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Cycle-Consistent Multi-Graph Matching for Self-Supervised Annotation of C.Elegans

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Article

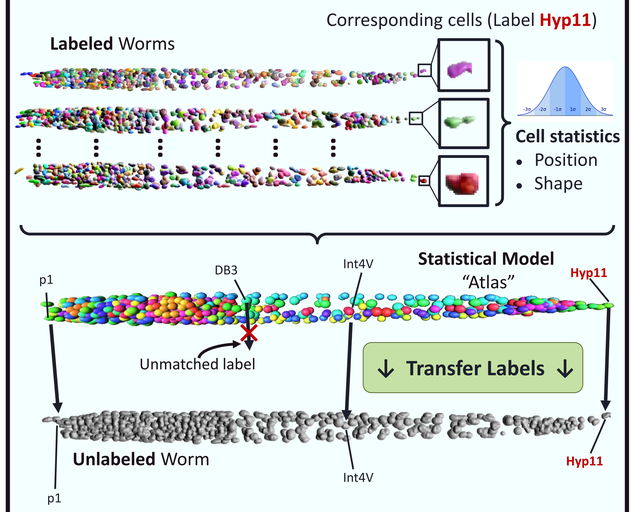
The subject

- *Caenorhabditis elegans (a small worm)*
- *1mm long, transparent body*
- *Stereotypical – always the same cells!*

The data

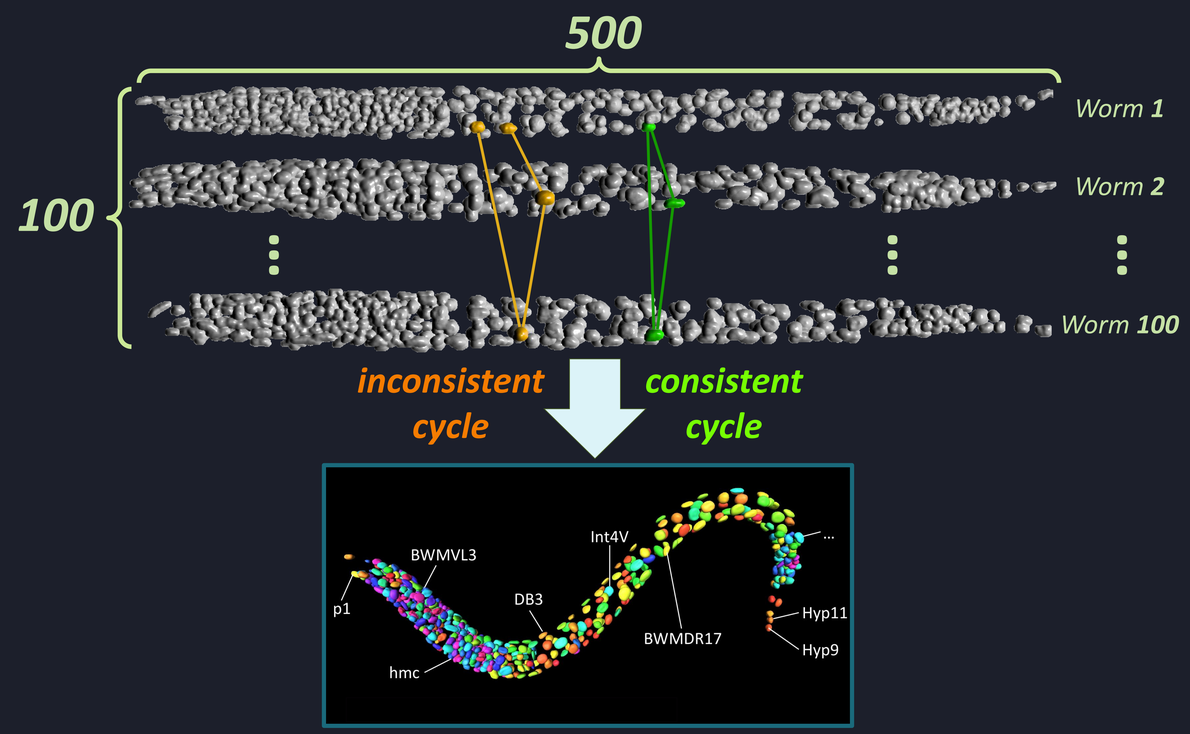
- *3D microscope images*
- *Cell nuclei segmentations - 558 cells*
- *Ground truth cell label annotations*

Previous State-of-the-Art



→ Can we do this **without** labels?

