Automated Multi-Parametric MRI Segmentation of Post-Treatment Glioma Sub-regions

using Classical Machine Learning and Active Contours

Project Report Week 1

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1. Objective of Week 1

The objective of Week 1 was to thoroughly understand the clinical problem statement, analyze the BraTS 2024 dataset structure, study multi-parametric MRI modalities, and configure the development environment for implementing a classical machine learning based segmentation pipeline.

This phase focused on building conceptual clarity before algorithmic development.

2. Problem Understanding

The project aims to segment post-treatment glioma sub-regions from multi-parametric 3D MRI volumes using classical machine learning techniques combined with contour-based refinement.

Unlike deep learning approaches used in BraTS 2024, this project emphasizes:

- Interpretability of features
- Handcrafted voxel-wise descriptors
- Statistical classification models
- Active contour boundary refinement

Target Segmentation Regions:

- Enhancing Tumor (ET)
- Necrotic Tumor Core (NETC)
- Non-Enhancing Tumor / Edema (SNFH)
- Resection Cavity

The task is formulated as voxel-wise multi-class classification on volumetric data.

3. Study of MRI Modalities

Each MRI modality provides complementary diagnostic information:

- **T1-weighted (T1):** Structural anatomy
- **T1 with contrast (T1Gd):** Enhancing tumor regions
- **T2-weighted (T2):** Fluid and edema

- **FLAIR:** Highlights infiltrative tumor regions

Fusion of these modalities improves tissue discrimination.

4. Dataset Exploration

The dataset consists of 3D NIfTI volumes (.nii.gz). Each subject contains four modalities and one segmentation mask.

Volume Properties:

- Typical size: $182 \times 218 \times 182$
- Near-isotropic resolution
- Multi-class integer segmentation labels
- Significant inter-patient intensity variation

Segmentation Label Encoding

Label Value	Tumor Region
0	Background
1	Necrotic / Non-enhancing core
2	Edema
3	Enhancing Tumor

Table 1: BraTS segmentation label structure

5. Dataset Visualization

An example axial FLAIR slice with segmentation overlay is shown below.

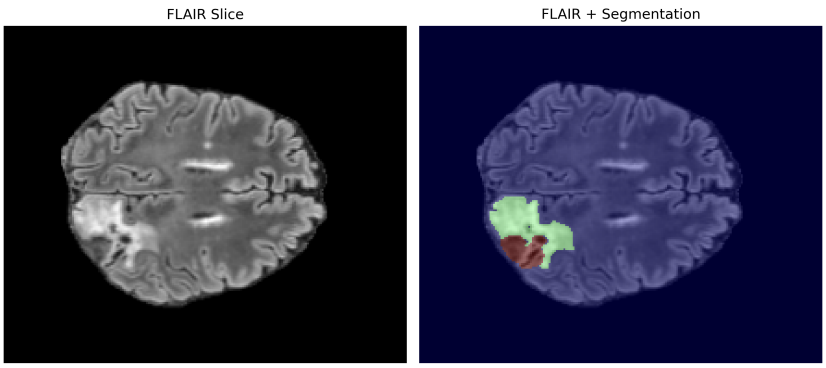

Figure 1: FLAIR slice with tumor segmentation overlay

This confirms correct loading of volumetric data and mask alignment.

6. Statistical Characteristics

Preliminary analysis reveals:

- Severe class imbalance (background dominates)
- Tumor occupies a small fraction of voxels
- Modality-specific intensity distributions

These observations motivate:

- Intensity normalization (z-score)
- Feature scaling
- Class-balanced sampling strategies

7. Environment Setup

The following libraries were installed and verified:

- Python 3.x
- NumPy
- Matplotlib
- Scikit-Image
- Scikit-Learn
- OpenCV
- SimpleITK
- ITK-SNAP (visual validation)

All volumes were successfully loaded and visualized.

8. Initial Technical Insights

- Raw voxel intensities are insufficient for accurate segmentation
- Texture-based features may improve discrimination
- Spatial neighborhood context is important
- Active contour refinement can improve boundary smoothness

9. Planned Evaluation Metrics

Segmentation performance will be evaluated using:

Dice Similarity Coefficient (DSC):

$$Dice = \frac{2|A \cap B|}{|A| + |B|}$$

- Hausdorff Distance
- Sensitivity
- Specificity

These metrics are standard in the BraTS challenge.

10. Plan for Week 2

- Intensity normalization
- Voxel-wise dataset preparation
- Feature extraction:
  - Intensity features
  - GLCM texture features
  - Gradient magnitude
- Baseline classifier implementation (Logistic Regression / Random Forest)
- Preliminary evaluation using Dice score

11. Conclusion

Week 1 established a solid theoretical and practical foundation. The dataset structure, imaging modalities, and segmentation labels were analyzed in depth. The development environment was configured and validated.
The project is now prepared to proceed toward preprocessing, feature engineering, and classical machine learning model implementation in Week 2.

References

Correia de Verdier, M., et al. (2024). *The 2024 Brain Tumor Segmentation (BraTS) challenge: Glioma segmentation on post-treatment MRI.* arXiv. https://doi.org/10.48550/arXiv.2405.18368
BraTS Consortium (2024). *BraTS 2024 Challenge Dataset.* Synapse. https://www.synapse.org/Synapse:syn53708249