Machine Learning for Microscopic Data Processing

Artificial Intelligence Under the Microscope: Teaching Computers to Recognize Complex Plant Structures for Pharmacy

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Motivation and Context

Why Do We Need AI in Microscopy?

Although modern artificial neural networks represent the state of the art in image analysis, they encounter a fundamental bottleneck in biology and pharmacy: **a lack of high-quality, validated, and annotated microscopic data**.

Objective

The aim was to automate the process of visual pharmacognostic analysis. We evaluated three distinct detection paradigms (YOLO, Faster R-CNN, DETR) on a novel FAIR-compliant dataset of complex botanical microstructures (e.g., *Verbascum* and *Althaea officinalis*).

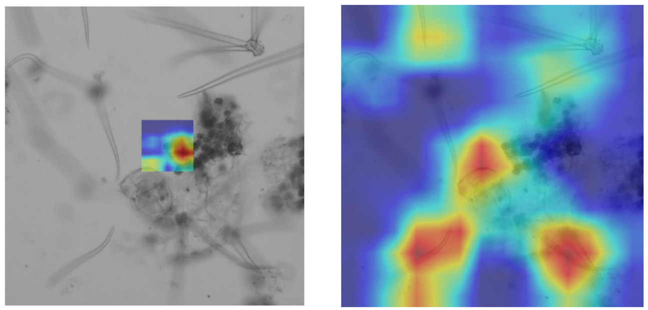
Real-World Impact

Transitioning from subjective manual observation to automated, statistically verifiable analysis means more efficient research into medicinal plants and standardized quality control of natural medicines.

Methods and Research

Architecture and Data Processing

A major challenge was the **severe class imbalance** and operator-induced spatial bias in the training set. The solution involved rigorous class consolidation and targeted geometric augmentation, which dramatically increased stability and accuracy across all classes.



(a) (b)

Grad-CAM (a) top prediction (b) full image.

Explainable Artificial Intelligence

To verify diagnostic transparency, we deployed **spatial detection-density heatmaps** and **Grad-CAM**. This proved that the model anchors its confidence to valid botanical features (cellular walls, trichomes) rather than spurious slide artifacts.

Results & Recommendations

Achieved Results

Among the tested architectures, the single-stage detector **YOLOv10x** proved statistically superior, bypassing NMS to effectively isolate dense fragments and outperforming Faster R-CNN (67.2 %) and DETR (67.0 %).

- **mAP@0.5:** **77.8 %**
- **mAP@0.5:0.95:** **49.2 %**

Key Findings

Algorithmic complexity alone is not enough. Experiments show that combining fast, anchor-free detectors with rigorous data pruning and transparent feature validation offers the greatest potential for full diagnostic automation.

Future Applications

The proposed pipeline establishes a highly optimized, reproducible foundation for real-time AI-assisted diagnostic co-pilots in pharmacognosy laboratories.