

Medical Image Processing With Federated Learning

Brain Tumor Segmentation on mpMRIs

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Introduction

Brain Tumors

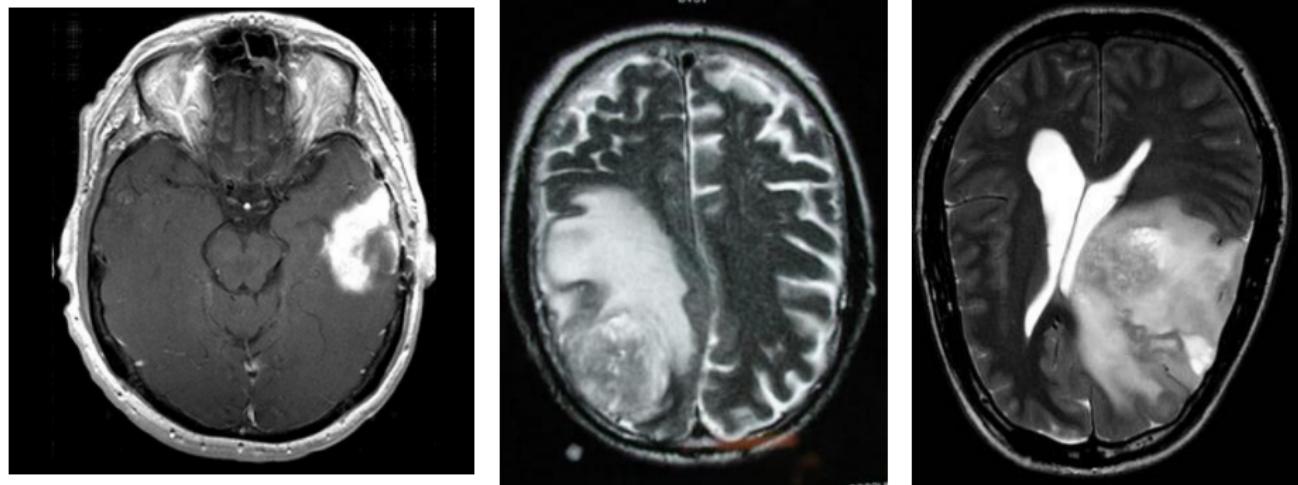


Figure: Brain Tumors

Brain tumors are abnormal cell growths that pressure brain tissue, causing headaches, seizures, and neurological issues.

MRI vs mpMRI

MRI (Magnetic Resonance Imaging) is a non-invasive imaging technique that uses magnetic fields and radio waves to create detailed images of soft tissues, commonly used for diagnosing conditions in the brain, spine, and other organs.

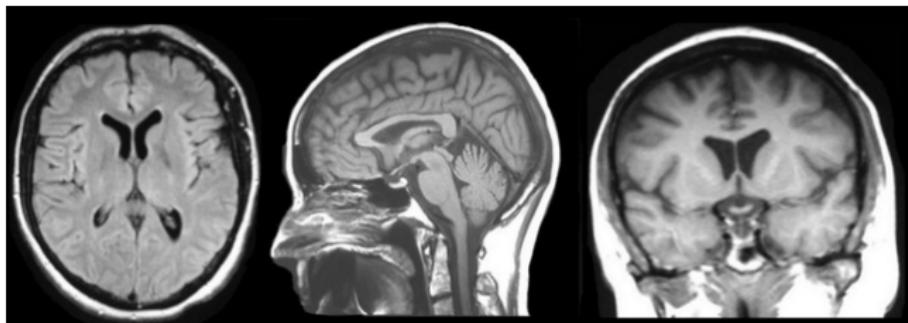


Figure: Magnetic Resonance Imaging

mpMRI (multiparametric MRI) is an advanced imaging technique that combines multiple MRI sequences, such as T1, T2, and diffusion-weighted imaging, to provide a more detailed assessment of tissues, particularly useful in cancer detection and diagnosis.