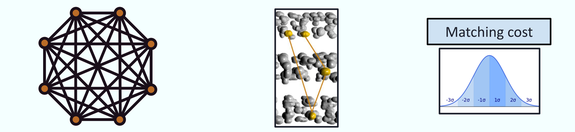
Learn Huge Multi-Matchings without Labels



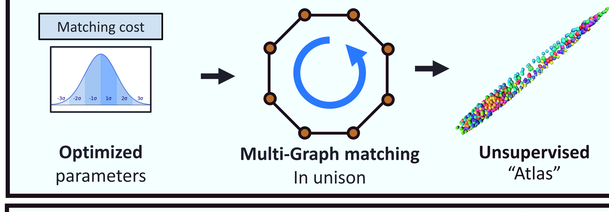
… using Bayesian Optimization

Our Pipeline

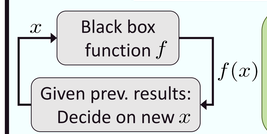
Step 1: Optimize Matching Parameters



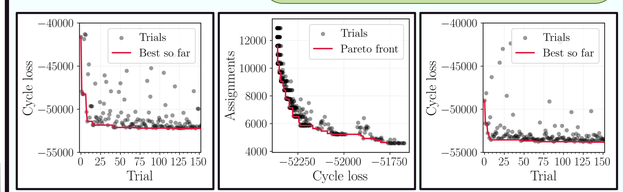
Step 2: Build Unsupervised Cell Atlas



Bayesian Optimization



Why Bayesian optimization?
- Piecewise constant objective
  → *Zero gradients*
- Limited dimensions – *12 parameters*
- Expensive – *5 min per iteration*

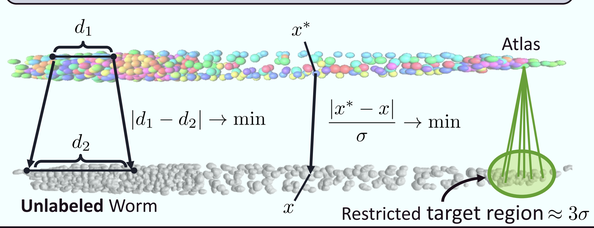


Step 1: Linear Terms
Linear assignment, dense

Step 2: Sparsity
Multi-objective

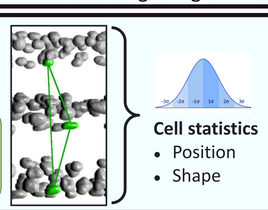
Step 3: Quadratic Terms
Graph matching, sparse

Graph Matching (NP-Hard)



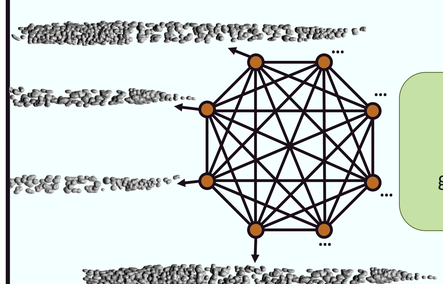
Idea

Corresponding cells from consistent multi-graph matching



Cell statistics
- Position
- Shape

Multi-Graph Matching

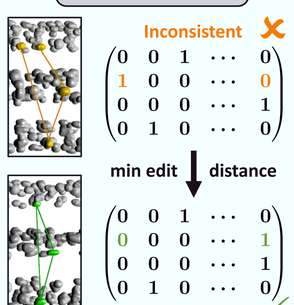


Goal
Min. sum over all pairwise graph matching problems

… Worm/Graph

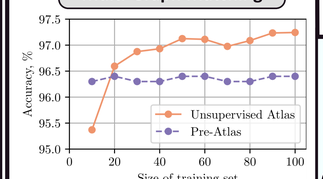
… Pairwise graph matching problem

Loss

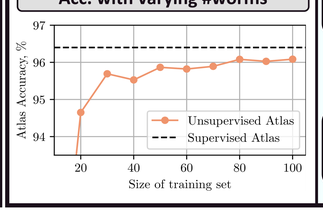


"Synchronization": Fix cycle-errors from pairwise solving

Accuracy Multi-Graph Matching



Acc. with varying #worms



Results

		Accuracy (average) ↑
Manual expert segmentation	Naïve unlearned	94.9%
	Supervised	96.4%
	Unsupervised	96.1%
Automated StarDist segmentation	Naïve unlearned	60.9%
	Supervised	**91.6%**
	Unsupervised	82.9%

Euclidean distances $\sigma = 1$

Off-the-shelf segmentation
StarDist
Schmidt U. & Weigert M. et al. "Cell Detection with Star-convex Polygons" *MICCAI, 2018.*