Project

CEN-444 Digital Image Processing

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Class & Section: BS-CS-7B

Tools Used:

- VS-Code & Co-Lab
- Pan-nuke dataset

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Abstract:

- This project is the implementation of a deep-learning based approach to achieve nuclei-segmentation using bio-medical images (from the pan-nuke data set). The method we use is a U-Net architecture that is trained on the pan-nuke dataset, that contains images along with their masks. The goal is to identify individual nuclei properly and precisely in the images. This is achieved by deploying a convolutional neural network with a narrow and expansive path, allowing feature extraction and localization. The training of the model is done using binary cross entropy loss and is evaluated by using both the training and testing datasets. The outcome demonstrates the effectiveness of the proposed method in segmenting nuclei, implying the use of the model for various biomedical image analysis tasks.

Introduction:

- Medical image analysis plays a pivotal role in modern healthcare, enabling physicians to extract important insights from complex imaging data for diagnosis, treatment scheduling, and medical research. Among the numerous tasks in medical image analysis, semantic segmentation stands out as a fundamental technique for defining and identifying specific regions of interest within images. In this project, the U-Net architecture has emerged as a powerful tool for semantic segmentation, especially in medical-imaging applications.
- Introduced by Ranneberger et al. in 2015, The U-Net model has a unique symmetric encoder-decoder structure, facilitating the localization of objects in images while capturing contextual information. This architecture of the U-Net, helps the model to learn the complex spatial relationships and hierarchies of features, making it well suited for tasks that require semantic segmentation to help identify parts such as nuclei, tumors, or organs in medical images.
- This project focuses on using the abilities of the U-Net model to perform semantic segmentation of nuclei in medical images (provided in the Pan-nuke dataset). Nuclei segmentation is an essential task in histopathology, cytology, and other medical concerns, providing information that is fruitful for diagnosing diseases like cancer, measuring cellular characteristics, and studying tissue morphology. These precise segmentations help researchers and physicians to automate tiresome manual tasks, extract quantitative features for analysis, and enhance the accuracy of a diagnosis.
- The training stage of this project, the model maps input images to their respective masks, and trying to minimize the segmentation errors and improve accuracy. By using an iterative optimization approach and monitoring the model's performance, we aim to create a robust segmentation model.
- The dataset used in this project is known as the Pan-nuke dataset, which is a dataset that is a collection of histopathology images used for nuclei segmentation. The dataset comprises of images from various tissue types like breast, skin, liver, bladder, and lungs. The dataset provides pixel-level annotations for each nuclei. The dataset contains 481 visual fields, of which 312 are sampled randomly from more than 20K whole slide images at different magnifications, from different sources. Overall, the dataset has 205,343 labeled nuclei, each with an instance segmentation mask.
- In this report we try to understand and dive into the methodology used for deploying tactics like data preprocessing, model building, and training, while highlighting the steps taken to implement the U-Net architecture for segmentation.

Literature Review and Links:

- The U-Net architecture introduced in 2015 has become a widely used model **(2),** that performs medical image segmentation tasks. U-Network's encode-decoder structure with skip connections allows localization of objects while capturing contextual information.
- Several variants of the U-Net have been proposed to enhance the performance of the architecture, Zhou et al. introduced U-Net++ **(1,7)** that uses nested skip connections to

reduce the semantic gap between the encoder and decoder. This was aimed to make the optimizer learning task easier by providing it with semantically similar feature masks.

- Alom et al. proposed the Recurrent Residual Convolutional Neural Network based on the U-Net **(6),** that embeds frequent convolutional layers and learning to improve usage for medical image segmentation. The authors demonstrate the effect of R2U-Net on various datasets.
- Researchers have explored the use of attention mechanisms in U-Net architectures. Song et al. introduced OAU-Net **(8),** a model that deploys outlined attention to selectively focus on relevant parts for segmentation. Helping the model focus on important features and improve its accuracy.
- The Pan-Nuke dataset **(3)**, available on Kaggle, plays the role of a cornerstone for evaluating nuclei segmentation models. This dataset contains pictures of different cells with corresponding masks, helping researchers to train and evaluate their models on a standardized dataset.
- Multiple studies utilize the U-Net and its variants for nuclei segmentation. Xu et al. **(6)** proposed a Multi-Scale Split Attention U-Net for automatic nuclei segmentation, showing better performance as compared to the original U-Net architecture.
- In 2023, Ramya Shree et al. **(4)** presented an Automatic Nuclei Segmentation on Microscopic images using Deep residual U-Net. Their approach uses the power of the residual learning to facilitate training of deeper U-Net architectures, leading to a better segmentation performance.