T1, T1CE, T2, FLAIR

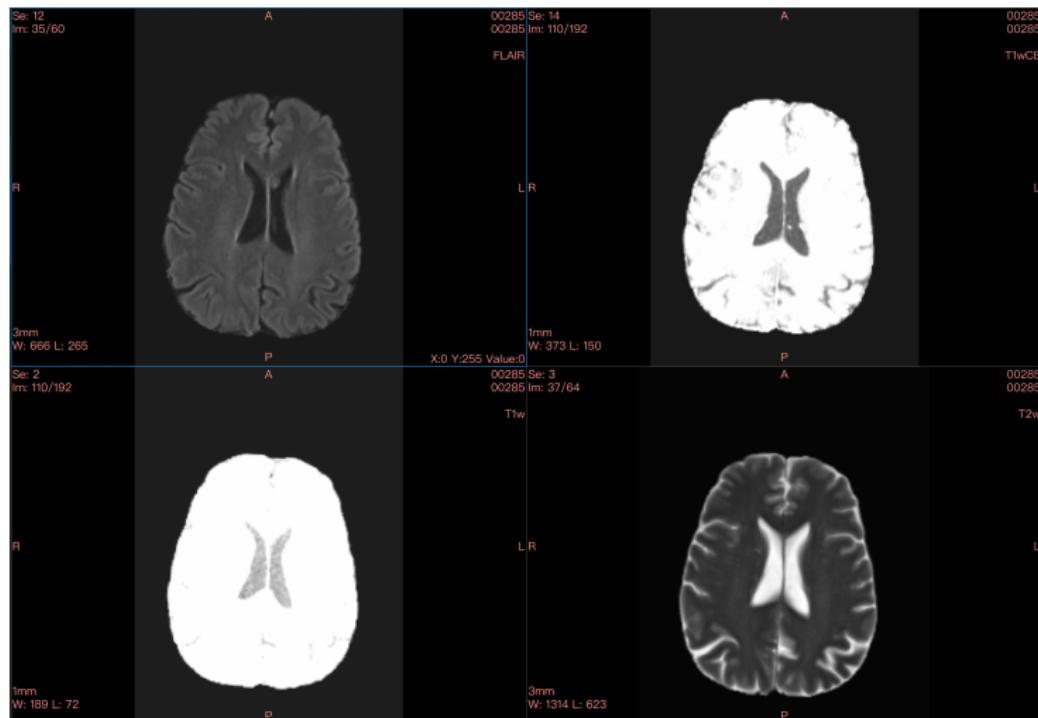


Figure: T1, T1CE, T2, FLAIR

BraTS2017 and BraTS2021

- These two datasets are from brain imaging challenges focused on deep learning applications, and they are meticulously labeled.
- BraTS2021 contains 1,251 images, while BraTS2017 contains 484 images.
 - BraTS2017 set the standard for segmenting brain tumor sub-regions.
 - BraTS2021 introduced an additional task to predict the MGMT promoter methylation status, linking imaging with genetic information.
- In this demonstration, we use BraTS2021 for training and BraTS2017 for testing.

EDA + Preprocessing

Normalize format of different datasets

```
data/BraTS2021d
├── BraTS2021_00002
│   ├── BraTS2021_00002_flair.nii.gz
|   └── BraTS2021_00002_seg.nii.gz
|   ├── BraTS2021_00002_t1.nii.gz
|   ├── BraTS2021_00002_t1ce.nii.gz
|   └── BraTS2021_00002_t2.nii.gz
└── BraTS2021_00005
    ├── BraTS2021_00005_flair.nii.gz
    |── BraTS2021_00005_seg.nii.gz
    ├── BraTS2021_00005_t1.nii.gz
    ├── BraTS2021_00005_t1ce.nii.gz
    └── BraTS2021_00005_t2.nii.gz
```

Figure: BraTS2021 directory

Each image has the shape of
 $(240, 240, 155)$

```
data/BraTS2017d
├── dataset.json
└── imagesTr
    ├── BRATS_001.nii.gz
    └── BRATS_002.nii.gz
└── labelsTr
    ├── BRATS_001.nii.gz
    └── BRATS_002.nii.gz
```

Figure: BraTS2017 directory

Each image has the shape of
 $(240, 240, 155, 4)$

Preprocess MRI Slices

Z-score Normalization

- **Objective:** Normalize image data to have a mean of 0 and a standard deviation of 1.
- **Formula:**

$$z = \frac{x - \mu}{\sigma}$$

where:

- x : The pixel value
- μ : The mean pixel intensity of the entire image
- σ : The standard deviation of the pixel intensities

Preprocess Labels

Objective: Simplify the label set by merging all tumor-related labels into a single "tumor" label.

- **Original Labels:**

- 0: Background
- 1: Edema
- 2: Non-enhancing tumor
- 3 (BraTS2017) or 4 (BraTS2021): Enhancing tumor

- **Simplified Labels:**

- 0: Background
- 1: Tumor (all tumor-related labels combined)

