Exploring Uncertainty in Image Segmentation Ensembles

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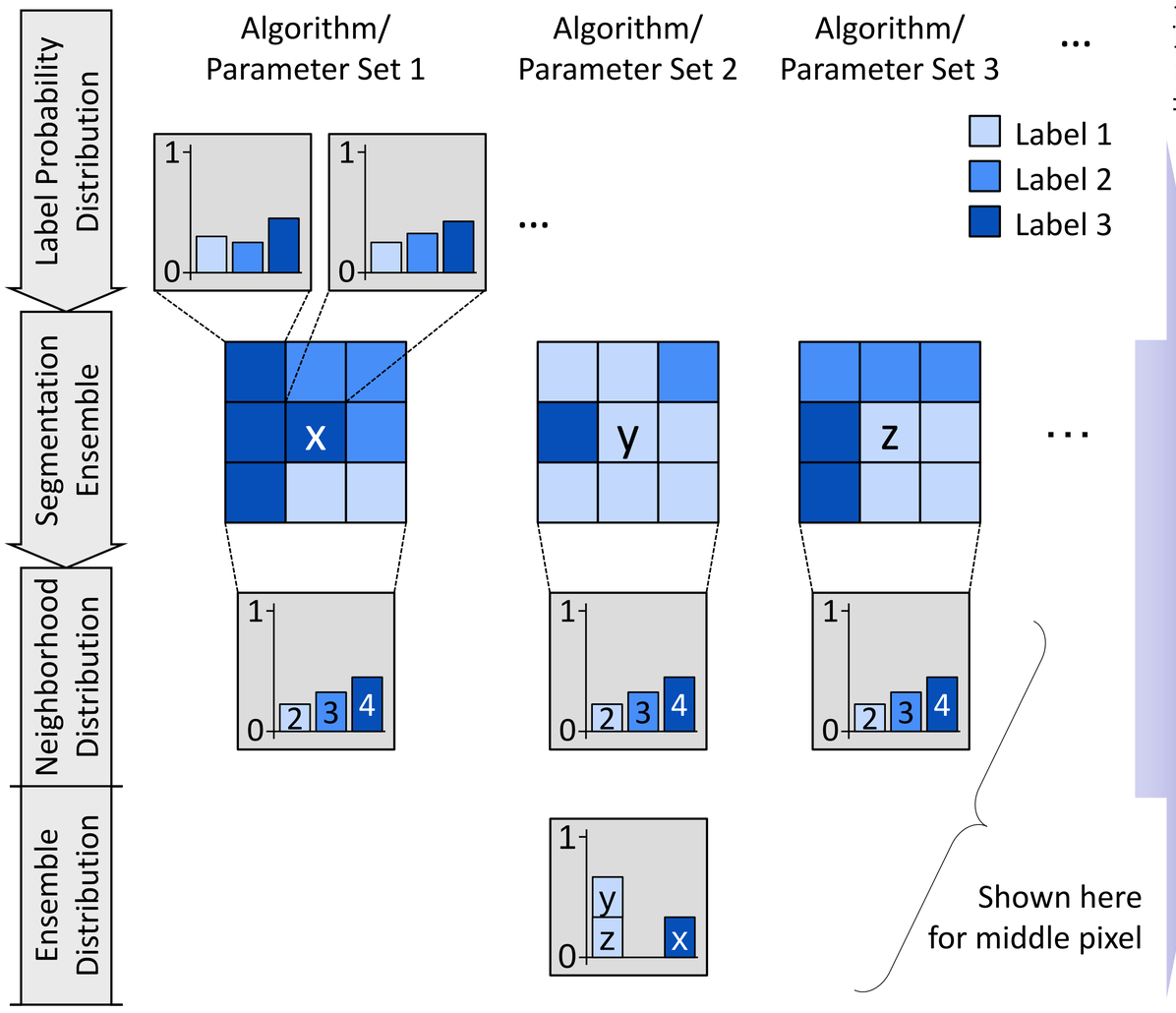
Introduction

Finding the most accurate image segmentation involves analyzing multiple results from different algorithms or parameterizations. In such segmentation ensembles, we identified three **uncertainty types** represented by:

- Results of probabilistic algorithms
- Local variability in the segmentation
- Variability across the ensemble

We propose visualization techniques for the analysis of such types of uncertainties in segmentation ensembles. For a global analysis we provide overview visualizations in the image domain as well as in the label space. Our probability probing and scatter plot based techniques facilitate a local analysis. We evaluate our techniques using case studies on industrial computed tomography and hyperspectral data.