The following list contains 10 different research papers that discuss nuclei-segmentation, or the U-Net architecture, some of them the team has been through whereas some of the links have not been visited but gathered from the internet.

1. Nested U-Net: A Novel Convolutional Neural Network for Biomedical Image Segmentation
   - July 2018.
   - https://arxiv.org/pdf/1807.10165
2. U-Net: Convolutional Networks for Biomedical Image Segmentation
   - November 2018.
   - https://link.springer.com/chapter/10.1007/978-3-319-24574-4_28
3. The Pan-Nuke dataset taken from Kaggle
   - https://www.kaggle.com/datasets/andrewmvd/cancer-inst-segmentation-and-classification
4. An Automatic Nuclei Segmentation on Microscopic Images using Deep Residual U-Net
   - In 2023.
   - https://thesai.org/Downloads/Volume14No10/Paper_61 An_Automatic_Nuclei_Segmentation_on_Microscopic_Images.pdf

5. Semantic Segmentation of human cell nucleus using deep U-Net and other versions of U-Net models
    - July 2022.
    - https://www.researchgate.net/publication/361995978_Semantic_segmentation_of_human_cell_nucleus_using_deep_U-Net_and_other_versions_of_U-Net_models
6. Recurrent Residual Convolutional Neural Network based on U-Net (R2U-Net) for Medical Image Segmentation
    - 27th March 2019
    - https://www.spiedigitallibrary.org/journals/Journal-of-Medical-Imaging/volume-6/issue-1/014006/Recurrent-residual-convolutional-neural-network-based-on-U-Net-R2U-Net/10.1117/1.JMI.6.1.014006.full
7. U-Net++: A Nested U-Net Architecture for Medical Image Segmentation
    - 20th September 2018
    - https://link.springer.com/chapter/10.1007/978-3-030-00889-5_1
8. Enhanced Nuclei Segmentation and Classification via Category Descriptors in the SAM Model
    - Bioengineering 2024
    - https://www.mdpi.com/2306-5354/11/3/294
9. Deep Learning Based Approaches for Semantic Segmentation
    - Electronic 2023
    - https://www.mdpi.com/2079-9292/12/12/2730
10. U-Net and its Variants for Medical Image Segmentation
    - 03-June-2023
    - https://ieeexplore.ieee.org/abstract/document/9446143

Methodology:

The methodology used in this project involves the following key-steps:

- **Data Preparation:**
    - The code of this project loads the training images and masks from the Pan-nuke dataset. Using OpenCV techniques, the images are read and processed according to the desired dimensions (256x256x3) and store them in the declared NumPy arrays (which are X_train for images, and Y_train for respective masks). The masks are resized and totaled to create the final segmentation masks
- **Model Building:**
    - The U-Net architecture is built using the Tensor-Flow and Keras libraries. The model consists of an encoder with convolutional and pooling layers that help capture the features and a decoder with transposed convolutions for precise localization.
    - Batch normalization and dropout layers are included that help in regularization, and skip connections are used to preserve information.
- **Compilation:**

- The model is compiled with the help of the Adam optimizer (that helps in gradient descent optimization), and binary cross-entropy loss function (to measure the difference between predicted and true masks), this is suitable for binary segmentation tasks like nuclei segmentation. Accuracy is the evaluation metric to monitor the performance of the model during its training.

- **Training:**
    - The training is done using a supervised learning approach, and on a GPU- enabled environment to help accelerate computation.
    - The model is trained on the compiled/preprocessed/prepared dataset using a batch size of 16 and a specified number of epochs. Callbacks like early stopping and model checkpointing are employed to prevent over-fitting and save the best model weights based on validation performance.
- **Evaluation:**
    - Once the model is trained, it is evaluated on a separate test set of images. Accuracy and Loss are used as metrics to assess the model's segmentation accuracy and generalization to unseen data.
- By focusing on these parameters, the code implements a U-Net model for nuclei segmentation, using deep learning techniques to achieve accurate segmentation results in medical images.

Conclusion:

- All-together, the implementation of the U-Net model for nuclei segmentation in medical images showcases the abilities of deep learning in accurately separating and segmenting nuclei. By using the U-Net architecture the project demonstrates a robust methodology for automated nuclei segmentation. The use of techniques like data preprocessing, model building, training, and the model working on the dataset provided has resulted in a model capable of effectively segmenting nuclei with high accuracy. More refinement and optimization of the model would enhance the model's abilities to perform better and expand it's application to various healthcare problems, and helping realize the significance of deep learning models in advancing medical image analysis and automated segmentation tasks.