Plot some samples

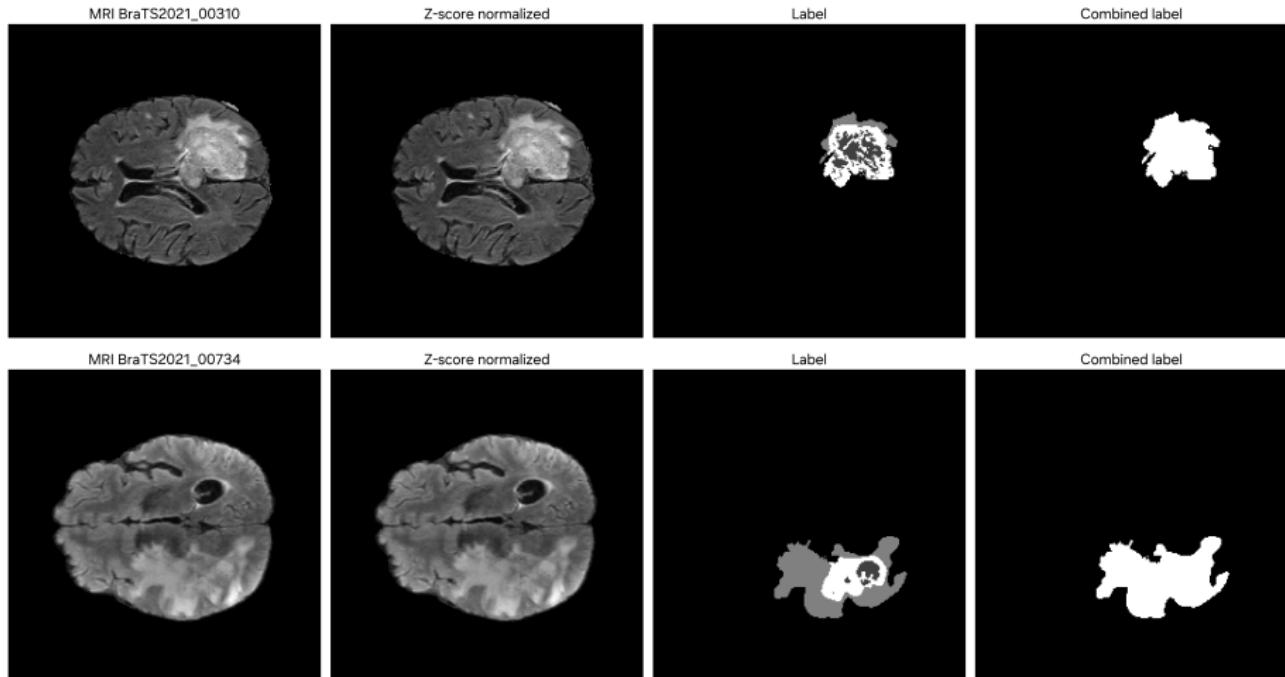


Figure: Some samples with respective labels

Augment Data

Goal: Expand the dataset by generating new variations of existing images.

Techniques:

- **Horizontal and Vertical Flip**

- **Horizontal Flip:** Flips the image along the horizontal axis.
- **Vertical Flip:** Flips the image along the vertical axis.

