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Brain Tumor Segmentation Using U-Net3+

Ch. Meghana

Department of Computer Science and Engineering-Emerging Technologies

Abstract: The measurement of tumour extent is a difficult task in brain tumour treatment planning and quantitative evaluation. Non-invasive magnetic resonance imaging (MRI) has evolved as a first-line diagnostic method for brain malignancies that does not require ionising radiation. The manual segmentation of brain tumour extent from 3D MRI volumes is a time-consuming job that heavily relies on the operator's knowledge. In this context, a dependable fully automatic segmentation approach for brain tumour segmentation is required for accurate tumour extent determination. In this work we offer a fully automatic method for brain tumour segmentation, which is based on U-Net-based deep convolutional neural networks. Our technique was tested using the Multimodal Brain Tumor Image Segmentation (BRATS 2018) datasets, which included 220 cases of high-grade brain tumour and 54 cases of low-grade tumour. Cross-validation has demonstrated that our method efficiently obtains promising segmentation.

Keywords: Brain tumor segmentation, deep neural networks, U-net, fully convolutional network, BraTS'2018 challenge.

I. INTRODUCTION

A. Introduction to Primary malignant brain tumors

Primary malignant brain tumors are highly devastating forms of cancer, not only due to their grim prognosis but also because of the detrimental impact they have on cognitive function and overall quality of life. The most common types of primary brain tumors in adults are primary central nervous system lymphomas and gliomas, with gliomas accounting for nearly 80% of malignant cases. The term "glioma" encompasses various subtypes of primary brain tumors, ranging from slower growing "low-grade" tumors to highly infiltrative malignant tumors with significant heterogeneity. Despite notable advancements in imaging techniques, radiotherapy, chemotherapy, and surgical procedures, certain types of malignant brain tumors, such as high-grade glioblastoma and metastases, are still considered untreatable, with a cumulative relative survival rate of only 8% at 2.5 years and 2% at 10 years. Additionally, the prognosis for patients with low-grade gliomas (LGG) varies, with an overall 10-year survival rate of approximately 57%.

B. Types of Primary Brain Tumors

Primary brain tumors can be categorized into two main types:

- 1) Primary central nervous system lymphomas
- 2) Gliomas.

Gliomas are the predominant type among primary brain tumors. Gliomas display considerable diversity, encompassing slow-growing low-grade tumors as well as highly infiltrative malignant tumors. Prior research has shown that magnetic resonance imaging (MRI) characteristics of newly identified brain tumors can provide valuable insights into their likely diagnosis and guide treatment strategies. Consequently, multimodal MRI protocols are commonly employed to evaluate brain tumor cellularity, vascularity, and blood-brain barrier (BBB) integrity.

a) Prognosis and Survival Rates:

Despite recent advancements in semi-automatic and fully automatic algorithms for brain tumor segmentation, there are still several ongoing challenges in this field. These challenges primarily stem from the high variation of brain tumors in terms of size, shape, regularity, location, and their heterogeneous appearance, including factors such as contrast uptake, image uniformity, and texture. Addressing these challenges is crucial to develop robust and accurate segmentation methods for brain tumors. Other potential issues that may complicate the brain tumor segmentation include Low-Grade Gliomas (LGG) and High-Grade Gliomas (HGG) and Challenges in Tumor Sub-region Identification

b) Role of MRI in Brain Tumor Diagnosis

Typical clinical MRI images are often acquired with higher in-plane resolution but lower interslice resolution to strike a balance between covering the entire tumor volume with good cross-sectional views and limited scanning time.

However, this can lead to inadequate signal-to-noise ratio and asymmetrical partial volume effects, which can impact the accuracy of segmentation. Gaussian hidden Markov random field was found to outperform other clustering algorithms for glioblastoma segmentation, but even the best-performing algorithm in that study achieved only 77% accuracy.

c) Importance of Image Segmentation in Brain Tumor Studies

Image segmentation in brain tumor studies, particularly with MRI scans, is vital for precise diagnosis and treatment planning. It entails accurately outlining tumor boundaries against the healthy tissues, facilitating an exact classification. This classification is crucial for tailoring appropriate treatment strategies, as different tumor types and grades may require distinct approaches.

