Ischemic Stroke Lesion Segmentation

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Preface

Stroke is the second most frequent cause of death and a major cause of disability in industrial countries. Its most frequent manifestation is the ischemic stroke, whose diagnosis often involves the acquisition of brain magnetic resonance (MR) scans to assess the stroke lesion's presence, location, extent, evolution and other factors. All known intervention are associated with considerable risks and require a careful weighting against the potential gains. An automated method to predict the final lesion outcome and to estimate the degree of disability would support clinicians in the difficult and time-critical decision making process.

New methods for stroke segmentation and outcome prediction are regularly proposed. But, more often than desirable, it is difficult to compare their fitness, as the reported results are obtained on private datasets. Challenges aim to overcome these shortcomings by providing (1) a public dataset that reflects the diversity of the problem and (2) a platform for a fair and direct comparison with suitable evaluation measures. Thus, the scientific progress is promoted.

With ISLES, we provide such a challenge covering ischemic stroke lesion as well as clinical outcome prediction from acute multi-spectral MRI data and intervention parameters. The task is backed by a well established clinical and research motivation and a large number of already existing methods. Each team may participate in either one or both of two sub-tasks:

TASK I Automatic prediction of the final lesion extend after (successful or failed) intervention in form of a binary mask.

TASK II Automatic prediction of the final clinical outcome after (successful or failed) intervention in from of the modified Ranking Scale (mRS).

The participants downloaded a set of training cases with associated follow-up expert segmentations and mRS scores to train and evaluate their approach, then submitted a short paper describing their method. After reviewing, a total of eight abstracts were accepted and compiled into this volume. At the day of the challenge, each teams' results as obtained on an independent test set of cases will be revealed and a ranking of methods established.

For the final ranking and more information, visit WWW.ISLES-CHALLENGE.ORG.

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Multi-task Fully Convolutional Networks for Simultaneous Stroke Lesion Segmentation and Clinical Outcome Prediction

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This submission explores the use of a whole volume, 3D, Multi-Task, Fully Convolutional Network (MTFCN) to simultaneously segment lesions and provide clinical outcome predictions in the context of stroke patient MRI for the 2016 ISLES Challenge. Fully Convolutional Networks (FCNs) are well suited to the task of semantic segmentation in both natural [1] and medical imaging contexts [3]. FCNs manifest as multi-scale, nonlinear filters. They are comprised of a downstream Convolutional Neural Network (CNN) path in conjunction with an upstream deconvolutional path. At the end of the downstream path is a descriptor that encodes the entire image space. Feature maps from the downstream path are then upsampled and merged in the upstream path to provide dense, multi-scale descriptors for pixel classification. In this work, we show how a MTFCN can be devised for the ISLES Challenge by adding a second network output at the end of the downstream path to incorporate image attribute prediction within the FCN architecture. Similar multi-task architectures have been used for image classification/reconstruction [4, 2], where it was found that feature salience for reconstruction and also classification performance both improved. Our work represents the first adaptation of the multi-task framework for simultaneous clinical outcome prediction and segmentation in a medical imaging context.

For the ISLES challenge, the entire network is trained end-to-end using stochastic gradient descent, where the objective function is an average of the mean squared error loss at the convolutional output for regression and the categorical cross entropy loss at the deconvolutional output for segmentation. The availability of high memory GPUs allows for a deep and narrow 3D MTFCN architecture to operate on the high dimension MRI data provided. We explore two different types of input to the MTFCN: one using the provided perfusion derived modalities, and another using the raw perfusion data. Model selection is performed using 5-fold cross-validation on the provided training data. The model achieving the best segmentation DICE score and lowest clinical outcome MSE averaged over the 5 folds is used on the challenge test cases.

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A Convolutional neural network exploiting contra-lateral features for brain lesion segmentation

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We propose a convolutional neural network (CNN) which leverages right-left hemisphere comparison. The method is inspired from observation of neuro-radiologists performing ischemia detection in imaging studies. It is rare that stroke occurs in both sides of the brain in a given episode, therefore comparison between hemispheres helps to discriminate between subtle changes in the affected side and the normal brain tissue. We hypothesis that exploiting contra-lateral features will therefore be useful when segmenting stroke lesions in MR.

The fist steps consist of isotropic re-sampling to 1mm voxels and alignment of the MR volumes to a reference dataset, designated as an atlas. Registered volumes are folded (like butterflys wings) along the brain midline. This folding results in two CNN intensity channels relating to the right and left sides of the brain, enabling bilateral comparison. Three additional channels encoding x, y, z atlas locations provide anatomical context. We train the Butterfly CNN on patches extracted from folded volumes. To address the problem of in-balance between normal and lesion voxels, we select all patches which contain lesion and a random sample of normal patches. This non-representative sampling of the training dataset results in an unacceptable level of false +ve errors. We therefore introduce a second stage in which the CNN is trained on those normal samples which were miss- classified in the first training stage.