- **Rotation**

- **90° Rotation**
- **180° Rotation**
- **270° Rotation**

Training

UNet

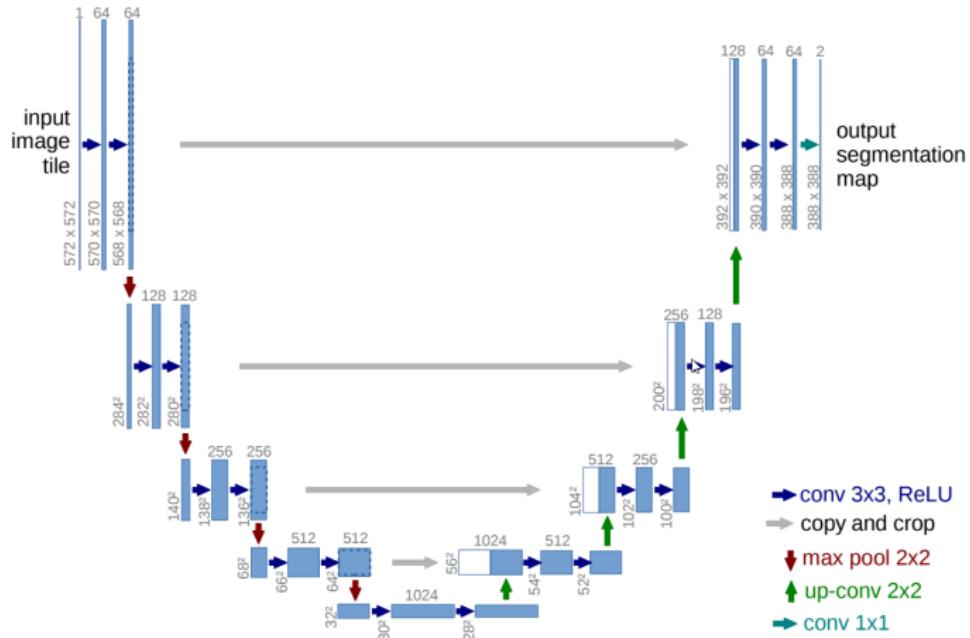


Figure: UNet Architecture

Centralized Train – Val – Test splits

Table: Train, Validation, and Test Splits with Dataset Sources

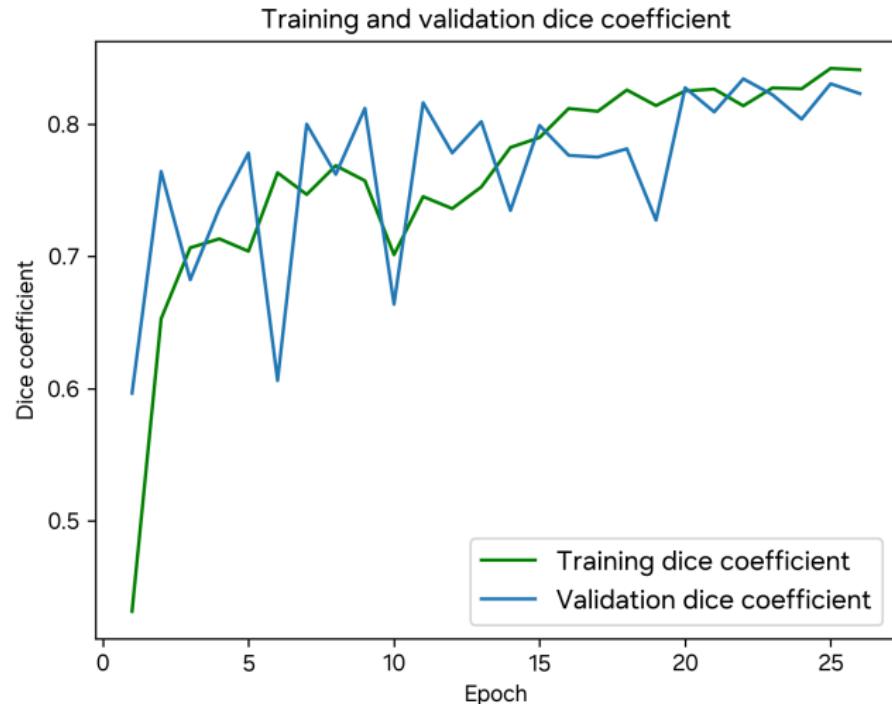
Split	%	#Images	Dataset
Train	90%	1126	BraTS2021
Validation	10%	125	BraTS2021
Test	100%	484	BraTS2017

Centralized Hyperparameters/Training configuration

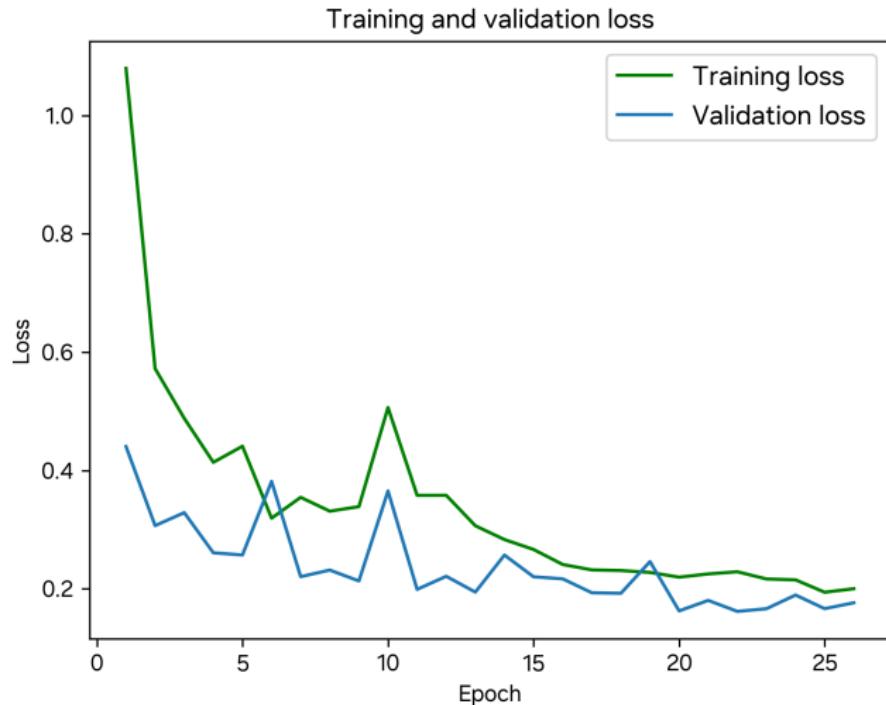
Techniques:

- Early stopping
- Reduce learning rate on plateau
- Dropout

Centralized Training process



Centralized Training process (cont'd)



Federated Train – Val – Test splits

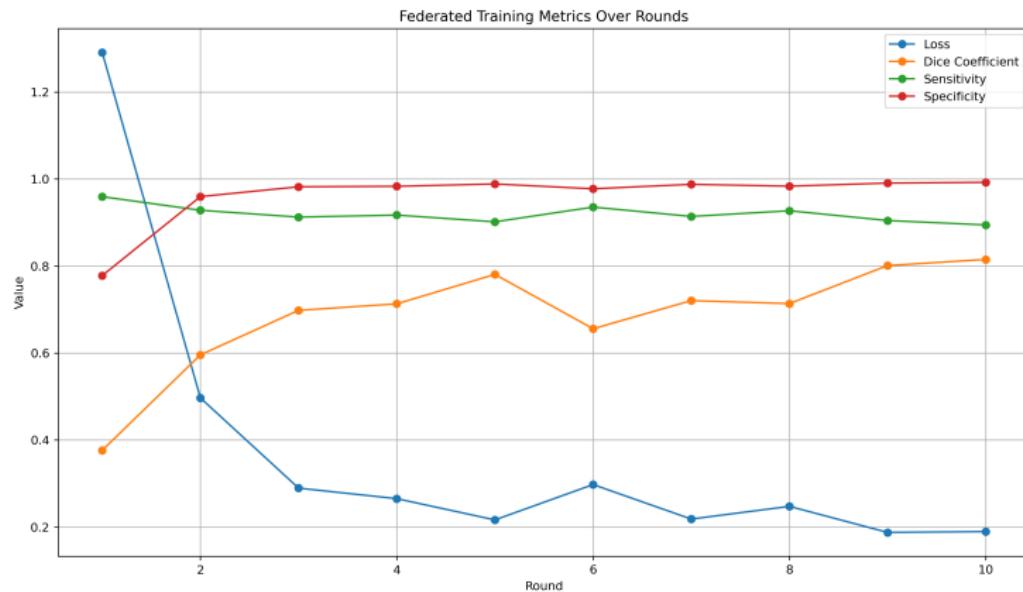
- The BraTS2021 dataset is divided into 3 non-overlapping parts.
- Each part represents a distinct data partition.
- Each client is only allowed to access and train on its own partition. No data sharing is allowed between clients.

