Title: **To Develop Some Novel Uncertainty Estimation Models Using Deep Learning Techniques For Image Segmentation**

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ABSTRACT

Deep learning–based image segmentation is indispensable in critical fields like medical diagnosis and autonomous navigation, yet model performance is undermined by various uncertainties, such as, ambiguous boundaries, inconsistent human annotations, and overconfident predictions. This thesis introduces a comprehensive framework of methods to quantify and mitigate these uncertainties, thereby enhancing segmentation accuracy, robustness, and interpretability.

First, we address **boundary uncertainty** by augmenting a U-Net with a spatial attention mechanism and proposing a Bi-category Hybrid Loss that jointly optimizes region overlap and edge sharpness. The resulting **COVID-CT-H-UNet** model demonstrates a 12% gain in Dice score and a 15% reduction in boundary error on COVID-19 lung CT scans compared to leading baselines.

To resolve **label uncertainty**, we develop a **multi-annotator consensus framework**. Our Class-Specific Distribution Learning captures the full distribution of expert labels per class, and the Annotator-Specific Preference Estimator model's individual biases. On public benchmarks (RIGA, QUBIQ), this approach reduces annotation-driven variability by 20% and boosts generalization to unseen annotators.

For **model uncertainty**, we propose two complementary strategies. A **copula-based ensemble** explicitly learns dependencies among multiple segmentation networks, yielding consistent 1–2% improvements in overall accuracy and mean IoU on urban scene and medical datasets. In parallel, **Confusion-Penalty Label Smoothing (CPLS)** adaptively reallocates smoothing mass based on validation-set confusion matrices, cutting Expected Calibration Error by up to 35% while improving classification accuracy by 3%.

Beyond segmentation, we demonstrate the broader applicability of uncertainty-aware learning. In an **object detection** setting—which is not a segmentation

task—early fusion of RGB, near-infrared, and thermal imagery with YOLOv3 raises mAP from 71.5% to 78.6% and halves prediction variance. Lastly, we introduce **GA-RISE**, a genetic-algorithm-optimized saliency method for **classification and detection**, which produces stable, focused heatmaps and outperforms RISE and GradCAM in insertion/deletion metrics.

Collectively, these contributions offer a unified toolkit for uncertainty estimation, improving boundary delineation, reconciling annotation variability, calibrating model confidence, integrating multi-modal data for detection, and delivering robust visual explanations—paving the way toward safer, more trustworthy deep learning systems in both segmentation and broader computer vision tasks.

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