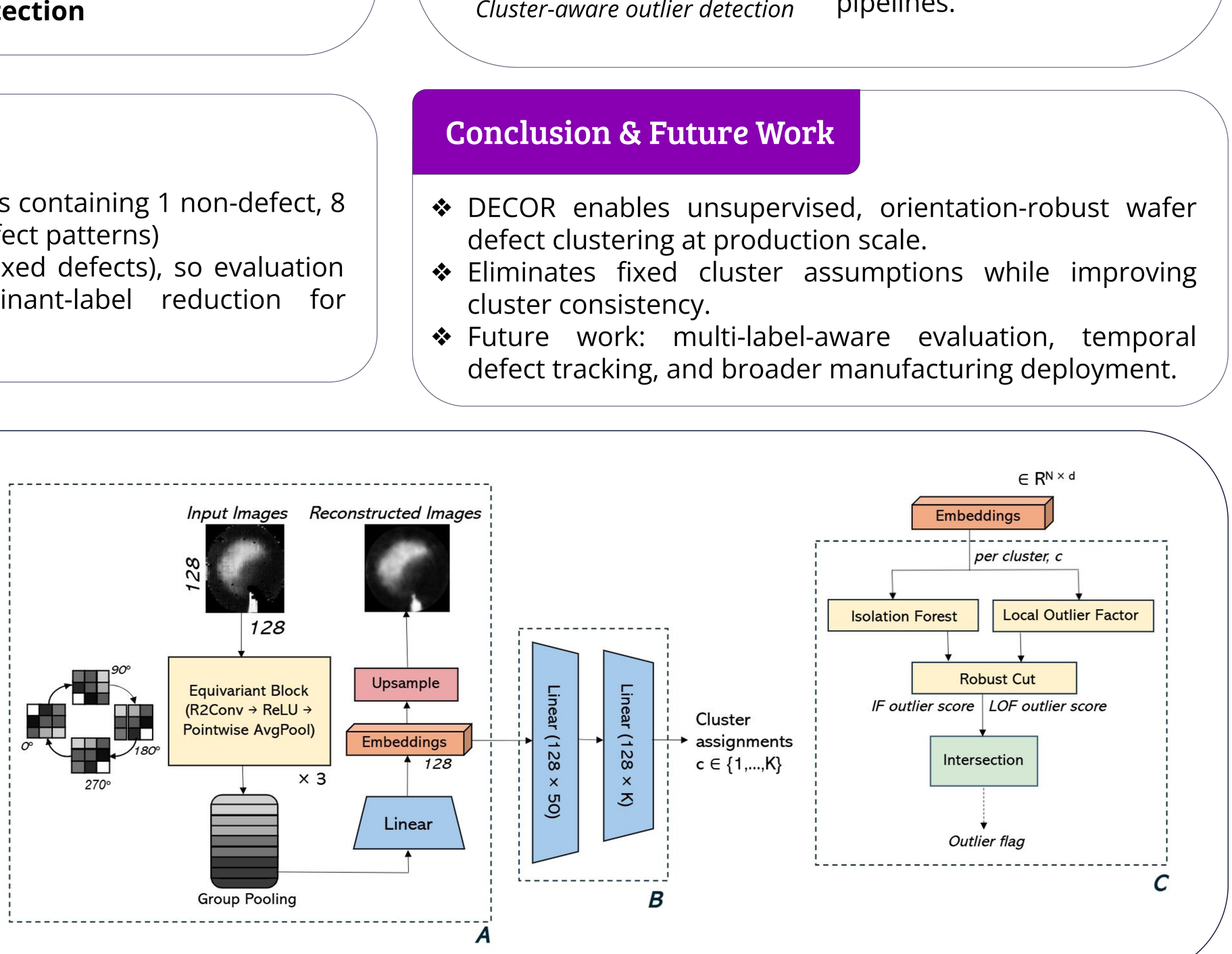
- Provides compact and rotation-consistent clusters which reflect true defect structure.
- Achieves NMI = 0.543 and ARI = 0.296, surpassing baseline clustering pipelines.

Conclusion & Future Work

- DECOR enables unsupervised, orientation-robust wafer defect clustering at production scale.
- Eliminates fixed cluster assumptions while improving cluster consistency.
- Future work: multi-label-aware evaluation, temporal defect tracking, and broader manufacturing deployment.

Methods

A. Extract 128-D embeddings from wafer images.
B. Cluster embeddings using DeepDPM.
C. Detect outliers within each cluster using an ensemble method.



* Work conducted as part of 2025 summer internship at Micron Technology