UNet-based Deep Neural Network for 3D Lung Segmentation

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Objective

- The recent developments in the field of Medical Imaging, Deep Learning, is a crucial technology to accelerate medical tasks and perform them precisely and automatically.
- 3D lung segmentation has a significant role in removing the unnecessary volume of 3D CT scans and segments the actual volume of the lungs in three dimensions, to simplify the 3D CT scan for further tasks.

Introduction

- Deep learning network such as U-Net and its variants provides excellent results for biomedical image segmentation.
- We propose a novel deep neural network architecture based on UNet, for the 3D lung segmentation task.
- The proposed model helps learn spatial dependencies in 3D and increases the propagation of volumetric information.
- We have investigated our network with different architectural modules, learning strategy, activation functions, optimizers, loss functions, and appropriate hyperparameters.
- Our proposed deep neural network is trained on the publicly available dataset - LUNA16 and achieves state-of-the-art performance on the VESSEL12 dataset and the testing set of LUNA16.

Methodology and Architecture

- We have developed a deep neural network architecture based on Recurrent and Residual Neural Networks and proposed its variants. We applied Squeeze-and-Excitation Residual module and utilized multiscale dilation. We trained these variants with Adam and Eve optimizers, and ReLU activation function.
- We have selected sets of scans randomly from the training set and trained them for the number of iterations. This strategy helps to overcome overfitting over the local set of training data.

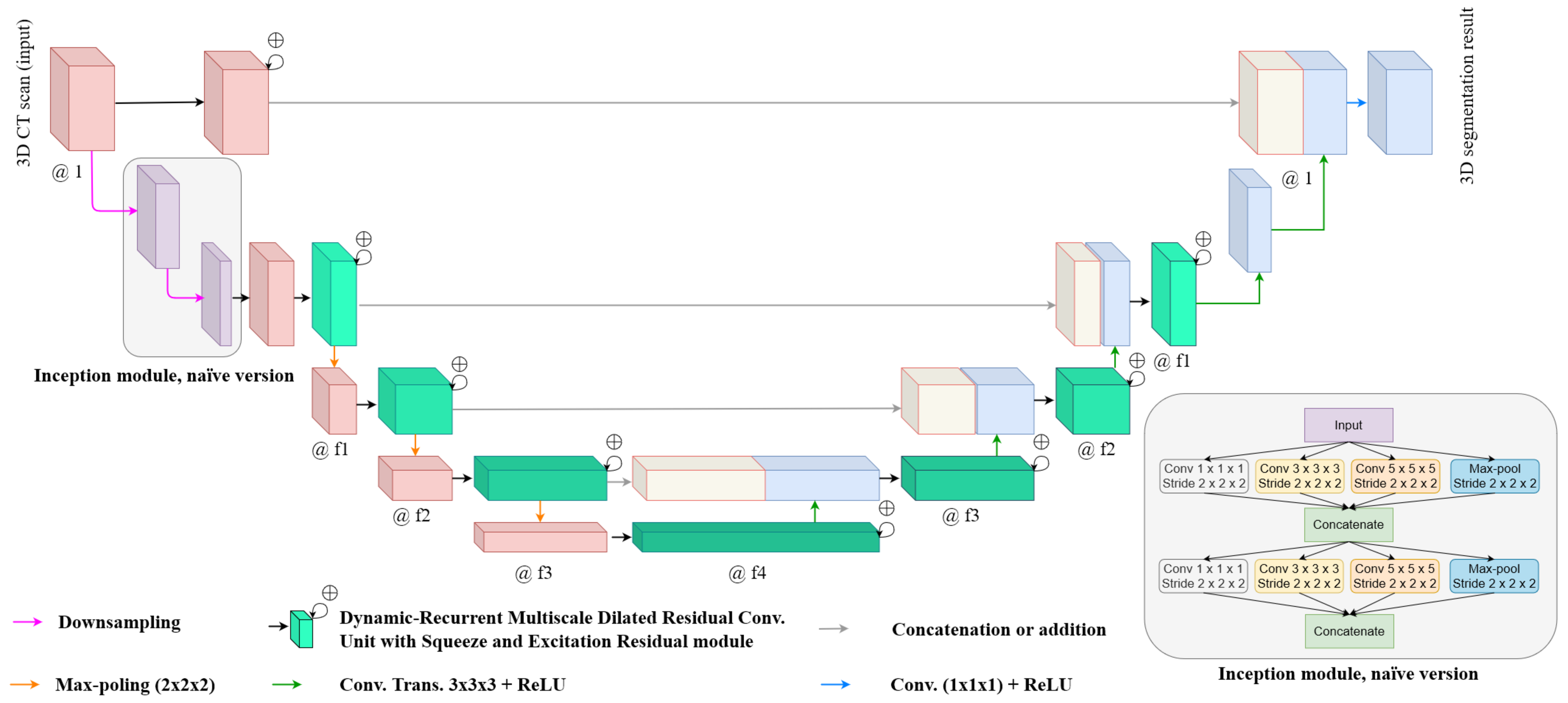

Fig. 1. 3D-UNet architecture with Dynamic-Recurrent Multiscale Dilated Residual Convolutional Unit (DR-MSR-CU).

