Conformal Prediction for Image Segmentation Using Morphological Prediction Sets

Paper & Code

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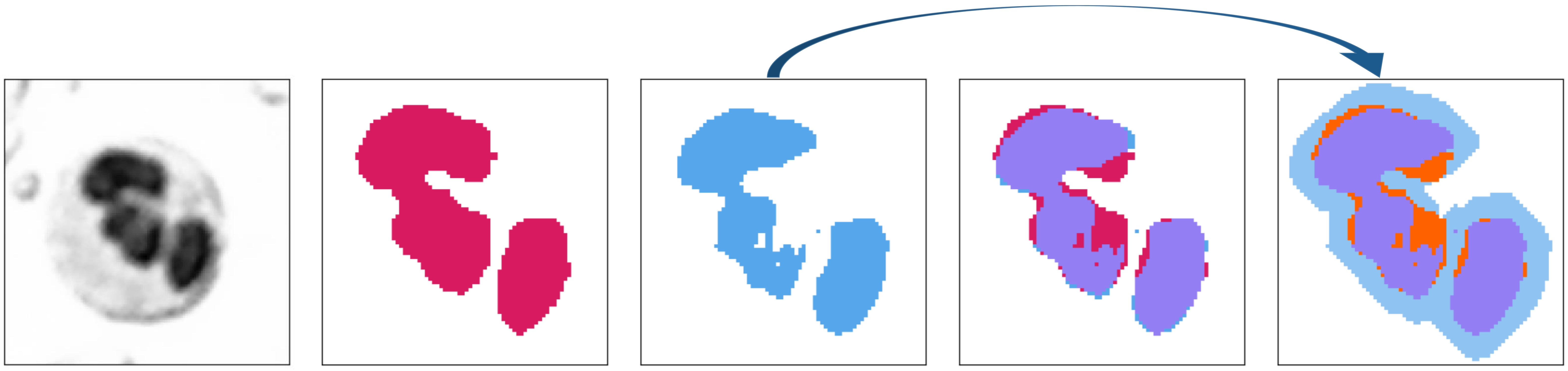
$$\underbrace{\text{Conformal Prediction} \;+\; \text{Mathematical Morphology}}$$

Morphological Conformal Prediction

Model-agnostic · Distribution-free · Finite-sample

Add **uncertainty margin**



Input X · : mask Y · : pred $\widehat{Y}$ · : true pos. $Y \cap \widehat{Y}$ · : margin $= \delta_B^6(\widehat{Y}) \setminus \widehat{Y}$ · : false neg. recovered

Input image source: White Blood Cell (WBC) dataset.
Zheng, X., et al. Fast and robust segmentation of white blood cell images by self-supervised learning. *Micron 107* (2018), 55–71.

Prediction Set: $\mathcal{C}_\lambda(X) := \underbrace{(\delta_B \circ \delta_B \circ \cdots \circ \delta_B)}_{\lambda \text{ dilations with kernel } B:}(\widehat{Y}) = \delta_B^\lambda(\widehat{Y})$

$B =$ (4-connectivity),

$B =$ (8-connectivity),
(...)

Acceptable error: $\alpha \in (0,1)$ **Tolerance hyperparam.:** $\tau \in (0,1)$

Calibration data: $((X_i, Y_i))_{i=1}^n$

Nonconformity score: $r(X_i, Y_i) = \inf\left\{\lambda \in \mathbb{N} : \frac{|Y_i \cap \mathcal{C}_\lambda(X_i)|}{|Y_i|} \geq \tau\right\}$

Estimation: $\hat{\lambda} = \lceil (n+1)(1-\alpha) \rceil\text{-th largest score in } \left(r(X_i, Y_i)\right)_{i=1}^n$

Results = it works

Theorem:
$$\mathbb{P}\left[\frac{|Y_{\text{test}} \cap \mathcal{C}_{\hat{\lambda}}(X_{\text{test}})|}{|Y_{\text{test}}|} \geq \tau\right] \geq 1 - \alpha$$

- ✓ Ensure **statistically valid coverage**
- ✓ Ensure **fewer false negatives**: margin captures false negatives
- ✓ **Always applicable** (minimal information, black-box)
- ✓ Can use **any extensive morphological operator** (dilation, etc.)
- ✓ **Margin size**, smaller is better: can compare competing predictors, architectures, etc.

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