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P4: Machine Learning, Intelligent Systems & AI for Science and Engineering

4. PackGNN-Select: Learned Conflict-Aware Set Packing for NMS-Free YOLO Object Detection

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Abstract: PackGNN-Select is a learned, conflict-aware set-selection framework that replaces non-maximum suppression in YOLO object detection. Standard NMS greedily keeps the highest-scoring box and removes neighbors whose overlap exceeds a fixed threshold. Although fast, it ignores appearance, context, localization quality, and whether strongly overlapping boxes belong to distinct objects. In crowded or occluded scenes, it may retain the wrong box, suppress a valid object, or leave duplicates.

The method reformulates post-processing as a structured set-packing problem. A frozen YOLO detector first produces a proposal pool. A confidence gate and top-N budget retain a compact candidate set. Each proposal becomes a graph node described by geometry, detector score, rank, class information, and an ROI appearance embedding. Context edges support message passing between related proposals, while conflict edges connect potentially redundant boxes.

A lightweight graph neural network produces a context-aware representation for every proposal. A utility head estimates the value of keeping each box from its confidence, localization quality, appearance, and neighborhood evidence. A pairwise conflict head predicts how undesirable it would be to retain two proposals together. Unlike fixed IoU suppression, this learned conflict score uses geometry, visual similarity, and class compatibility to distinguish duplicates from nearby instances.

The subset is produced by an unrolled differentiable solver. It begins with utility-based keep probabilities and repeatedly lowers the probability of proposals that strongly conflict with other likely selections. This process approximates maximum-weight set packing: retain high-utility proposals while minimizing redundancy. Since the solver is differentiable, the ROI encoder, GNN, utility head, and conflict head can be optimized jointly.

Training supervises the output as a set rather than teaching the network to imitate NMS. A coverage loss encourages every ground-truth object to be represented by a well-localized proposal. A duplicate loss penalizes jointly selected conflicting boxes. A cardinality term regulates set size, while an optional quality head predicts proposal-to-ground-truth IoU and improves confidence-localization alignment. An auxiliary binary objective separates useful proposals from background hypotheses. During inference, the keep probability is combined with the detector score, and detections are returned without ordinary NMS. A high-IoU safety filter may remove pathological duplicates.

PackGNN-Select changes post-processing from independent scoring and greedy suppression into learned global reasoning over the proposal set. It is lightweight, detector-agnostic, and attachable to existing YOLO models without redesigning their backbone or detection head. Its contribution is the joint modeling of proposal utility and pairwise incompatibility, targeting a compact, accurate, high-recall, and non-redundant detection set.