Unsupervised WMH segmentation using SegAE

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1 Method

1.1 CNN architecture

The segmentation autoencoder (SegAE) is an autoencoder with fully convolutional layers on three resolution scales. The input to SegAE consists of three-dimensional (3D) patches of size $80 \times 80 \times 40$ from the FLAIR and T1 images. The autoencoder is constrained to reconstruct the corresponding image patches with a linear unmixing model, where the weights (endmembers) and segmentations (abundances) are non-negative, and the segmentations sum to one. A brainmask for each input patch (obtained by binarizing the sum of the input channels) is applied before and after the Softmax layer.

The non-negativity constraint and the sum-to-one constraint of the segmentations are enforced with a Softmax activation function. The weighted sum is implemented with a 1x1x1 convolutional layer that is constrained to have non-negative weights and zero bias. With appropriate regularization, the Softmax-layer outputs a soft segmentation of the materials present in the images, such as grey matter (GM), white matter (WM), cerebrospinal fluid (CSF) and white matter hyperintensities (WMH). A U-net like architecture [1] is used for the previous layers consisting of 3D convolutional layers (kernel size $3 \times 3 \times 3$) followed by leaky rectified linear units (LReLU) activation functions and batch normalization layers. Downsampling is performed with $2 \times 2 \times 2$ strided convolutions, but $2 \times 2 \times 2$ upsampling is performed to obtain an output of the same size as the input.

1.2 Cost function

The cost function used here is based on Cosine proximity. Three terms are used in the cost function: 1) A negative average of Cosine proximity over the true and predicted image patches; 2) same as 1) except a Laplace differential operator is first applied to the input patches; and 3) a regularization term based on a sum of Cosine proximity between the Softmax outputs (the regularization coefficient used here was 0.02).

1.3 Preprocessing

Skullstripping was performed on the training images using the MONSTR skullstripping method [2]. A 3D U-net was trained on the MONSTR skullstripping masks with the T1 and FLAIR images as input, to make skullstripping faster in the testing phase. The U-net used for skullstripping was of the same architecture as SegAE, except the final layers for the linear sum and brainmasking layer were omitted, and the output was single channel.

Inhomogeneity correction was performed by 1) training SegAE once to obtain a soft tissue and lesion segmentation, 2) applying N4 bias correction [3] with a pure-tissue probability mask [4] obtained from step 1), but excluding the lesion and CSF areas, and 3) training SegAE again using the original images as input but the inhomogeneity corrected images for the evaluation of the loss function. Thus, SegAE learns to segment the original images without the need for intermediate inhomogeneity correction when evaluating new images that are not in the training set.

1.4 Post-processing

The output from SegAE corresponding to WMH segmentation is thresholded with a threshold of 0.87, and objects smaller than 3 voxels are removed from the segmentation.

References

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