II. RELATED WORK

- 1) Schwartzbaum, J.A., Fisher, J.L., Aldape, K.D., Wrensch, M.: Epidemiology and molecular pathology of glioma. *Nat. Clin. Pract. Neurol.* 2, 494–503 (2006) proposed Gliomas account for almost 80% of primary malignant brain tumors, and they result in more years of life lost than do any other tumors. Glioblastoma, the most common type of glioma, is associated with very poor survival, so glioma epidemiology has focused on identifying factors that can be modified to prevent this disease. Only two relatively rare factors have so far been conclusively shown to affect glioma risk--exposure to high doses of ionizing radiation, and inherited mutations of highly penetrant genes associated with rare syndromes.
- 2) Smoll, N.R., Schaller, K., Gautschi, O.P.: Long-term survival of patients with glioblastoma multiforme (GBM). *J. Clin. Neurosci.* 20, 670–675 (2013) proposed Long-term survival is an often used, yet poorly defined, concept in the study of glioblastoma multiforme (GBM). This study suggests a method to define a time-point for long-term survival in patients with GBM. Data for this study were obtained from the Surveillance, Epidemiology and End-Results database, which was limited to the most recent data using the period approach. Relative survival measures were used and modelled using piecewise constant hazards to describe the survival profile of long-term survivors of GBM. For patients with GBM, the first quarter of the second year (5th quarter) post-diagnosis is considered to be the peak incidence of mortality with an excess hazard ratio of 7.58 (95% confidence interval = 6.54, 8.78) and the risk of death due to GBM decreases to half of its rate at 2.5 years post-diagnosis.
- 3) Yamahara, T., Numa, Y., Oishi, T., Kawaguchi, T., Seno, T., Asai, A., Kawamoto, K.: Morphological and flow cytometric analysis of cell infiltration in glioblastoma: a comparison of autopsy brain and neuroimaging. *Brain Tumor Pathol.* 27, 81–87 (2010) proposed Even when we successfully perform a total extirpation of glioblastoma macroscopically, we often encounter tumor recurrence. We examined seven autopsy brains, focusing on tumor cell infiltration in the peripheral zone of a tumor, and compared our findings with the MRI images. There has so far been no report regarding mapping of tumor cell infiltration and DNA histogram by flow cytometry, comparing the neuroimaging findings with the autopsy brain findings. The autopsy brain was cut in 10-mm-thick slices, in parallel with the OM line. Tissue samples were obtained from several parts in the peripheral zone (the outer area adjacent to the tumor edge as defined by post-contrast MRI) and then were examined by H&E, GFAP, and VEGF staining.

III. DESIGN AND METHODOLOGY

We aim to perform brain tumor image segmentation using a combination of basic image segmentation and extraction algorithms, employing the U-Net 3+ architecture. This approach relies on image analysis techniques to accurately delineate tumor regions.

Proper classification plays a crucial role in achieving accurate segmentation. By leveraging our proposed method, we can ensure appropriate classification, leading to precise tumor segmentation. To illustrate the process visually

Fig. a block diagram of our proposed method is provided below.

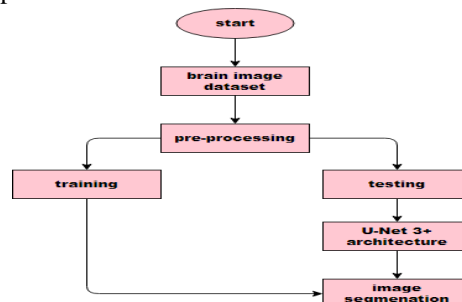


Fig: Block diagram of proposed method

1) *Input Preprocessing:*

Acquire medical imaging data, such as MRI scans, containing brain tumor images. Perform preprocessing steps, including image normalization, intensity adjustment, and noise reduction, to enhance the quality and consistency of the input data.

2) *U-Net3+ Architecture Overview:*

The U-Net 3+ architecture consists of an encoder-decoder structure with dense skip connections, allowing for improved information flow and feature reuse. The architecture aims to capture both local and global context information, facilitating accurate segmentation of brain tumors.

3) *Encoder Module:*

The encoder module comprises a series of convolutional layers followed by pooling layers to gradually downsample the input image. Each convolutional layer applies filters to extract high-level features from the input, capturing important patterns and structures. The pooling layers reduce spatial dimensions, enabling the network to capture more abstract information while preserving important features.

4) *Decoder Module:*

The decoder module reconstructs the spatial information by upsampling the feature maps obtained from the encoder. Each upsampling step is accompanied by skip connections, which concatenate feature maps from the corresponding encoder levels. These skip connections enable the U-Net 3+ architecture to combine high-resolution details from earlier layers with the contextual information captured at deeper levels.

Contrast Limited AHE (CLAHE) - is a variant of adaptive histogram equalization that addresses the problem of noise amplification. It limits the amplification of contrast to mitigate this issue. In CLAHE, the degree of contrast amplification near a specific pixel value is determined by the slope of the transformation function. Image enhancement techniques aim to improve the visual quality of an image as perceived by humans.

Normalize: Image normalization is a common technique in image processing that adjusts the range of pixel intensity values. Its primary purpose is to convert an input image into a range of pixel values that are more standard or typical, hence the term "normalization."

