Brain Tumor Classification Using CNNs and Grad-CAM

AIGC 5502 – Image Processing Midterm Report

July 1, 2025

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Abstract

This project developed an accurate (94%) and interpretable CNN model for brain tumor classification using a publicly available dataset of MRI scans as our images to create training and test sets.

1. Introduction

Brain tumor classification from MRI scans is a critical task in medical imaging, aiding clinicians in accurate diagnosis and treatment planning. This project presents a deep learning workflow using Convolutional Neural Networks (CNNs) to classify brain tumors from MRI images into four categories: **glioma**, **meningioma**, **pituitary**, and **no tumor**. The pipeline includes data preprocessing, model development, evaluation, and interpretability via Grad-CAM (Gradient-weighted Class Activation Mapping).

Objectives:

- Develop an automated CNN model for accurate brain tumor classification.
- Enhance image interpretability using CLAHE (Contrast Limited Adaptive Histogram Equalization).
- Evaluate model performance with metrics such as accuracy, precision, recall, and F1-score.
- Incorporate Grad-CAM to visualize regions contributing to predictions, ensuring clinical explainability.

2. Dataset Description

Data Source:

The dataset consists of MRI scans from Kaggle, organized into:

- **Training Set**: Contains labeled images (5,712 samples) across four categories.
- **Testing Set**: Contains 1,311 images for validation.

Classes:

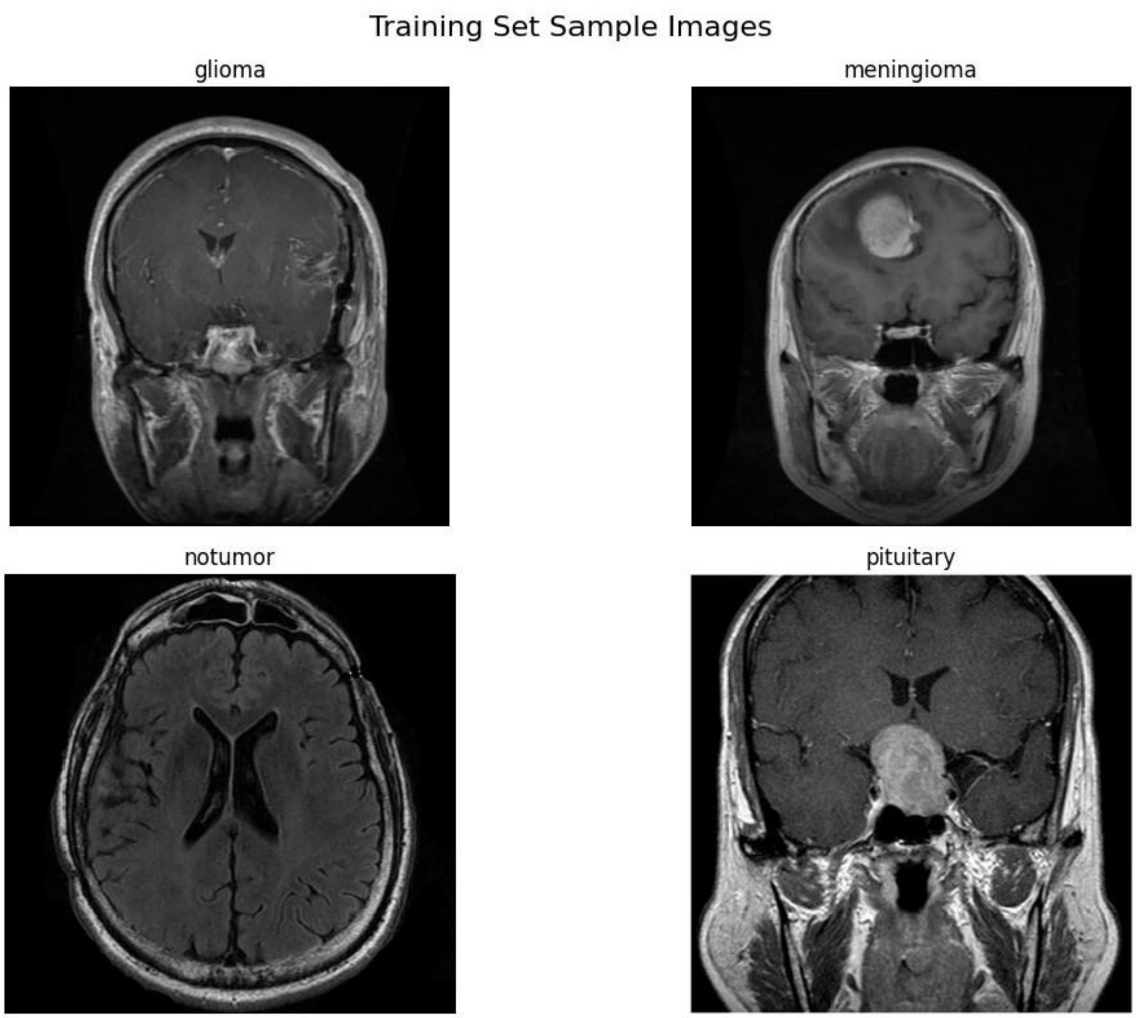
- **Glioma**: Tumors arising from glial cells.
- **Meningioma**: Tumors originating in the meninges.
- **Pituitary**: Tumors in the pituitary gland.
- **No Tumor**: Normal brain scans.