Federated Hyperparameters/Training configuration

General Configuration:

- Number of clients: 3
- Strategy: FedAvg
- Training & evaluation distribution: All clients (`fraction_fit = 1.0`, `fraction_evaluate = 1.0`)
- Result aggregation: Weighted average of metrics Dice, Sensitivity, Specificity, etc.
- Training: The model is updated over 10 consecutive global rounds.

Federated Training process



Evaluation

Evaluation Metrics

- **Dice Coefficient (DC):**

$$DC = \frac{2 \times |\text{Predicted} \cap \text{Ground Truth}|}{|\text{Predicted}| + |\text{Ground Truth}|}$$

Measures the overlap between the predicted segmentation and the ground truth. Higher values indicate better overlap.

- **Sensitivity (Recall):**

$$\text{Sensitivity} = \frac{\text{True Positives}}{\text{True Positives} + \text{False Negatives}}$$

Indicates the model's ability to correctly identify **positive** cases (e.g., tumor regions).

- **Specificity:**

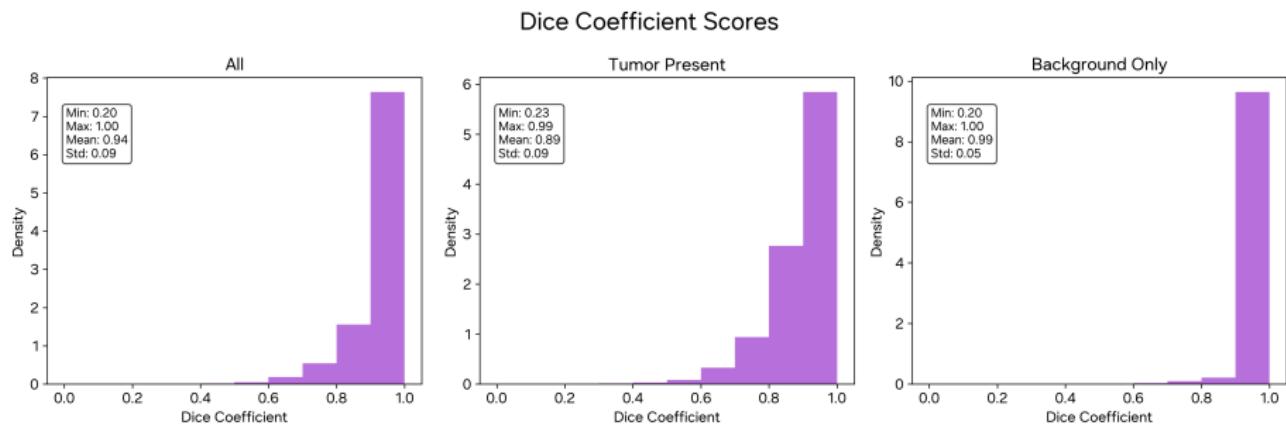
$$\text{Specificity} = \frac{\text{True Negatives}}{\text{True Negatives} + \text{False Positives}}$$

Reflects the model's accuracy in identifying **negative** cases (e.g., non-tumor regions).

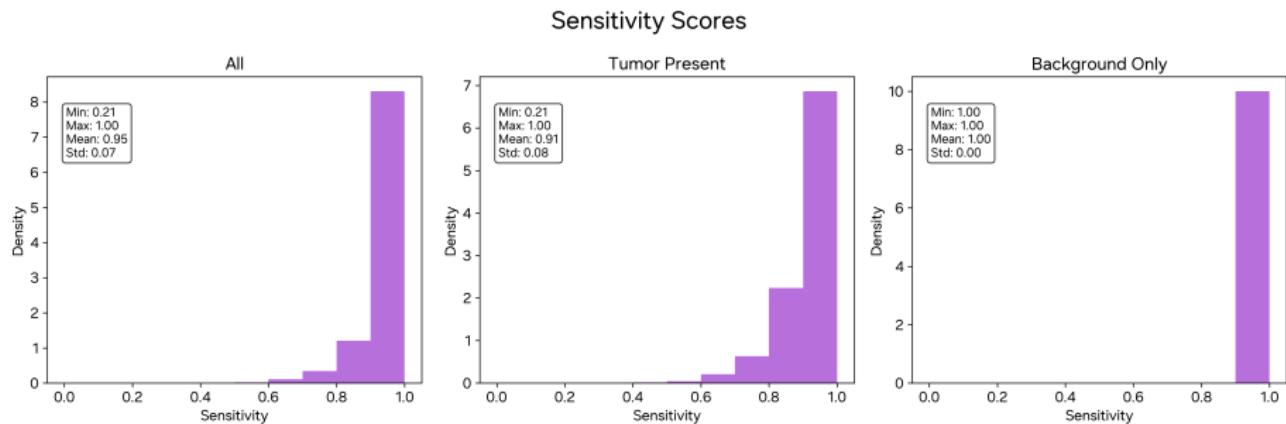
Centralized Performance on several metrics

