Distribution-free Uncertainty Quantification for Contour Segmentation in PET Imaging

Wenhui Zhang W.ZHANG.2@RESEARCH.GLA.AC.UK
Mathematics and Statistics, University of Glasgow,UK

Surajit Ray SURAJIT.RAY@GLASGOW.AC.UK
Mathematics and Statistics, University of Glasgow, UK

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Abstract

Quantifying uncertainty in contour segmentation is crucial for reliable decision-making in medical diagnostics, particularly in applications such as tumour segmentation of PET (Positron Emission Tomography) scans. Deep learning models, while powerful, often provide pixel-wise uncertainty estimates that lack anatomical guarantees and can lead to overconfidence and unpredictable behaviour on out-of-distribution samples (Ghoshal et al., 2021). While recent works have explored the use of conformal prediction with risk controlling for image-to-image regression problems (Angelopoulos et al., 2022), uncertainty quantification for contour or manifold representations remains a largely unexplored area. Building upon our previous work on predicting contour segmentation using an end-to-end deep learning framework (Zhang and Ray, 2023), we propose a novel approach that combines density level sets with the conformal risk-controlling theory. We therefore aim to derive predictive regions with risk controlling for contour or manifold objects, providing a statistical guarantee of containing the ground truth with a user-specified confidence level.

Our methodology treats the entire object as a unified entity, offering a comprehensive assessment of confidence that goes beyond pixel-wise prediction intervals. This holistic approach to uncertainty quantification facilitates more informed decision-making, naturally finding its application in the context of tumour segmentation in PET images. The proposed framework demonstrates statistical adaptability under varying conditions of image clarity and noise, making it suitable for dependable medical imaging analysis. Ultimately, our research aims to enhance decision-making processes in medical diagnostics through robust uncertainty quantification, providing medical professionals with a powerful tool to assess the confidence of contour segmentation results and guide further examination when necessary.

Keywords: Conformal prediction, uncertainty quantification, contour segmentation, PET imaging, tumour segmentation

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