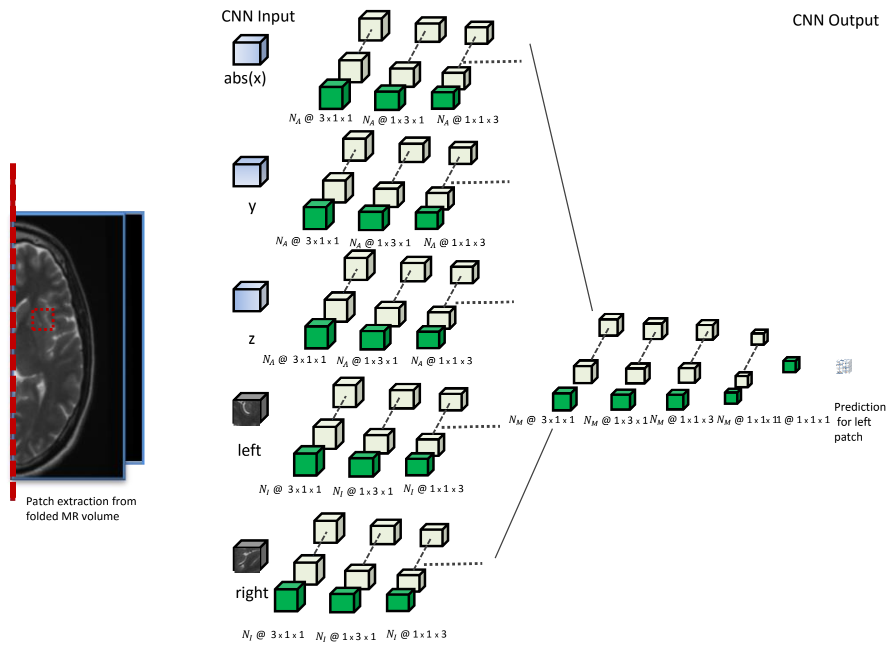

Fig. 1. The CNN architecture. CNN parameters during initial experiments (*likely to change*): input patch size 20x20x20 voxels; we use relu activation function; small filters chains decomposed spatially (e.g. 3 layer of convolutions just in one dimension with the following filters: 3x1x1, 1x3x1, 1x1x3). The number of kernels for the atlas channels $N_A = 2$ whereas for the left and right intensity channels $N_I = 32$. The input channels are treated separately for first 6 layers before merging; number of kernels after merging $N_M = 64$. The output is fully convolutional allowing for the efficient prediction of all voxels of the dataset in a single pass.

Combination of CNN and Hand-crafted feature for Ischemic Stroke Lesion Segmentation

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1 Motivation

CNN can automatically learn discriminative local features and give superior performance than hand-crafted features in various applications such as image classification, semantic segmentation and object detection. CNN has also been applied to MRI brain image analysis and achieved state-of-the-art results for brain tumor region segmentation [3, 4], stroke lesion segmentation [4], and mircobleeds detection [2]. Recently, some studies (e.g. [5]) show that hand-crafted features may provide complementary information with CNN, hence combining them with the features extracted from CNN may give improved performance than only using the features from CNN. Motived by this, we formulate the segmentation of ischemic stroke lesion in acute MRI scans as a pixel-level classification using a combination of CNN and hand-crafted features.

2 CNN Architecture

We used a CNN architecture which is similar to [1]. It is a fully convolutional neural network containing a downsampling path and three upsampling paths. In the task of stroke lesion segmentation, there is a large variation on the size, location and shape of lesions. Therefore, encoding information at multiple scales is necessary and preferable than considering information at only one level. The downsampling path is able to extract the abstract information with high-level semantic meaning, while the three upsampling paths are designed to capture the fine details. These three upsampled feature maps are then combined at the later stages of the CNN architecture so that the classification layer fully make use of the information appears at multiple scales [1].

3 Hand-crafted Feature

We use the following hand-crafted features:

- intensity;
- the hemispheric intensity difference between two symmetric pixels in the axial view;
- first order statistics in a $w \times w$ volume patch;
- maximum response filter (MR8) [6].

At each 2D pixel location, these local features are extracted independently from each image modality and combined together to get a feature representation for that pixel.