Split	Dataset	Dice Coef ↑	Sensitivity ↑	Specificity ↑
Train	BraTS2021	0.8140	0.8959	0.9949
Validation	BraTS2021	0.8344	0.8927	0.9937
Test	BraTS2017	0.8005	0.8445	0.9936

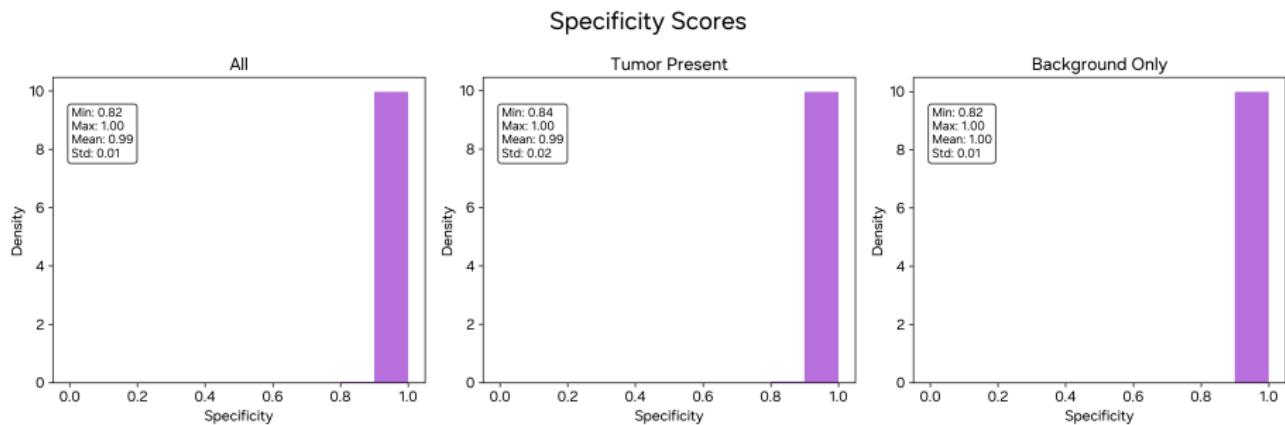
...And Centralized corresponding histograms (1/3)



...And Centralized corresponding histograms (2/3)



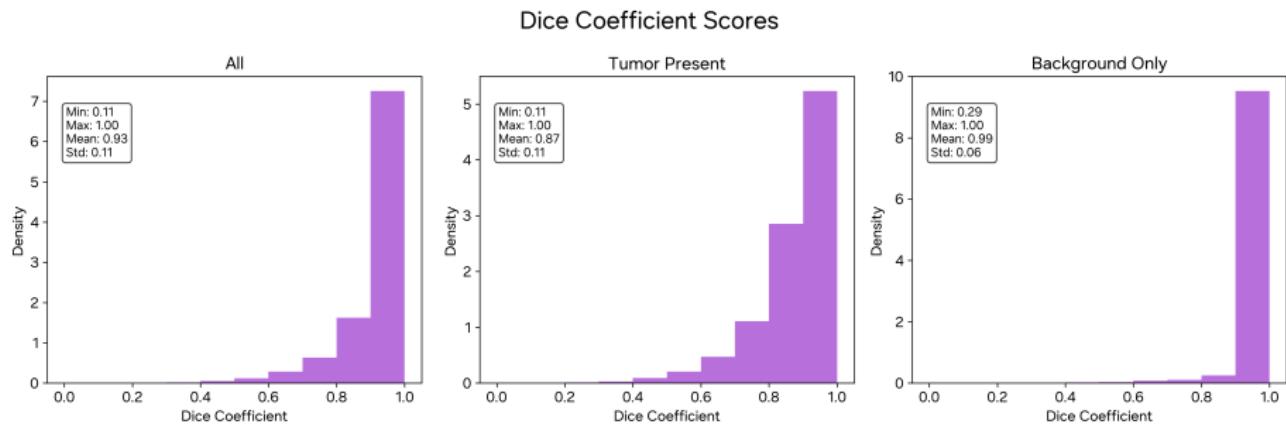
...And Centralized corresponding histograms (3/3)