Biomedical Image Segmentation

- Re-designed Skip Pathways
- Deep Supervision
- Experimental Results

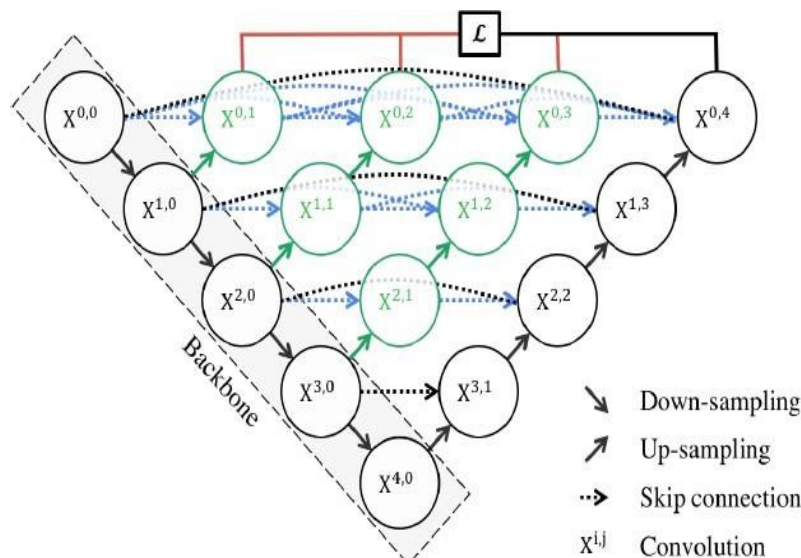


Fig: Working Principle of U-Net Architecture

The U-Net architecture is named after its distinct U-shaped structure, which is evident from a brief observation of the above diagram. The architecture is characterized by its fully convolutional nature, meaning it primarily consists of convolutional layers and lacks other types of layers such as dense or flatten layers.

The architecture is divided into two main parts: the contracting path and the expanding path. The contracting path captures the context and reduces the spatial dimensions of the input through a series of convolutional and pooling layers. This path is often referred to as the encoder as it encodes the input into a lower-dimensional representation.

IV. UNET3+ ARCHITECTURE

The U-Net3+ architecture is an extension of the original U-Net architecture specifically designed for brain tumor segmentation. It aims to improve the performance of tumor segmentation by incorporating additional features and skip connections.

The U-Net3+ architecture consists of three main components: the contracting path, the bridge, and the expansive path. These components work together to capture both local and global context information and enable precise tumor segmentation.

1) Contracting Path:

The contracting path in U-Net 3+ is similar to the original U-Net architecture. It consists of several encoder blocks, each consisting of two convolutional layers followed by batch normalization and ReLU activation. The encoder blocks progressively downsample the input image, capturing high-level features and reducing the spatial dimensions. Skip connections are created at each level by concatenating the output of each encoder block to the corresponding decoder block.

2) Bridge:

The bridge in U-Net 3+ is a modification that enhances the original architecture. It introduces a "3+" block, which consists of three convolutional layers. The 3+ block is placed after the final encoder block and helps capture more detailed information and improve feature representation.

3) Expansive Path:

The expansive path is responsible for upsampling the feature maps and reconstructing the segmented image. It consists of decoder blocks that are reconnected to their corresponding encoder blocks through skip connections. Each decoder block performs upsampling using transpose convolutions (also known as deconvolutions) to increase the spatial dimensions.

Understanding the Working of U-Net3+ Architecture for Brain Tumor Segmentation

The U-Net 3+ architecture is specifically designed for brain tumor segmentation, aiming to improve the accuracy and performance of the segmentation process.

It incorporates skip connections and additional features to capture both local and global context information. The brain tumor segmentation process using the U-Net 3+ architecture can be summarized in the following steps:

4) Preprocessing:

Before applying the U-Net 3+ model, the brain tumor images are preprocessed to enhance their quality and standardize their characteristics. This may involve steps such as resizing the images, normalizing pixel intensities, and applying contrast enhancement techniques.

5) Encoding:

The encoding phase begins with the input brain tumor image. The image is passed through a series of encoder blocks in the contracting path of the U-Net3+ architecture. Each encoder block consists of two convolutional layers followed by batch normalization and ReLU activation. These blocks capture and extract high-level features from the input image while progressively reducing the spatial dimensions.

6) Skip Connections:

At each level in the contracting path, skip connections are created by concatenating the output of the corresponding encoder block with the input of the decoder block at the same level. These skip connections enable the model to retain and utilize detailed information from earlier layers during the decoding process.

7) *Bridge:*

After the final encoder block, the U-Net 3+ architecture introduces a "3+" block in the bridge. This block consists of three convolutional layers and helps capture more detailed information and enhance the feature representation.