Uncertainty Types in Segmentation Ensembles



To cover the range of results possible with the analyzed algorithms, multiple segmentation results are computed, utilizing all algorithms and sampling their parameter space. The label probability distribution delivered by probabilistic *algorithms* represents the first uncertainty type we identified. For each result, an additional uncertainty type results from considering the distribution in the *neighborhood* of each pixel. The distribution across the *ensemble* for each pixel represents a third type of uncertainty information.

The segmentations and the distributions (algorithm, neighborhood and ensemble) derived from these are computed as a preprocessing step. For each of those distributions, uncertainty values are computed using Shannon entropy.

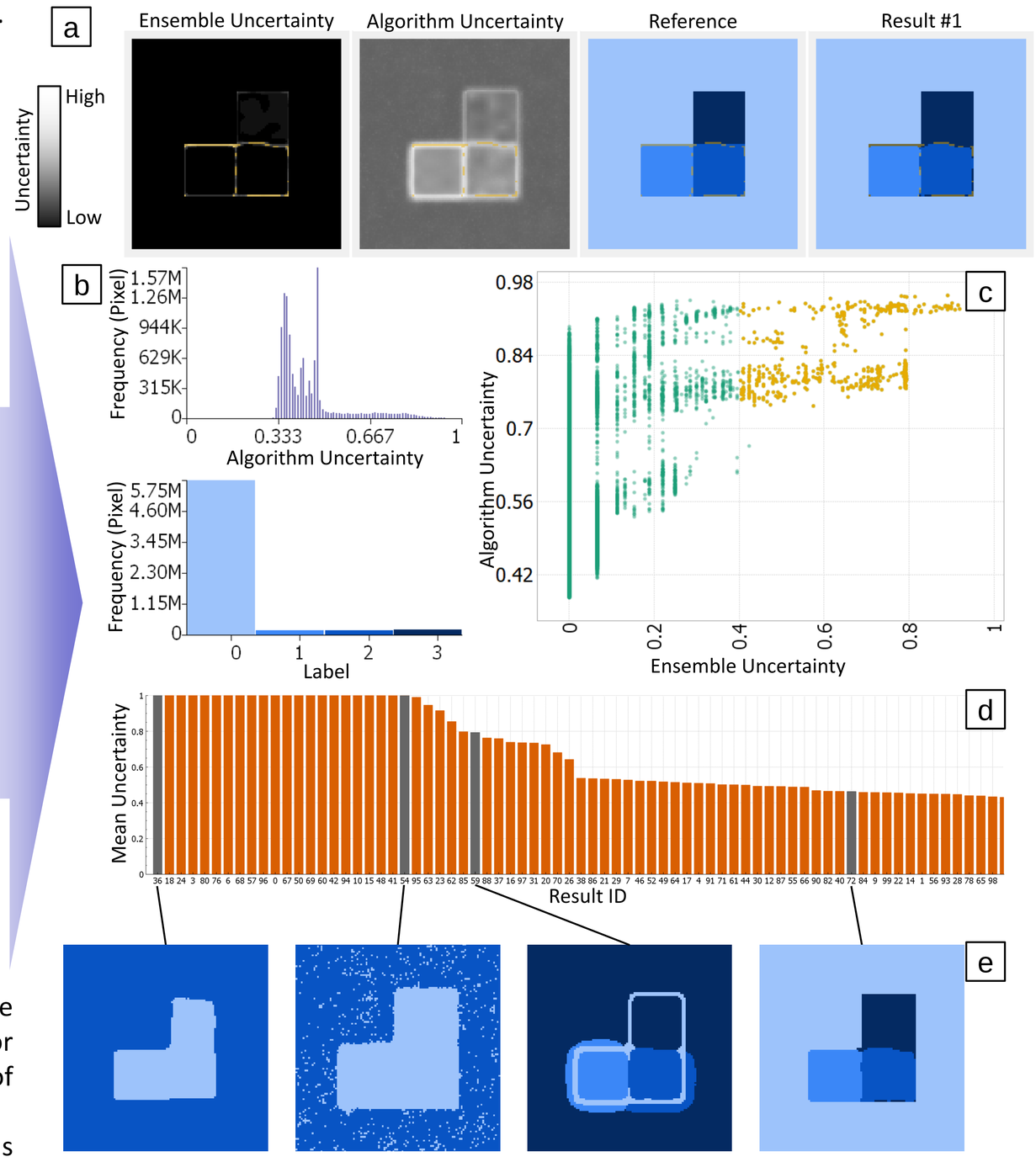
Visual Analysis of Computed Tomography Data

Visualizations:

- (Average) uncertainty images (a), alongside single results and reference
- Histograms (b) for the distribution of labels and uncertainty values
- Scatter plot (c) showing correlations between uncertainty types
- Bar chart of mean (algorithm) uncertainty per segmentation result (d)