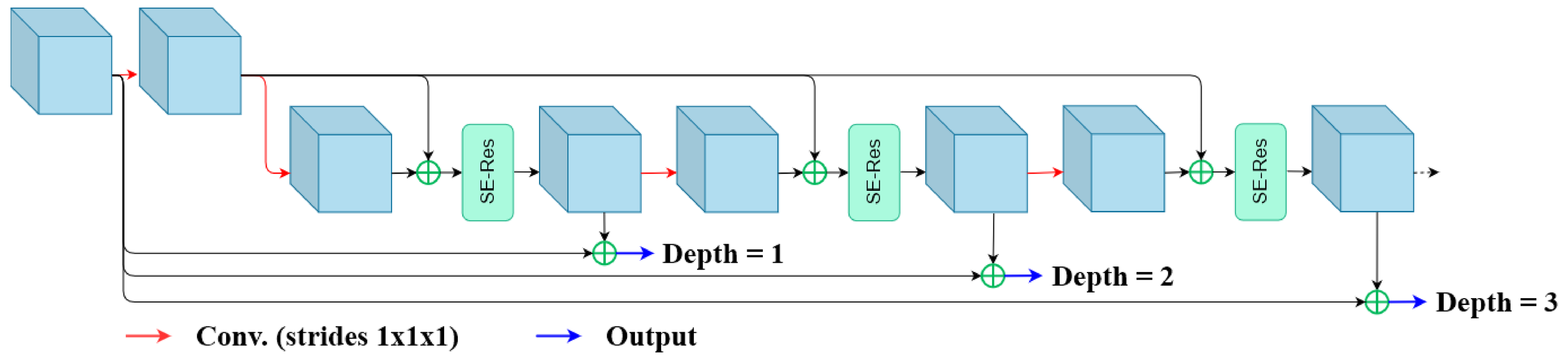

Fig. 2. Dynamic-Recurrent Multiscale Dilated Residual Convolutional Unit (DR-MSR-CU) with Squeeze-and-Excitation Residual module.

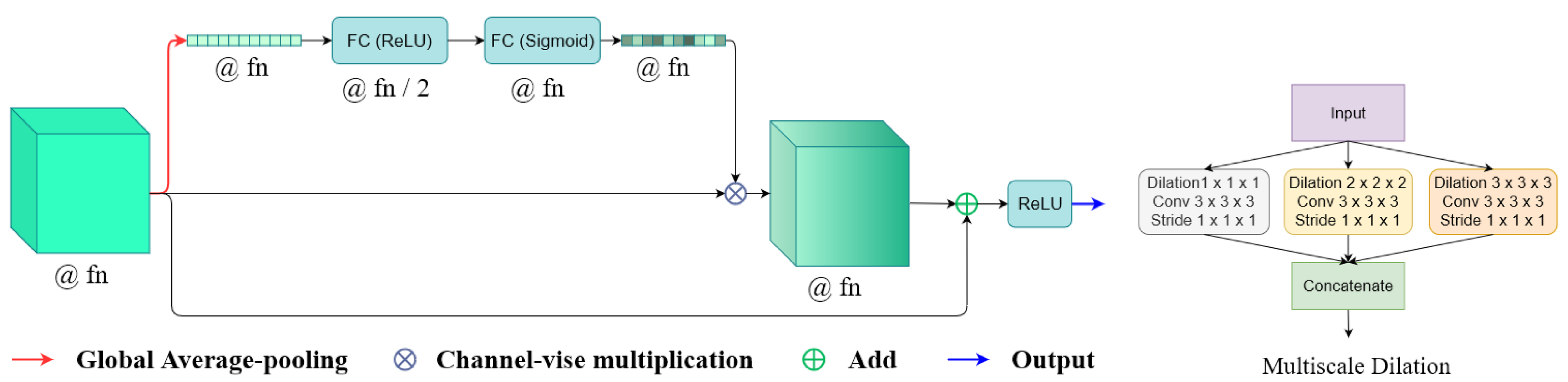

Fig. 3. Squeeze-and-Excitation Residual module, Multiscale Dilation module.

