A Helmholtzian Deep Learning Approach to Glomeruli Segmentation Using Energy-Based Models for Uncertainty Estimation

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Histologic analyses of glomeruli in renal tissues yield a substantial amount of information about overall kidney health or diseases stemming from glomerular structural damage. Current medical practices of standard glomeruli assessment are completed through a manual evaluation of the quantification of normal and abnormal glomeruli in kidney biopsies, which is laborious, costly, and function with high degrees of error from missed or misclassified glomeruli. Moreover, the input of an in-house trained nephropathologist is needed for a kidney biopsy analysis — labor that is not readily available in large quantities at medical centers. To address this, we propose a deep learning framework to segment glomeruli, incorporating a novel energy-based model inspired by Helmholtz' Free Energy to compute prediction uncertainty at inference-time. Uncertainty estimates allow nephropathologists to prioritize which model prediction to validate or invalidate, greatly expediting their medical workflow. Our usage of energy as a confidence estimate can be generalized to any segmentation neural network architecture. Because our energy approach is theoretically aligned with the probability density of inputs, we demonstrate both empirically and mathematically that our energy-based model outperforms the traditional softmax confidence score in our settings. Our framework was trained on data provided by HuBMAP and AIDPATH and achieved a validation F1-score of 94.7% on an unseen dataset. These results were shown to perform significantly better than previously related works. Overall, our approach to segment glomeruli with a confidence score maximizes the efficiency of nephropathologists with a drastically expedited process of extracting glomerular features from large histopathological images.

Awards Won:

Fourth Award of $500

China Association for Science and Technology (CAST): Award of $1,200