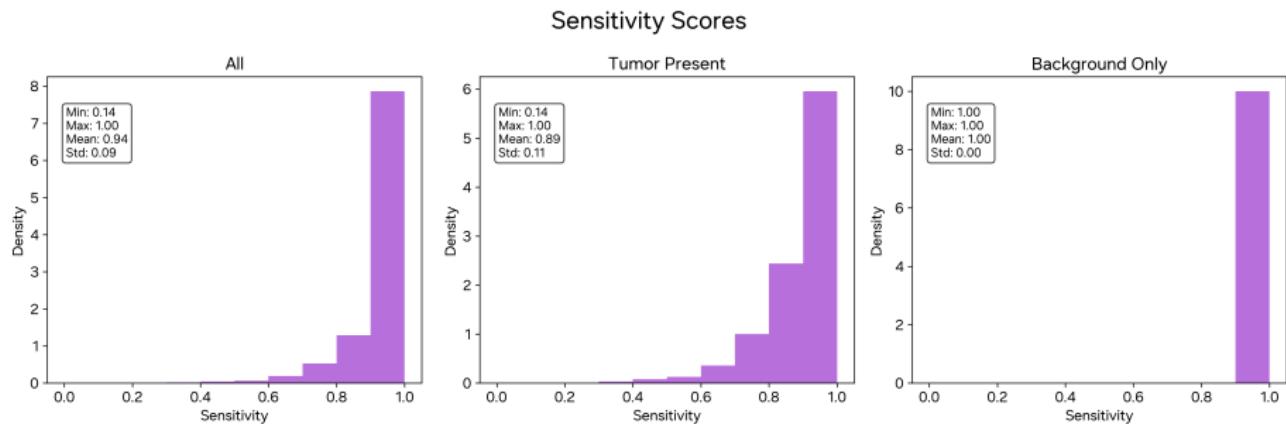
Federated Performance on several metrics

Split	Dataset	Dice Coef ↑	Sensitivity ↑	Specificity ↑
Validation	BraTS2021	0.8152	0.8945	0.9924
Test	BraTS2017	0.7938	0.8206	0.9931

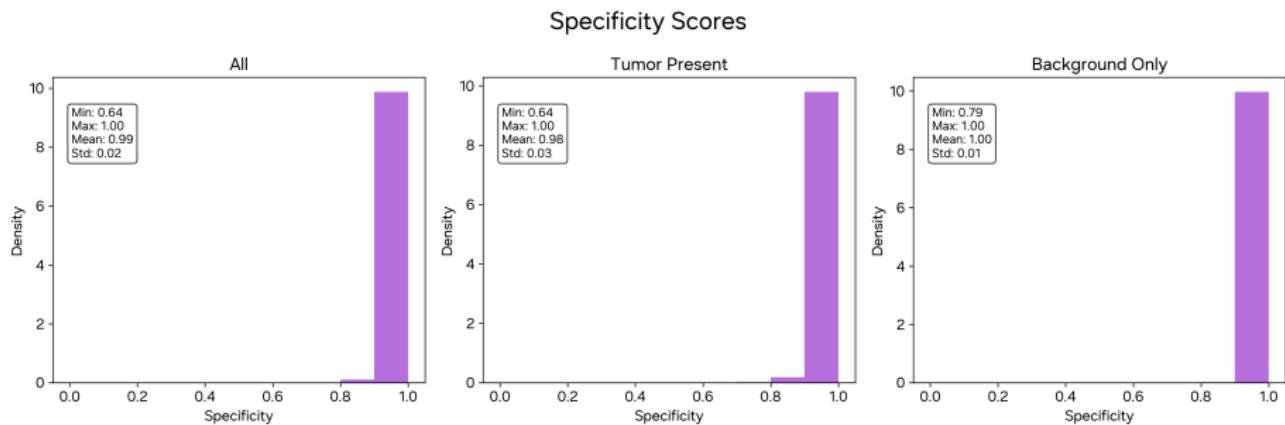
...And Federated corresponding histograms (1/3)



...And Federated corresponding histograms (2/3)



...And Federated corresponding histograms (3/3)



Compare Federated with Centralized

Experiment	Dataset	Dice Coef ↑	Sensitivity ↑	Specificity ↑
Federated	Validation	0.8152	0.8945	0.9924
	Test	0.7938	0.8206	0.9931
Centralized	Validation	0.8344	0.8927	0.9937
	Test	0.8005	0.8445	0.9936