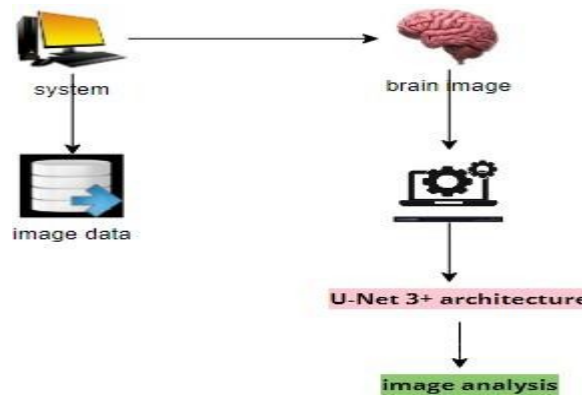
8) *Decoding:*

The decoding phase begins with the bridge output and proceeds through a series of decoder blocks in the expansive path of the U-Net 3+ architecture. Each decoder block performs upsampling using transpose convolutions to increase the spatial dimensions. The skip connections from the contracting path are used to concatenate the features from the corresponding encoder blocks, allowing the model to access both high-level and detailed information during the upsampling process.

9) *Output Layer:*

The output layer of the U-Net 3+ architecture consists of a convolutional layer followed by a softmax activation function. This final layer generates the segmented tumor mask, highlighting the tumor regions in the input image. The predicted mask can be further post-processed to refine the segmentation results if necessary.

Understanding the Working Structure of U-Net 3+ Architecture



V. DATASET AND DATA PREPARATION

A. *Data Set:*

The BraTS' 2018 contest offers a large dataset for training. It includes 210 MRI scans for High-Grade Glioma (HGG) and 75 MRI scans for Low-Grade Glioma (LGG). Each MRI scan has dimensions of 240x240x155, and they contain FLAIR, T1, T1-enhanced, and T2 volumes. The dataset has undergone co-registration, resampling to 1 mm³, and skull-stripping. An example of the data and its corresponding ground truth is depicted in Fig: 5.1.1(a). The goal of the dataset is to segment various types of brain tumors, such as necrosis, edema, non-enhancing, and enhancing tumors.

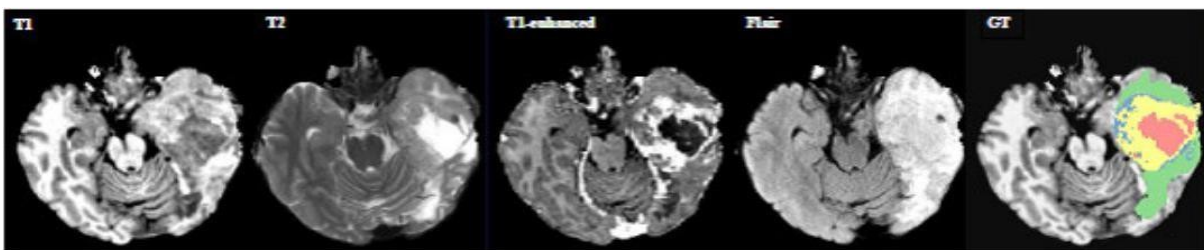


Fig: 5.1.1(a). Sample MRI images and ground truth labels, from left to right, T1, T2, T1- enhanced, and the label images; Green: edema, yellow: enhancing tumor, red: necrosis and non-enhancing.

The common MRI sequences used as input for brain tumor segmentation with U-Net architecture are:

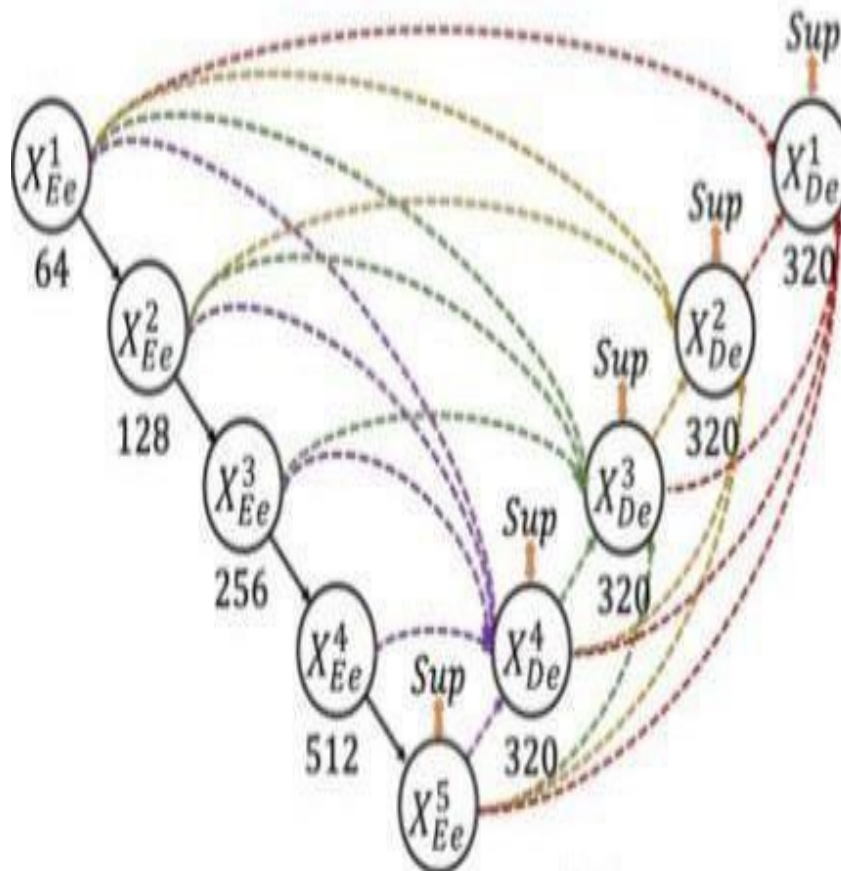
- 1) T1-weighted (T1) image: This MRI sequence highlights the contrast between different brain tissues based on the relaxation time of protons. T1-weighted images are useful for visualizing anatomical structures and are often used as a baseline for comparing other MRI sequences.