Sample Visualization:

Training Set Samples
Figure: Example MRI scans from each class.

Data Distribution:

Class	Training Samples	Testing Samples
Glioma	1,321	300
Meningioma	1,339	306
No Tumor	1,595	405
Pituitary	1,457	300



3. Model Architecture

CNN Structure:

The CNN consists of the following layers:

1. **Convolutional Blocks:**
   - Three blocks of **Conv2D + MaxPooling + Dropout** for feature extraction.
   - Filters: 32 → 64 → 128.
   - ReLU activation.
2. **Dense Layers:**
   - **Flatten** layer to transition from spatial to dense features.
   - Fully connected layers (128 neurons) with Dropout (0.5) for regularization.
   - **Softmax** output for 4-class classification.

Loss Function: `sparse_categorical_crossentropy`
Optimizer: `Adam`
Metrics: `Accuracy`

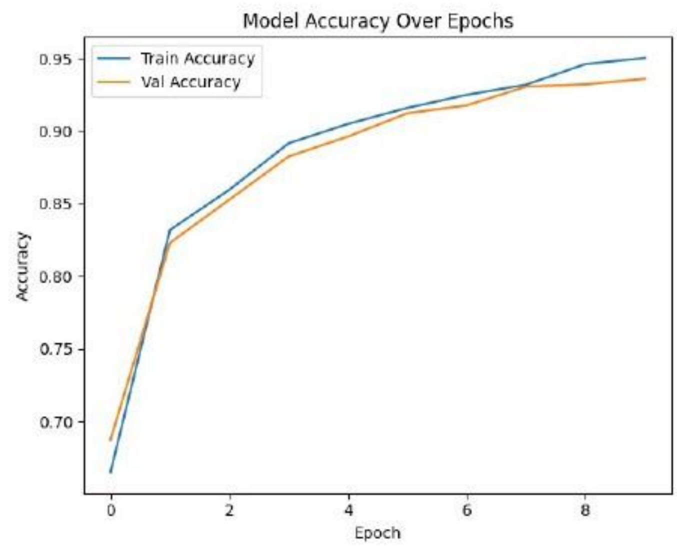
4. Methodology

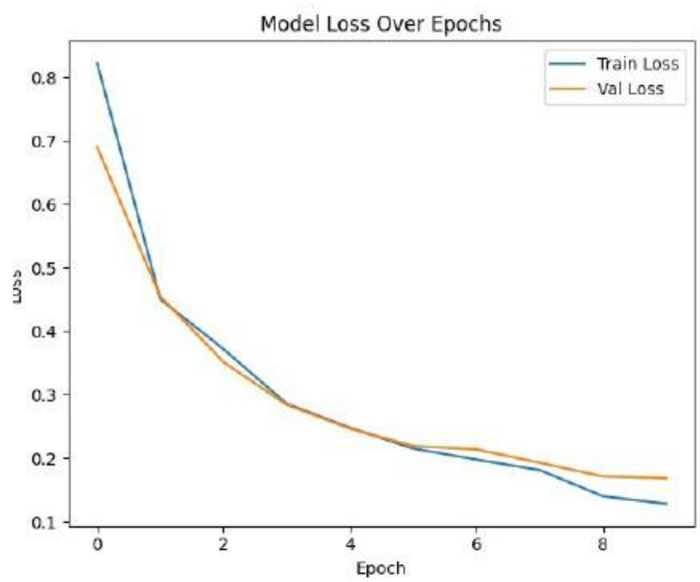
Preprocessing Steps:

1. **Grayscale Conversion:** RGB → Single-channel for efficiency.
2. **Resizing:** All images standardized to **150×150 pixels**.
3. **CLAHE Enhancement:** Adaptive contrast improvement.
4. **Normalization:** Pixel values scaled to **[0, 1]**.