- We have considered Soft-DSC, which is a variant of the Dice Similarity Coefficient (DSC). We are using Exponential Logarithmic Loss calculated with the addition of DSC and Weighted Cross Entropy with Logits (WCEL), with a ratio.

$$Soft\ DSC = \frac{2\sum_i^N p_i g_i}{\sum_i^N p_i^2 + \sum_i^N g_i^2} \quad (1)$$

$$Loss_{ELL} = w_{DSC} Loss_{DSC} + w_{Cross} Loss_{Cross} \quad (2)$$

$$Loss_{DSC} = (-\ln(DSC))^{\gamma_{DSC}} \quad (3)$$

$$Loss_{WCEL} = WCEL^{\gamma_{WCEL}} \quad (4)$$

Experimental Results

- LUNA16 consists of 888 CT scans. We have considered 876 CT scans in our analysis, out of which 100 CT scans are for training, and 776 CT scans are for testing. We tested our architecture with VESSEL12 and compared the results with Extended V-Net and V-Net in Table 1.

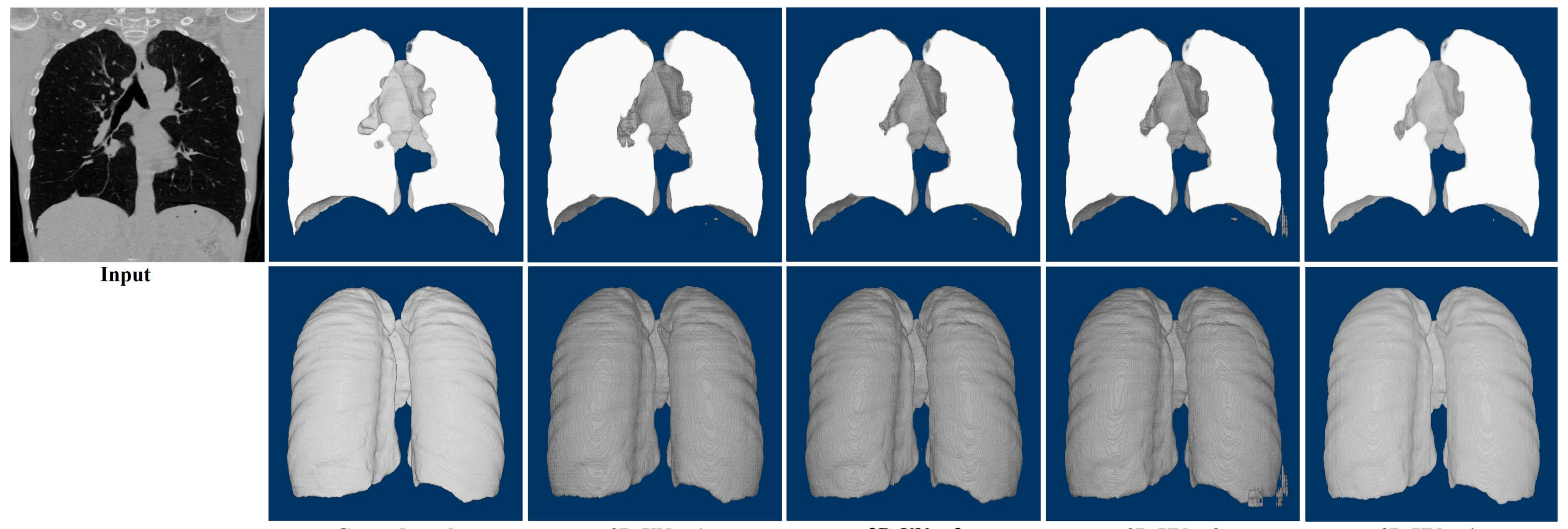

Fig. 4. Visualization of 3D CT scan, ground-truth, and the segmentation results using the proposed methods. The first row and second row show the dissected and entire lungs, respectively.

Table 1. Comparison of Soft-DSC from proposed architecture with [2], for VESSEL12, and LUNA16 (776 CT scans) as testing sets.

	Extended V-Net [2]	V-Net [3]	3D-UNet-4
Training scans	700	700	100
Training iterations	8400	8400	12500
Soft-DSC (VESSEL12)	0.987	0.972	**0.9920**
Soft-DSC (LUNA16)	–	–	**0.9859**

Applicability for COVID-19 Diagnosis

- This is the application of a trained segmentation model on LUNA16, for segmenting the lungs to simplify the detection and segmentation of Ground-Glass Opacities (GGO) regions produced by COVID-19.