- 2) T2-weighted (T2) image: T2-weighted MRI sequences are sensitive to the differences in water content and are particularly useful for detecting edema, inflammation, and fluid-filled structures in the brain. Tumor soft tissue exhibits different signal intensities on T2-weighted images compared to surrounding healthy tissue.
- 3) T1-contrast-enhanced (T1-Enhanced) image: In this MRI sequence, a contrast agent (such as gadolinium) is administered intravenously to enhance the visualization of vascular structures and areas with disrupted blood-brain barrier, such as tumor tissue. Tumor typically shows enhanced uptake of the contrast agent, leading to better delineation of tumor boundaries.
- 4) FLAIR: FLAIR images suppress the signal from CSF, resulting in a high contrast between CSF-filled spaces and surrounding tissues. This property makes FLAIR images valuable for detecting abnormalities, including brain tumors, and for visualizing tumor margins and peritumoral edema.
- 5) Ground Truth (GT) image or Mask: This image serves as the reference or gold standard for brain tumor segmentation. It is a binary mask where each pixel is labeled as either tumor or background (non-tumor). Ground truth masks are typically manually annotated by experts or derived from histological analysis.

B. UNET 3+ Implementation: Working of Unet3+ Architecture:

The U-Net 3+ architecture is distinguished by its encoder and decoder components. In this setup, the decoder initiates its operations following the downsampling of the feature map to 2x2x2. While maintaining modularity, the decoder's primary task is to refine the encoder's feature map to enhance spatial dimensions. Each decoder block comprises three smaller blocks.

The encoder consists of five interconnected blocks, each with pooling operations and convolutional blocks with specific filters. The fifth block acts as a bottleneck layer. Similarly, the decoder consists of five blocks, with each layer concatenated with the preceding and encoding layers. Batch normalization and ReLU activation are applied to each layer except the last. Full-scale skip connections facilitate connectivity between the encoder and decoder, as well as within the decoder sub-networks.