4 Patient-specific Classifier

As there is a large variation of lesions in the dataset, it will be beneficial to train a pool of binary classifiers instead of one. Each binary classifier in this pool is designed to separate the positive (lesion) features extracted from a patient from all the negative (normal) features extracted from the same patient. In this way we believe that some rarely appeared lesions can be easily discriminated from the normal tissue compared to a binary lesion classifier which is trained using all the training data (without using patient information). In the testing time a voting strategy (averaging the top 3 probabilities obtained by the binary classifiers in the pool) is used to get the prediction of an input.

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Residual Volumetric Network for Ischemic Stroke Lesion Segmentation

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1 Introduction

We propose a 3D convolutional neural networks (3D CNNs) based method for lesion outcome prediction. The proposed 3D network takes advantage of fully convolutional architecture to perform efficient, end-to-end, volume-to-volume training. More importantly, we introduce the recent proposed residual learning technique into our network, which can alleviate vanishing gradients problem and improve the performance of our network.

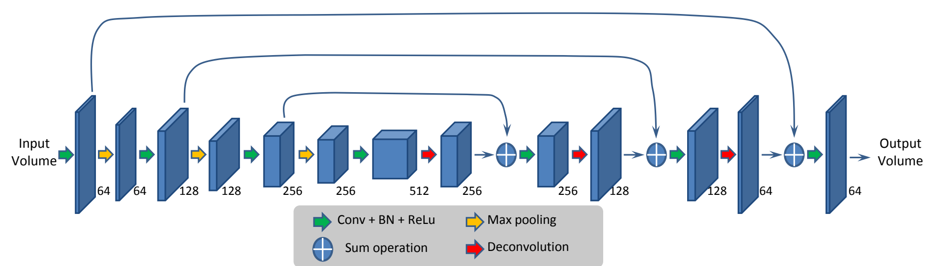

Fig. 1: Illustration of our proposed residual volumetric network. Numbers represent the number of feature volumes in each layer.

Fig. 1 demonstrates the architecture of our proposed residual volumetric network. It employs 3D fully convolutional architecture and is organized in a residual learning scheme. The layers of our network are all implemented with a 3D manner (under caffe library), thus the network can highly preserve and deeply exploit the 3D spatial information of the input volumetric data. We adopt small convolution kernels with size of $3 \times 3 \times 3$ in convolutional layers. Each convolutional layer is followed by a rectified linear unit (ReLU). Note that we also employ batch normalization layer (BN) before each ReLU layer. The BN layer can accelerate the training process of our network. At the end of the network, we add a $1{\times}1{\times}1$ convolutional layer as a classifier to generate the segmentation results and further get the segmentation probability volumes after passing the softmax layer. Note that our network might appear similar to U-Net, but there are differences: We use summation units instead of concatenation units when combining different paths, and thus we can reformulate our network as residual learning scheme; additionally, we adopt recently developed batch normalization technique to improve our performance.

Random forests for stroke lesion and clinical outcome prediction

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1 Introduction

Ischemic stroke is caused by an obstruction in the cerebral blood supply and, if diagnosed early, part of the under-perfused tissue can potentially be salvaged. Since the available treatment options are not risk-free, the decision has to be made individually, depending on the potential gain and under great time restriction. The prediction of the final lesion outcome in form of A binary mask (Task I) and the prediction of the clinical outcome in form of the modified Rankin Scale (mRS) (Task II) are therefore of great clinical interest. The ISLES 2016 challenge offers a public dataset and associated expert groundtruth to allow researchers to compare their methods in these two fields directly and fairly. Our contribution works with carefully selected features extracted from the MR sequences and used to train a random forest (RF).

2 Method

The data consists of multi-spectral (ADC, PWI maps and raw PWI 4D volumes) scans and associated clinical measures. The final lesion outcome as delineated in a 90 days follow-up scan (Task I) and the 90 days mRS score (Task II) serve as groundtruths. More details on the data can be found on `www.isles-challenge.org`.

Task I: Lesion outcome prediction From each MR sequence we extract the features previously presented in [1], but furthermore employ a hemispheric difference measure to make use of the pseudo-quantitative values provided by the PWI maps. For voxel-wise classification we employ RFs.

Task II: Clinical outcome prediction Based on the segmentation results from Task I, we extract lesion characteristics as well as local image features from the supplied cases to train a regression forest. Applied, this yields a prediction of the mRS score for a formerly unseen case.

3 Discussion

Our method has been shown to provide competitive lesion segmentation results in glimo segementation as well as acute and semi-acute stroke in the previous year's edition of the ISLES challenge. The results from this year's challenge will show if the advantages of our flexible design also extend to outcome prediction.