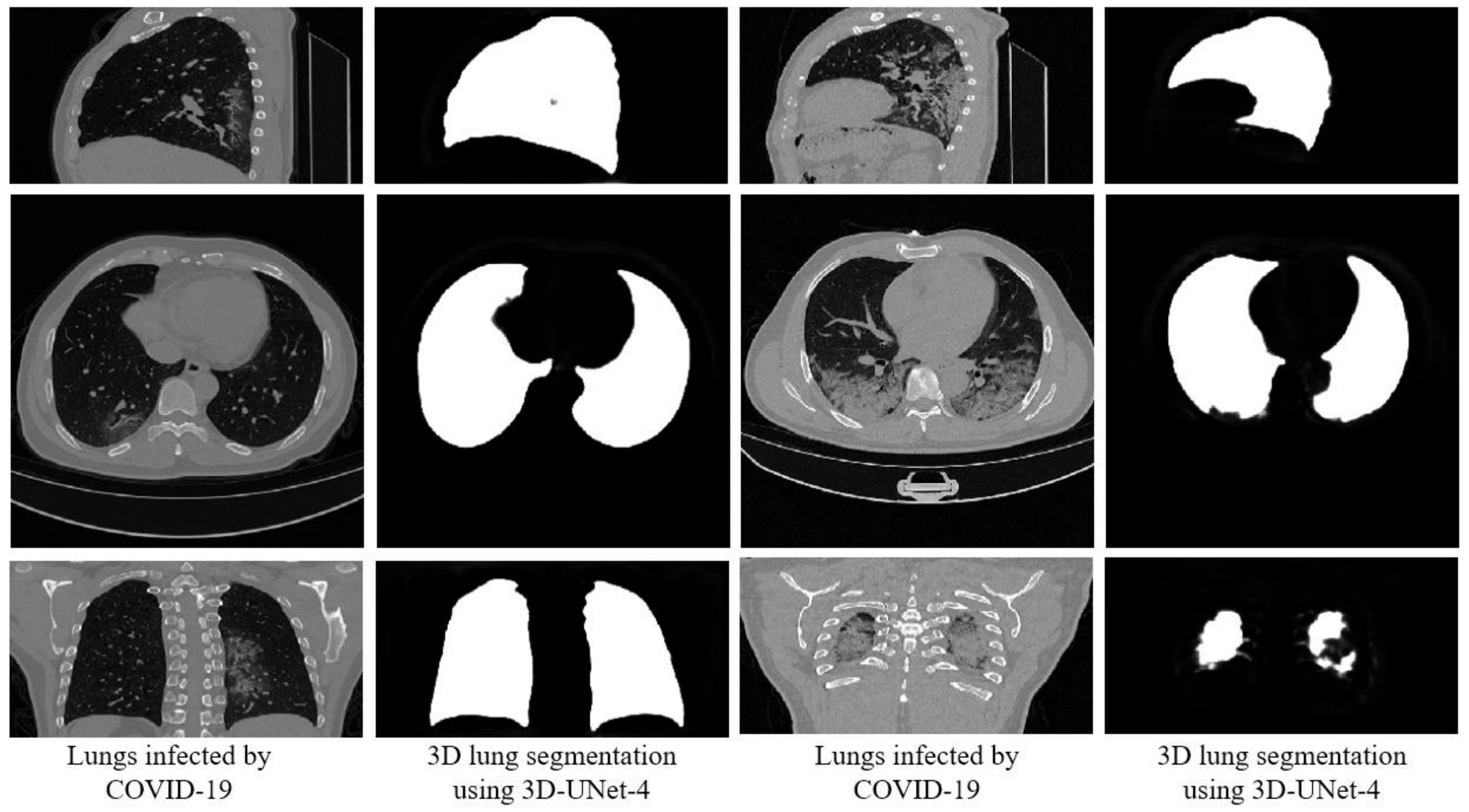

Fig. 5. Lungs infected by COVID-19 and 3D lung segmentation using proposed 3D-UNet-4.

Conclusion

- We have proposed our deep neural network with its variants. We have used less number of training samples without applying data augmentation and achieved state-of-the-art results. The current research can be helpful in the segmentation of nodules from the segmented lungs, and also other modalities of medical imaging.

References

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2. Patrick Sousa, Adrian Galdran, Pedro Costa, and Aurélio Campilho. "Learning to Segment the Lung Volume from CT Scans Based on Semi-Automatic Ground-Truth.", IEEE, 2019.
3. Fausto Milletari, Nassir Navab, and Seyed-Ahmad Ahmadi. "V-net: Fully convolutional neural networks for volumetric medical image segmentation." 2016 Fourth International Conference on 3D Vision (3DV). IEEE, 2016.