U-Net3+ Architecture

VI. ANALYSIS AND RESULTS

A. Training Data into U-Net3+ Model:

```
Model: "UNet_3Plus"
Layer (type)                Output Shape                Param #    Connected to
-----
input_layer (InputLayer)    [(None, 128, 128, 3) 0
conv2d (Conv2D)             (None, 128, 128, 64) 1792      input_layer[0][0]
batch_normalization (BatchNorma (None, 128, 128, 64) 256      conv2d[0][0]
tf.nn.relu (TFOpLambda)    (None, 128, 128, 64) 0        batch_normalization[0][0]
conv2d_1 (Conv2D)          (None, 128, 128, 64) 36928     tf.nn.relu[0][0]
batch_normalization_1 (BatchNor (None, 128, 128, 64) 256      conv2d_1[0][0]
tf.nn.relu_1 (TFOpLambda)  (None, 128, 128, 64) 0        batch_normalization_1[0][0]
max_pooling2d (MaxPooling2D) (None, 64, 64, 64) 0        tf.nn.relu_1[0][0]
conv2d_2 (Conv2D)          (None, 64, 64, 128) 73856     max_pooling2d[0][0]
batch_normalization_2 (BatchNor (None, 64, 64, 128) 512      conv2d_2[0][0]
tf.nn.relu_2 (TFOpLambda)  (None, 64, 64, 128) 0        batch_normalization_2[0][0]
...
Total params: 26,984,833
Trainable params: 26,971,777
Non-trainable params: 13,056
```

```
Epoch 1/5
WARNING:tensorflow:From C:\Users\surya\anaconda3\Lib\site-packages\keras\src\utils\tf_utils.py:492: The name tf.ragged.RaggedTensorValue is deprecated. Please use tf.compat.v1.ragged.RaggedTensorValue instead.

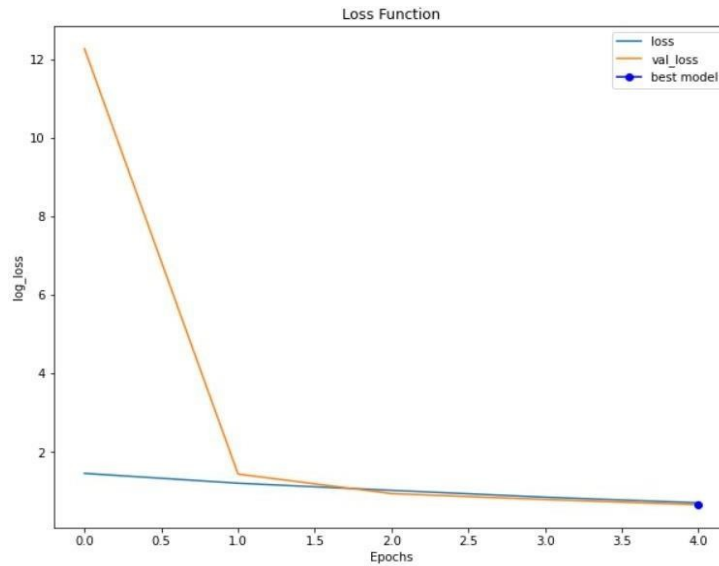
WARNING:tensorflow:From C:\Users\surya\anaconda3\Lib\site-packages\keras\src\engine\base_layer_utils.py:384: The name tf.executing_eagerly_outside_functions is deprecated. Please use tf.compat.v1.executing_eagerly_outside_functions instead.

20/20 [=====] - ETA: 0s - loss: 1.4505 - accuracy: 0.9157 - iou: 0.0724 - dice_coef: 0.1307
Epoch 1: val_loss improved from inf to 3.00059, saving model to model-brain-mri.h5
20/20 [=====] - 1443s 73s/step - loss: 1.4505 - accuracy: 0.9157 - iou: 0.0724 - dice_coef: 0.1307 - val_loss: 3.0006 - val_accuracy: 0.9920 - val_iou: 3.9444e-05 - val_dice_coef: 7.8888e-05 - lr: 0.0010
Epoch 2/5
20/20 [=====] - ETA: 0s - loss: 1.2039 - accuracy: 0.9887 - iou: 0.2235 - dice_coef: 0.3582
Epoch 2: val_loss improved from 3.00059 to 1.28941, saving model to model-brain-mri.h5
20/20 [=====] - 4501s 229s/step - loss: 1.2039 - accuracy: 0.9887 - iou: 0.2235 - dice_coef: 0.3582 - val_loss: 1.2894 - val_accuracy: 0.9855 - val_iou: 0.0337 - val_dice_coef: 0.0648 - lr: 0.0010
Epoch 3/5
20/20 [=====] - ETA: 0s - loss: 1.0166 - accuracy: 0.9891 - iou: 0.2157 - dice_coef: 0.3434
Epoch 3: val_loss improved from 1.28941 to 0.95119, saving model to model-brain-mri.h5
20/20 [=====] - 1992s 97s/step - loss: 1.0166 - accuracy: 0.9891 - iou: 0.2157 - dice_coef: 0.3434 - val_loss: 0.9512 - val_accuracy: 0.9912 - val_iou: 0.0472 - val_dice_coef: 0.0896 - lr: 0.0010
Epoch 4/5
20/20 [=====] - ETA: 0s - loss: 0.8415 - accuracy: 0.9916 - iou: 0.1766 - dice_coef: 0.2869
Epoch 4: val_loss improved from 0.95119 to 0.79544, saving model to model-brain-mri.h5
20/20 [=====] - 1192s 59s/step - loss: 0.8415 - accuracy: 0.9916 - iou: 0.1766 - dice_coef: 0.2869 - val_loss: 0.7954 - val_accuracy: 0.9902 - val_iou: 0.0280 - val_dice_coef: 0.0537 - lr: 0.0010
Epoch 5/5
20/20 [=====] - ETA: 0s - loss: 0.6994 - accuracy: 0.9908 - iou: 0.2637 - dice_coef: 0.4073
Epoch 5: val_loss improved from 0.79544 to 0.68281, saving model to model-brain-mri.h5
20/20 [=====] - 1046s 53s/step - loss: 0.6994 - accuracy: 0.9908 - iou: 0.2637 - dice_coef: 0.4073 - val_loss: 0.6828 - val_accuracy: 0.9918 - val_iou: 0.0402 - val_dice_coef: 0.0765 - lr: 0.0010
```

Accuracy of the Model

After training the model with the data, validation is conducted to prevent data redundancies. Subsequently, upon applying the UNET 3+ model to the trained dataset, tumors are accurately identified and segmented.

