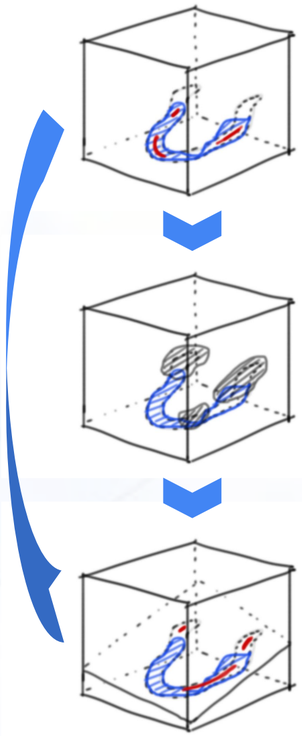
Effect of Different Uncertainties in Medical Image Segment Error Estimation

From “Interactive Segmentation of 3D Medical Images” | Sungjin Kim, sjmich2k@gmail.com | TU Delft

1. Motivation & Question

In the process of the interactive segmentation of 3D medical images below, *“What is the effect of using different ways to quantify uncertainty?”*

We use the pipeline from [1] and its uncertainty methods, and a new method: ensemble method [2]



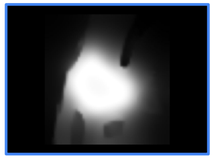
User Annotation & Segment
User marks areas (red) of the organ (dotted) for the automatic segmentation algorithm to make predictions (blue).

Uncertainty estimation
Uncertain areas are estimated (slashed - black) by uncertainty field algorithms. They represent areas of high error probabilities.

Plane Fetch (Most Uncertain)
A 2D plane slice that intersect the most amount of uncertainty is fetched, enabling user annotation on the slice to be most effective at improving the segmentation.

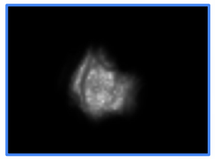
2. Methodology

We compare the four intermediate uncertainty energies from [1] and their final combined uncertainty. We then compare it to the ensemble method uncertainty.



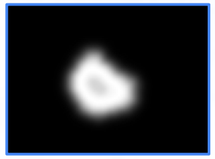
Entropy Energy
Directly calculated from segmentation probabilities. Measures the ambiguity of the prediction of each voxels.

Boundary Energy
Penalizes weak image gradients around segmentation boundaries, as in such areas segmentations tend to become inaccurate.

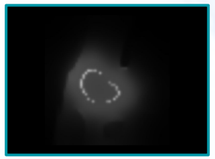


Regional Energy
Compares the image intensity of voxels to the distribution of different labels, and calculates their likeliness to labels.

Smoothness Energy
Measures the distance to the segmentation boundaries of neighboring voxels. High uncertainty as more neighbors are closer.



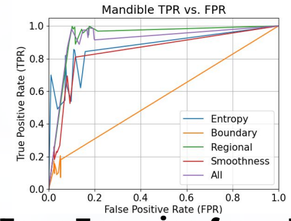
Combined Uncertainty (from [1])
0.8 Entropy + 0.05 Boundary + 0.15 Regional

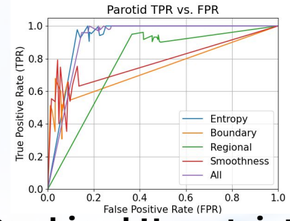


Ensemble Method Uncertainty
Measures the differences of multiple predictions with the same input. The more difference, the more uncertain.

3. Results & Discussion

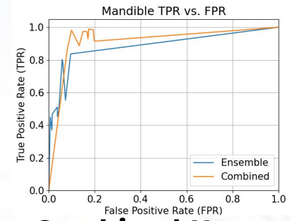
We evaluate different uncertainties for different segmentations of the mandible and parotid glands. We then check the correlation between the generated uncertainty fields and the error image via ROC curves.

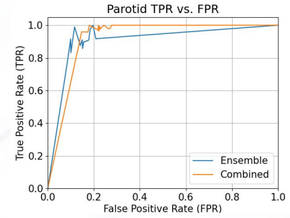




Four Energies from [1] and Combined Uncertainty

Entropy Energy has high TPR while keeping FPR minimum, *Regional Energy* has higher TPR while sacrificing FPR. The *Combined Uncertainty* integrates the two for best results.





Combined Uncertainty and Ensemble Method

Ensemble Method has lower FPR than the *Combined Uncertainty*, however it performs worse for big images such as the mandible.

We prove the utility of the combined uncertainty from [1] in this research. Future works may also prove much significant advantages of the ensemble method in segmentations with better accuracies, produced by different segmentation algorithms.

References

1. Top, A., Hamarneh, G., & Abugharbieh, R. (2011, September). Active learning for interactive 3D image segmentation. In International Conference on Medical Image Computing and Computer-Assisted Intervention, 603-610. Springer, Berlin, Heidelberg.
2. Zou, K., Chen, Z., Yuan, X., Shen, X., Wang, M., & Fu, H. (2023). A Review of Uncertainty Estimation and Its Application in Medical Imaging, 2–3.