Enabling Uncertainty Measurement in Multi-subregion Tumor Segmentation: BraTS 2025 Pediatrics

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Introduction

- Pediatric gliomas are the most common CNS tumors in children.
- MRI segmentation is key for diagnosis, treatment planning, and follow-up.
- Manual segmentation is slow and inconsistent. Thus, there is a need for automation.
- 2025 BraTS-PED challenge enables pediatric-specific model development.
- The goal is to implement a robust, reproducible, uncertainty-aware pipeline for clinical use.

Methods

Experiment 1 Baseline

- Standard nnU-Net v2 pipeline with no modifications.

Experiment 2 Masking Brain Subregions

- Used SynthSeg to segment atlas-based brain subregions and masked low/no-tumor regions, focusing model training on relevant anatomy.

Experiment 3 Skull Stripping

- Applied SynthStrip to remove non-brain tissues, reducing irrelevant anatomical variation and testing its effect on segmentation performance.

Experiment 4 Synthetic Channels

- Expanded input to 15 channels by adding voxel-wise combinations (pairwise, triple, all-four) of MRI sequences to encourage earlier feature integration.

Experiment 5 Skull Stripping as Auxiliary Task

- Incorporated skull stripping as an auxiliary prediction task (multi-task learning) to guide feature learning and improve tumor segmentation.

Experiment 6 WT Segmentation

- Simplified model to predict WT as a single binary mask, creating a robust WT detector for downstream steps.

Experiment 7 Cropping + Ensemble

- Cropped inputs around WT region (with margin) and trained four single-channel models (ET, NET, CC, ED). Merged predictions using a sequential overwrite strategy to create final masks.

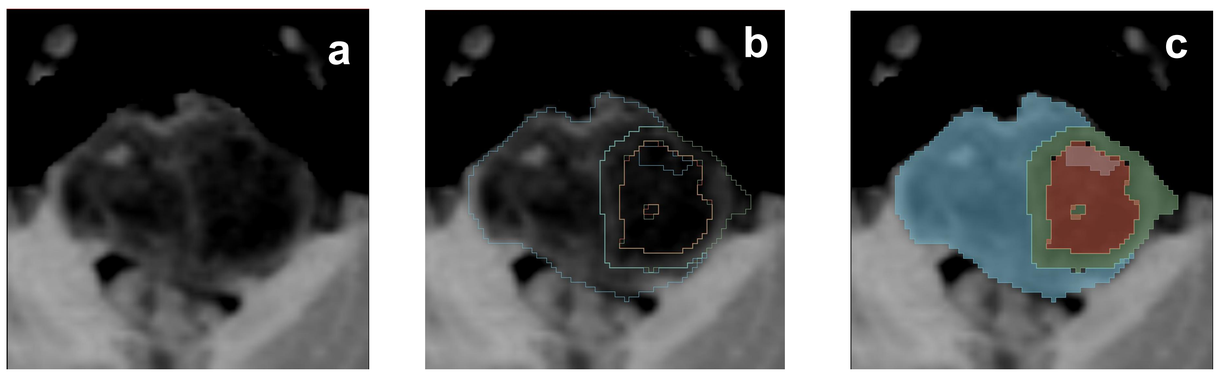

Fig. 6. Uncertainty-enabled brain tumor segmentation: a) cropped WT region, b) subregion contours, c) ensembled segmentation mask with uncertain regions

Conclusion

We deliver the first uncertainty-enabled baseline for pediatric brain tumor segmentation on BraTS-PEDs 2025. Skull stripping and atlas-based subregion masking yield consistent performance gains with minimal cost, while synthetic-channel augmentation shows little benefit. Our region-focused ensemble achieves the strongest ET and NET results and provides voxel-wise uncertainty maps to support clinical review.

Abbreviations

CC – Cystic Component
CV – Cross-validation
CNS – Central Nervous System
EDA – Exploratory Data Analysis
ED – Peritumoral edema
ET – Enhancing Tumor
MRI – Magnetic Resonance Imaging
NET – Non-Enhancing Tumor
T1N – pre-contrast native T1-weighted MRI Sequence
WT – Whole Tumor

Contributions

- EDA: First characterization of BraTS-PED 2025, revealing subregion imbalance and intensity variation.
- Baseline: Established nnU-Net benchmarks for pediatric tumor segmentation.
- Modules: Evaluated preprocessing and modeling steps (skull stripping, cascading, synthetic channels).
- Uncertainty: Introduced voxel-wise ensemble method for uncertainty identification.

Results

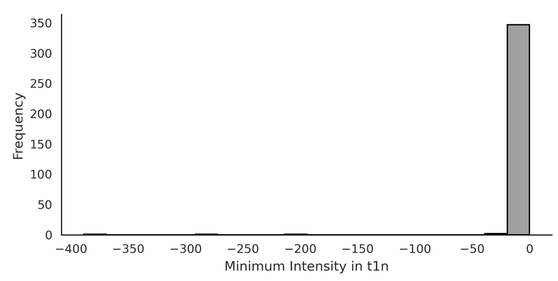

Fig. 1. Distribution of minimum intensity values in the T1N sequence across all cohorts.