LossFunctionGraph:



LossFunction Graph

A loss function graph with log loss (cross-entropy loss) on the x-axis and epochs on the y-axis visualizes how the loss changes over the course of training. Here's how to interpret it:

- X-axis (Log Loss): Log loss, also known as cross-entropy loss, measures the difference between the predicted probability distribution and the true distribution of the data. It quantifies how well the model's predictions match the actual labels. The lower the log loss, the better the model's performance.
- Y-axis (Epochs): Epochs represent the number of complete passes through the training dataset during the training process. Each epoch corresponds to one cycle of training, where the model learns from the data and updates its parameters to minimize the loss function.
- Graph: The graph plots log loss (cross-entropy loss) on the x-axis and epochs on the y-axis. As training progresses (moving from left to right along the x-axis), the loss ideally decreases over successive epochs (moving from top to bottom along the y-axis). This indicates that the model is learning and improving its performance over time.

Final Accuracy:

20/20[=====]-ETA:0s-loss:1.4505-accuracy:

0.9157-iou:0.0724-dice_coef:0.1307

Epoch 1: val_loss improved from inf to 3.00059, saving model to model-brain-mri.h520/20

[=====]-1443s73s/step-loss:1.4505-

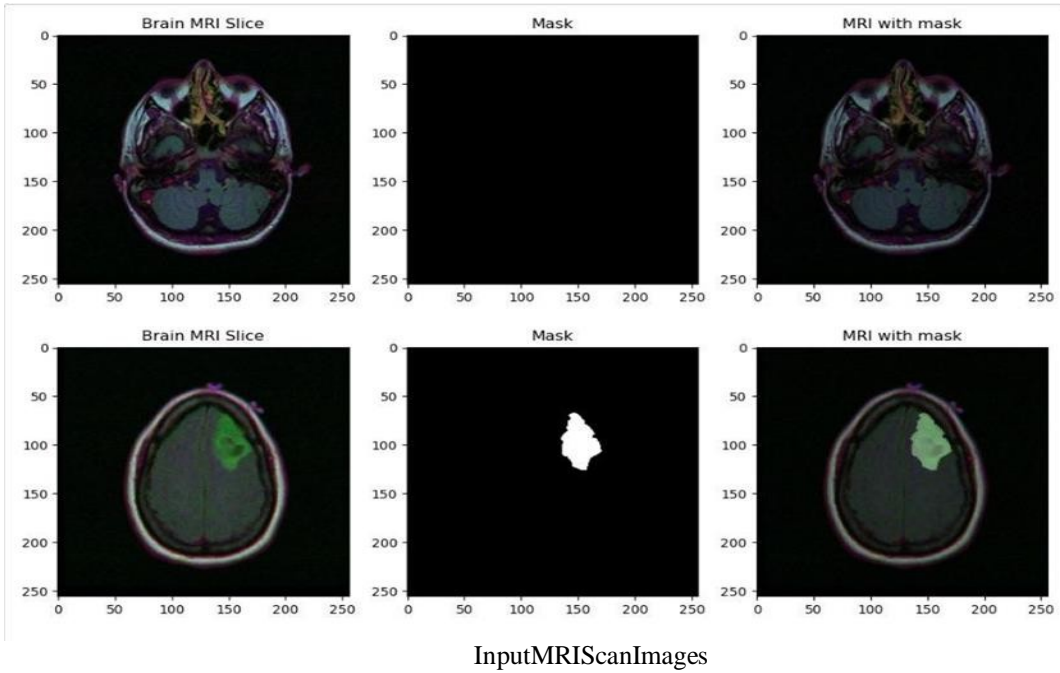
accuracy:0.9157-iou:0.0724-dice_coef:0.1307-val_loss:3.0006-val_accuracy:0.9920 - val_iou: 3.9444e-05 - val_dice_coef: 7.8888e-05 - lr: 0.0010