References

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Segmentation of Ischemic Stroke Lesion using Random Forests in Multi-modal MRI Images

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Multi-modal magnetic resonance imaging (MRI) can be used for detecting the ischemic stroke lesion and can provide quantitative assessment of lesion area. It can be established as an essential paraclinical tool for diagnosing stroke. For a quantitative analysis of stroke lesion in MRI images, clinical expert manual segmentation is still a common approach and has been employed to compute the size, shape and volume of the stroke lesions. However, it is time-consuming, tedious, and labor-intensive task. Moreover, manual segmentation is prone to intra-and inter-observer variabilities. Herein, we present an automated segmentation method for ischemic stroke lesion segmentation in multi-modal MRI images. The method is based on an ensemble learning technique called random forest (RF), which generates several classifiers and combines their results in order to make decisions. In RF, we employ several meaningful features such as intensities, entropy, gradient etc. to classify the voxels in multi-modal MRI images. The segmentation method is validated on training data, obtained from MICCAI ISLES-2016 challenge dataset. The performance of the method is evaluated relative to the manual segmentation, done by the clinical experts. The experimental results show the robustness of the segmentation method, and that it achieves reasonable segmentation accuracy for segmenting the ischemic stroke lesion in multi-modal MRI images.

A Deep-Learning Based Approach for Ischemic Stroke Lesion Outcome Prediction

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The ISLES 2016 challenge aims to address two important aspects of Ischemic stroke lesion treatment prediction. The first aspect relates to segmenting the brain MRI to identify the areas with lesions and the second aspect relates to predicting the actual clinical outcome in terms of the patient's degree of disability. The input data consists of acute MRI scans and additional clinical such as TICI scores, Time Since Stroke, and Time to Treatment.

To address this challenge we take a deep-learning based approach. In particular, we first focus on the segmentation task and use an automatic segmentation model that consists of a Deep Neural Network (DNN). The DNN takes as input the MRI images and outputs the segmented image, automatically learning the latent underlying features during the training process. The DNN architectures we consider utilize many convolutional layers with small kernels, e.g., 3x3. This approach requires fewer parameters to estimate, and allows one to learn and generalize from the somewhat limited amount of data that is provided.

One of the architectures we are currently utilizing is based on the U-Net [1], which is an all-convolutional network. It acts as an auto-encoder, that first "encodes" the input image by applying combinations of convolutional and pooling operations. This is followed by the "decoding" step that up-scales the encoded images, while performing convolutions. The all-convolutional architecture of the U-Net allows it to handle input images of different dimensions as in the challenge dataset. In our experiments, we found that this architecture yielded excellent performance on the previous ISLES 2015 dataset. Although the modalities in the 2016 challenge are different, our initial training experiments have yielded promising segmentation results.

Our next steps involve addressing the regression challenge. There is limited amount of labeled data for this task. Our approach will be to include these outcomes as part of the segmentation training directly. This will allow the DNN to learn latent features that can directly help with the classification task.

References

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Deep Convolutional Neural Network Approach for Brain Lesion Segmentation

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Brain lesion segmentation is a challenging problem because the amount of lesion area is extremely small and the size of available training magnetic resonance images are limited. To handle this, we exploit millions of 3D patches and 3D convolutional kernels for our proposed model. By treating each 3D patch as training data we capitalize on spatial information and overcome the problem of limited medical data. Our final segmentation model is an ensemble of two deep convolutional neural networks inspired by fully convolutional networks and the U-Net(Ronneberger et al., 2015). We implement the proposed model in Python with Lasagne and Keras.

* Authors contributed equally

** I am the corresponding author of the abstract ''Deep Convolutional Neural Network Approach for Brain Lesion Segmentation'' and in the name of all co-authors I declare that MICCAI has the right to distribute the submitted material to MICCAI members and workshop / challenge / tutorial and MICCAI attendees.
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Incorporating time to reperfusion into the FASTER model of stroke tissue-at-risk

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In a recent paper, we introduced the tool FASTER (Fully Automated Stroke Tissue Estimation using Random Forests), which aims to give an assessment of the tissue at risk in acute stroke beyond the usual paradigm of predefined thresholds on single maps. The FASTER system assesses the likelihood of tissue damage using decision forest classifers, mapping local statistical features of perfusion and diffusion imaging onto maps of the tissue predicted to be lost even if reperfusion is established, and the tissue predicted to be lost only if there is no reperfusion. These models are trained only on extreme cases, in which reperfusion was total and rapid (TICI 3), or completely absent (TICI 0).

In this work we attempt to go further, predicting the likely tissue loss in the case of TICI grades 1-2b, by interpolating between the two predictions yielded by FASTER, and incorporating the time to revasculariston.

Acknowledgments

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Ischemic Stroke Lesion Segmentation

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