Model Training:

- **Epochs:** 10
- **Batch Size:** 32
- **Validation Split:** 20% held-out for validation.





5. Results

Training Performance:

Epoch	Training Accuracy	Validation Accuracy	Training Loss	Validation Loss
1	54.12%	68.73%	1.0588	0.6899
10	95.78%	93.59%	0.1186	0.1685

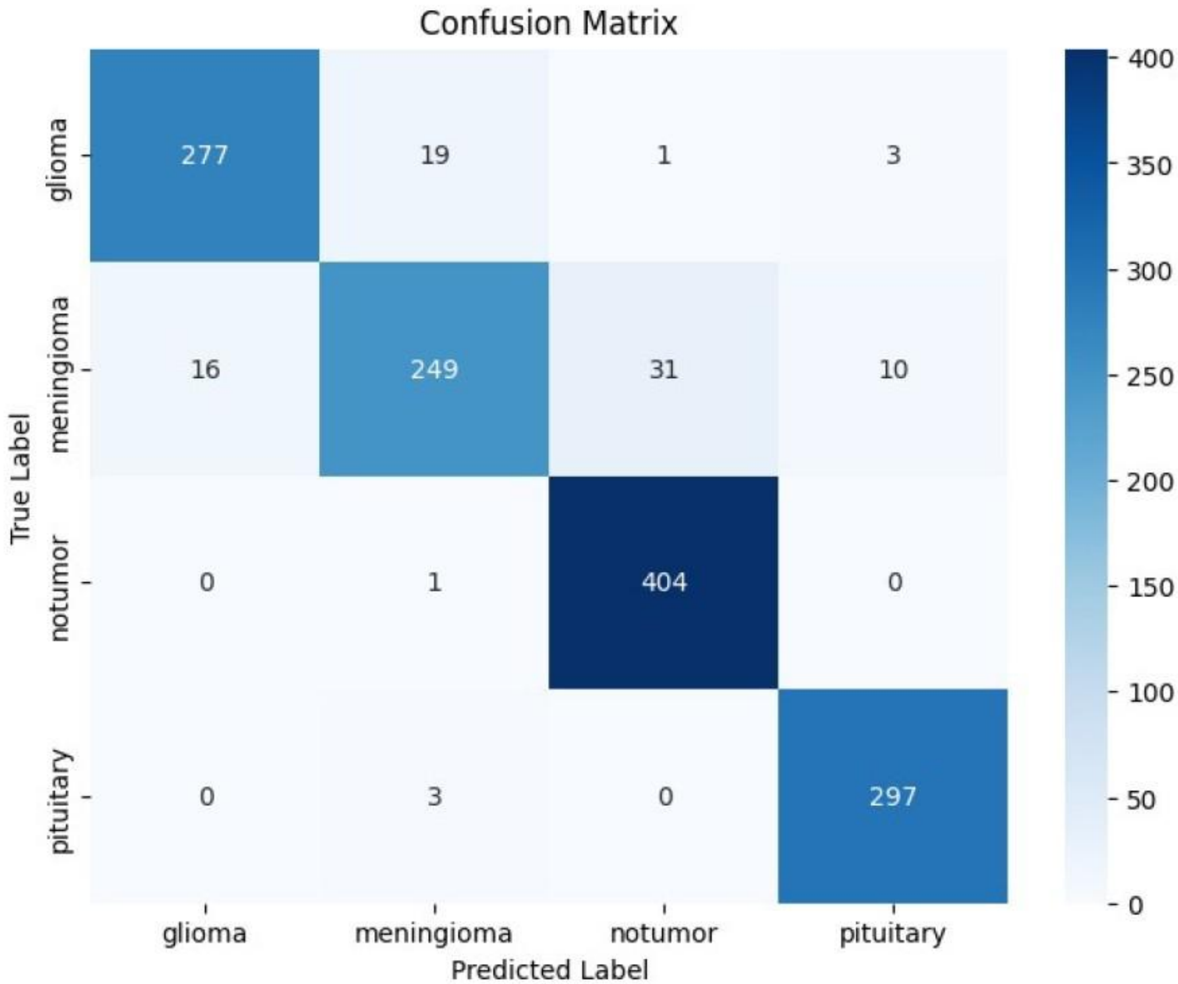
Final Test Metrics:

- **Overall Accuracy: 94%**
- **Precision (Macro Avg): 0.94**
- **Recall (Macro Avg): 0.93**
- **F1-Score (Macro Avg): 0.93**

Class-Specific Performance:

Class	Precision	Recall	F1-Score	Support
Glioma	0.95	0.92	0.93	300
Meningioma	0.92	0.81	0.86	306
No Tumor	0.93	1.00	0.96	405
Pituitary	0.96	0.99	0.97	300

Confusion Matrix:



Confusion Matrix

- **Key Observation:** Meningioma had lower recall (81%), with some confusion with glioma and no-tumor classes.

6. Visualizations

Accuracy & Loss Curves:

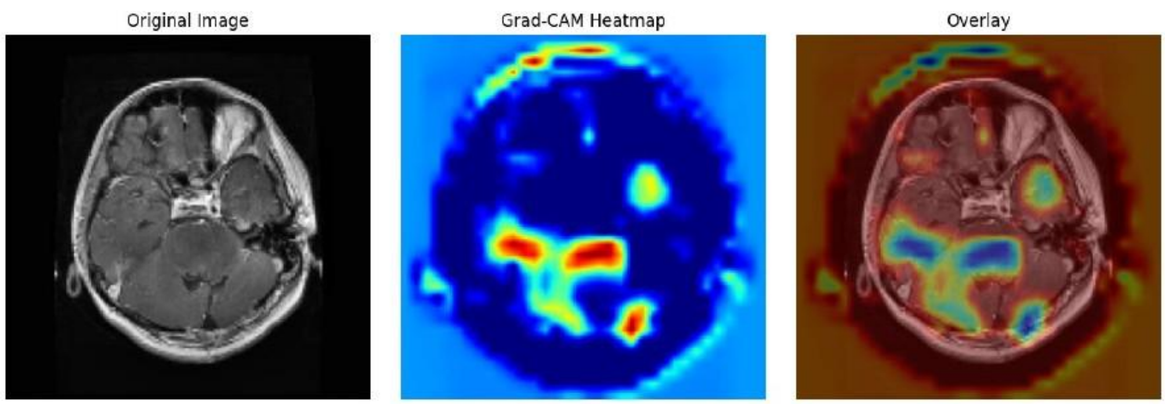
Training Curves

- **No Overfitting:** Validation accuracy closely follows training accuracy.

Grad-CAM Interpretability:

Grad-CAM Output

- **The model accurately identifies tumor-localized regions.**
- **Highlights model transparency in clinical decision-making.**



7. Interpretation and Discussion

Key Findings:

- The CNN achieved **94% accuracy**, demonstrating strong generalization.
- **Grad-CAM** confirmed that the model focuses on **medically relevant regions** for classification.
- **Meningioma misclassifications** suggest potential areas for improvement.

Challenges & Solutions:

Challenge	Solution
Low contrast in MRI scans	CLAHE enhancement improved feature visibility.
Class imbalance	Future work could incorporate weighted loss or augmentation.
Model explainability	Grad-CAM helps build clinician trust.

8. Conclusion

This project developed an **accurate (94%) and interpretable** CNN model for brain tumor classification. Key contributions include:

- **Preprocessing with CLAHE** for improved image quality.
- **Robust CNN architecture** with regularization to prevent overfitting.
- **Grad-CAM explanations** for clinical interpretability.

Future Work:

- **Data Augmentation** for better meningioma recall.
- **Transfer Learning** with ResNet/VGG for higher accuracy.
- **Larger, multi-center datasets** for improved generalizability.

9. References

1. Selvaraju, R. R., et al. "Grad-CAM: Visual Explanations from Deep Networks." *ICCV 2017*.
2. CLAHE: https://docs.opencv.org/3.4/d5/daf/tutorial_py_histogram_equalization.html
3. Dataset Source: Kaggle Brain Tumor MRI Dataset. https://www.kaggle.com/datasets/masoudnickparvar/brain-tumor-mri-dataset\

10. Group Member Contributions

Group #1

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Eric Efon
Daniel Mehta
Thomas Nash
Jeffrey Ng

All team members provided equal contributions to the technical coding, report and presentation components of the project.