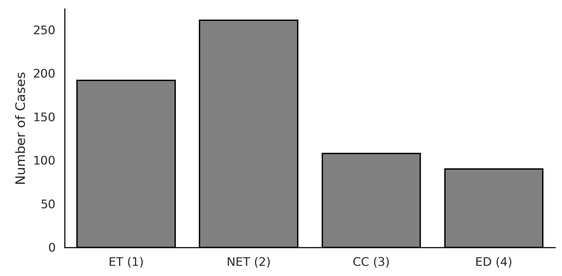

Fig. 2. Presence of tumor subregions in the BraTS-PEDs 2025 training set.

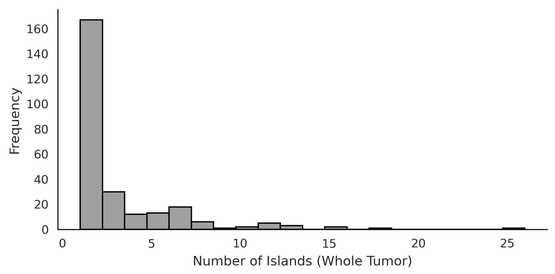

Fig. 3. Distribution of the number of disconnected islands in the WT masks.

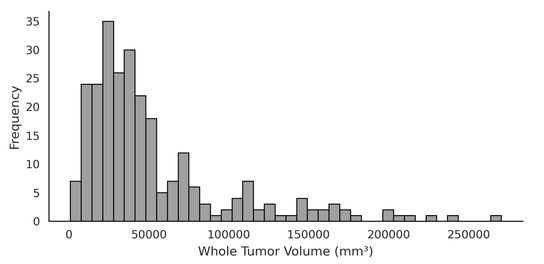

Fig. 4. Distribution of WT volumes in the BraTS-PEDs 2025 training set.

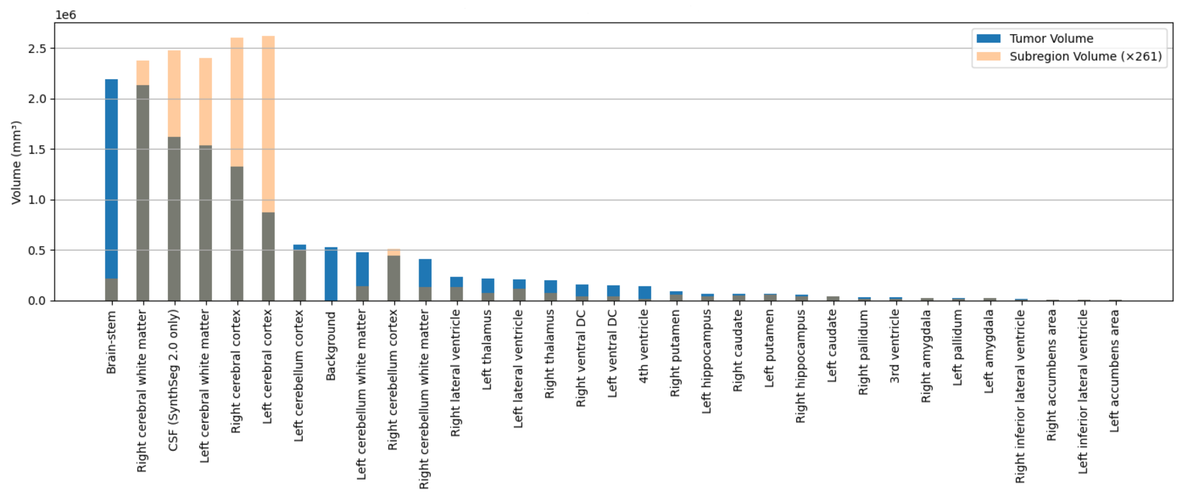

Fig. 5. Distribution of WT volumes in the BraTS-PEDs 2025 training set.

2025 BraTS-PED Training Set

Table 1. CV Dice scores for WT and subregion segmentation across all experiments.

Experiment	WT Dice	ET Dice	NET Dice	CC Dice	ED Dice	Running Time per-epoch (s)
Experiment 1	*	0.7012	0.9083	0.4956	0.4639	66
Experiment 2	*	0.7083	0.9144	0.5683	0.5017	57
Experiment 3	*	0.7426	0.9182	**0.5792**	**0.5131**	51
Experiment 4	*	0.7176	0.8950	0.4941	0.4254	151
Experiment 5	*	0.7007	0.9199	0.4922	0.4834	67
Experiment 6	**0.9609**	NA	NA	NA	NA	**48**
Experiment 7	*	**0.7763**	**0.9603**	0.4571	0.4316	180

2025 BraTS-PED Validation Set

Table 2. Validation Dice scores for WT and subregion segmentation across all experiments.

Experiment	WT Dice	ET Dice	NET Dice	CC Dice	ED Dice
Experiment 1	0.9370	0.6081	**0.9068**	0.6846	0.9011
Experiment 2	0.8895	0.6104	0.8679	0.6969	0.8352
Experiment 3	0.9238	0.6582	0.8926	0.7029	0.9341
Experiment 4	0.9239	**0.6968**	0.8957	**0.7133**	0.9560
Experiment 5	**0.9357**	0.6328	0.9060	0.7109	0.8901
Experiment 6	0.9305	NA	NA	NA	NA
Experiment 7	0.9252	0.6644	0.8711	0.5845	**0.9670**