Visualization

A closer look to some **good** samples

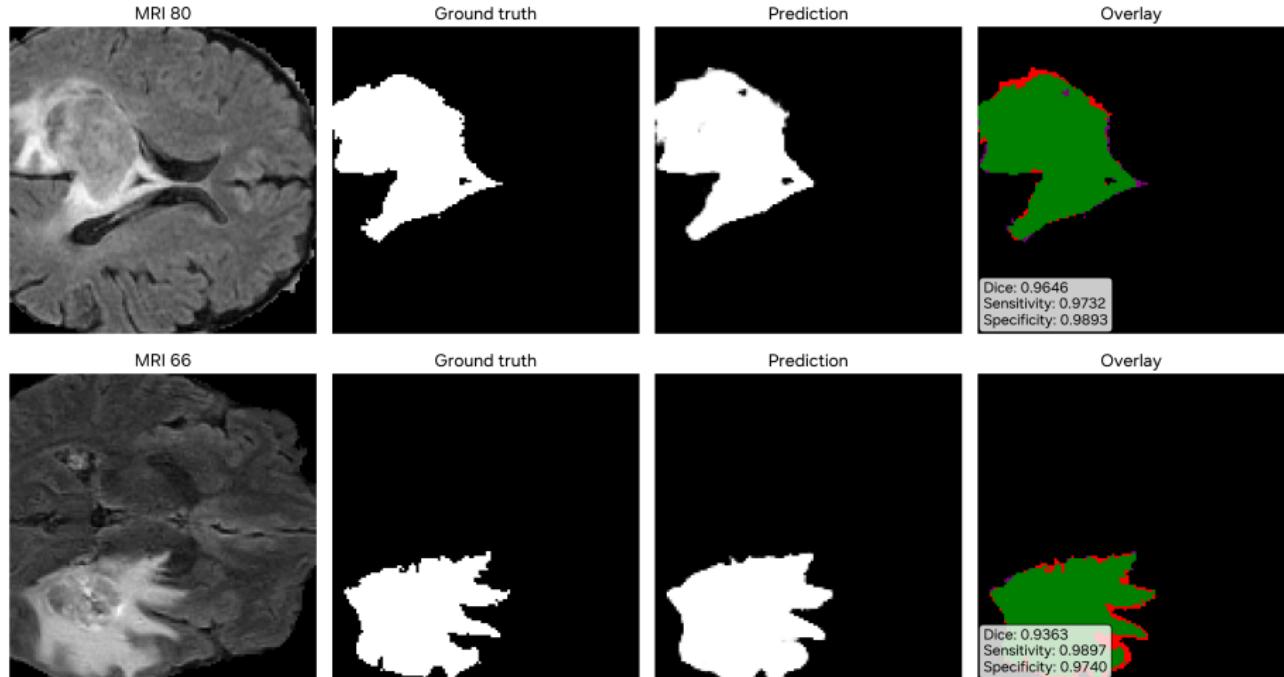


Figure: Some samples

A closer look to some **bad** samples

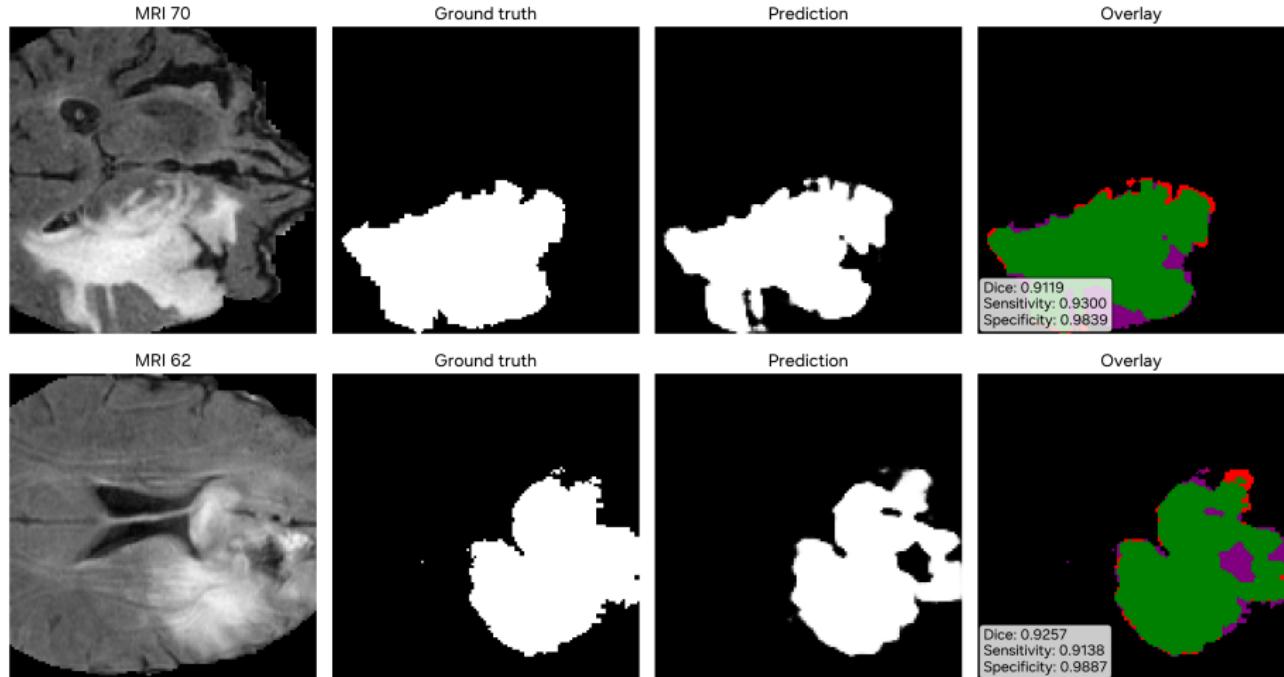


Figure: Some samples

Thank you for your attention!