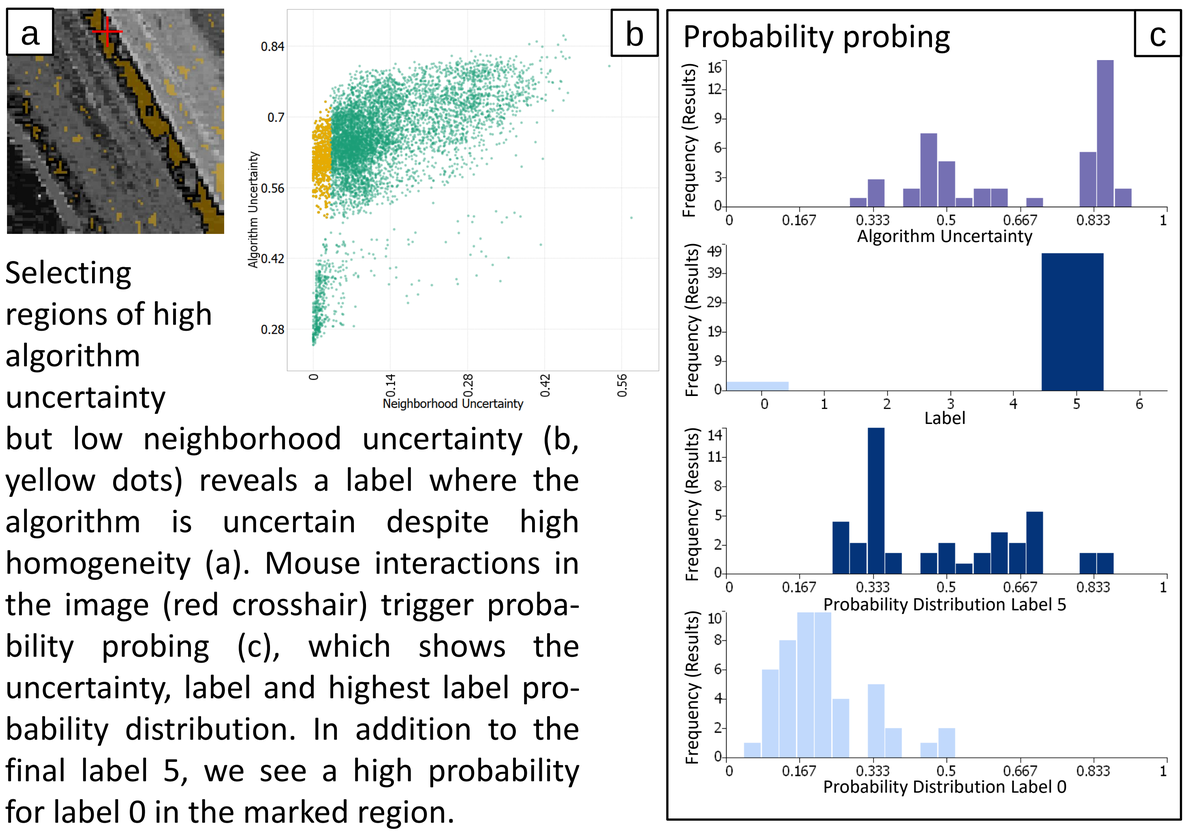
Interactions:

- Selecting in scatter plot highlights corresponding pixels in images in (a).
- Individual segmentation results (e) can be shown by clicking on the bar of the respective result in (d).
- Hovering in the images in (a) triggers probability probing (see lower left of this poster).



When selecting results with high average algorithm uncertainty, as shown in the three left-most images in (e) above, we see that segmentation results with high uncertainty result in bad segmentation quality compared to the reference segmentation shown in (a). We can conclude that the algorithm uncertainty in this case can provide a direct indication of segmentation quality. The average algorithm uncertainty for the ensemble shown in the second image from the left in (a) further tells us that the borders between the different labels have the highest local uncertainty, especially the borders around the lower left rectangular region. We can therefore focus our further refinement on these regions.

Visual Analysis of Hyperspectral Data



Selecting regions of high algorithm uncertainty but low neighborhood uncertainty (b, yellow dots) reveals a label where the algorithm is uncertain despite high homogeneity (a). Mouse interactions in the image (red crosshair) trigger probability probing (c), which shows the uncertainty, label and highest label probability distribution. In addition to the final label 5, we see a high probability for label 0 in the marked region.

Conclusion and Future Work

We have systematically categorized the uncertainty available in a segmentation ensemble into algorithm, neighborhood and ensemble uncertainty. We propose techniques for analyzing this information, and case studies on how this information can be used to analyze segmentation algorithms. We are currently looking into further ways of how to use these technique to improve the performance of segmentation algorithms, and how to apply this uncertainty information to combining segmentation results.

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