Epoch 2/5

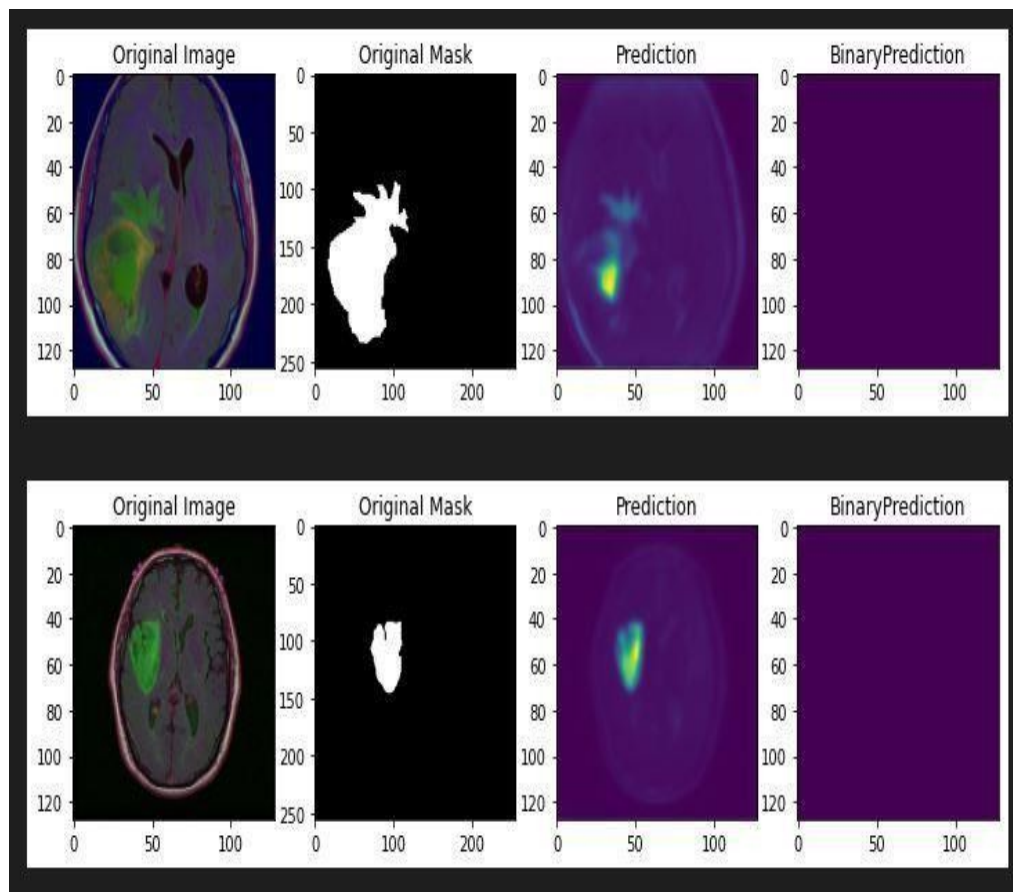
11/20[=====>.....]-ETA:26:19-loss:1.2450-accuracy:0.9887-

iou:0.2274-dice_coef:0.3609

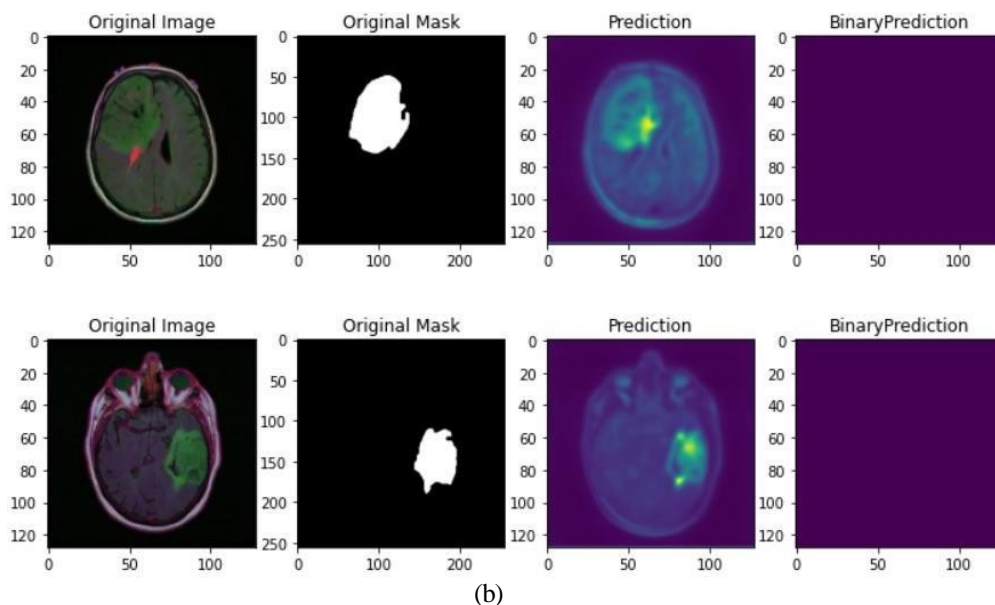
Input Data:



VII.IMPLEMENTATION RESULTS



(a)



VIII. CONCLUSION

In conclusion, this project focused on the segmentation of brain tumor images using the advanced U-Net 3+ architecture. We successfully completed the task by employing a dataset specifically curated for brain tumor segmentation. The U-Net 3+ architecture, known for its ability to capture detailed information at different scales, was trained using the dataset (BRATS 2018). During the training phase, the model learned to accurately identify and segment tumor regions in the brain images. This segmentation process involved differentiating the veins from the tumor regions, effectively highlighting the areas of interest.

IX. FUTURE SCOPE

There is scope for further feature enhancement and exploration in the UNet3+ architecture for brain tumor segmentation. Here are a few potential areas of improvement and feature scope:

- 1) Firstly, there's potential for refining the model's performance through optimization efforts, such as experimenting with different activation functions and layer configurations to enhance accuracy and efficiency.
- 2) Additionally, integrating multiple imaging modalities like MRI, CT, or PET scans could improve segmentation results by effectively combining information from different sources.

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