Deep Learning Architecture For Brain Vessel Segmentation

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Introduction

We explore and propose an automated method for brain vessel segmentation to alleviate the following identified problems:

- Difficulty and delay in manual vessel segmentation due low contrast images from medical imaging processes.
- Health Hazards of contrast enhancing dyes
- Cost involved in manual brain vessel segmentation

A transfer learning approach is adapted to perform vessel segmentation of the human brain [1].

Convolutional Neural Networks (CNN)

CNNs are the main deep learning structures used in image processing and the main architectures used in this task. They consist of several layers for different purposes illustrated below.

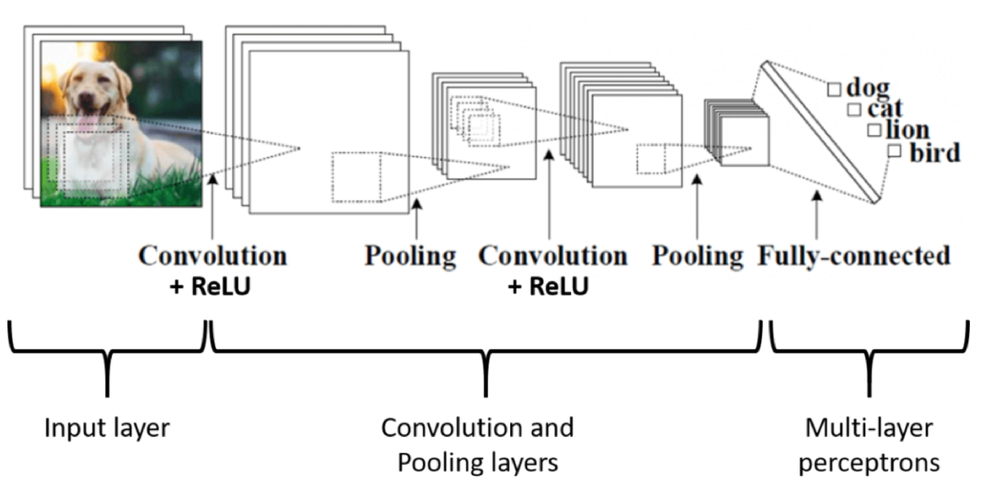

Fig. 1: CNN Architecture [2]

Mathematically, the continuous convolution of two functions in 1 dimension is expressed by;

$$f(t) * g(t) = \int_0^t f(\tau)g(t-\tau)d\tau. \quad (1)$$

Convolutions have several properties including:

- Commutativity
$$f * g = g * f; \quad (2)$$
- Associativity
$$f * (g * h) = (f * g) * h; \quad (3)$$
- Distributivity
$$f * (g + h) = (f * g) + (f * h). \quad (4)$$

A special type of CNN, the Fully Convolutional Network(FCN) is mostly used in segmentation tasks. A common filter applied for this task is the edge detection filter illustrated below.

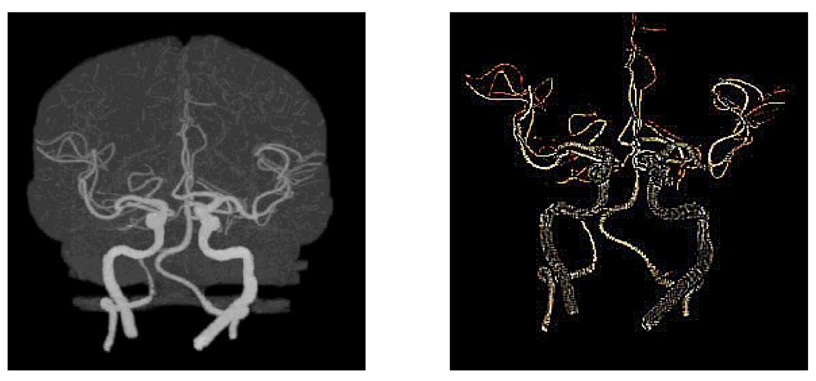

Fig. 2: Convolution on Circle of Wilis

BackBone Model Architecture

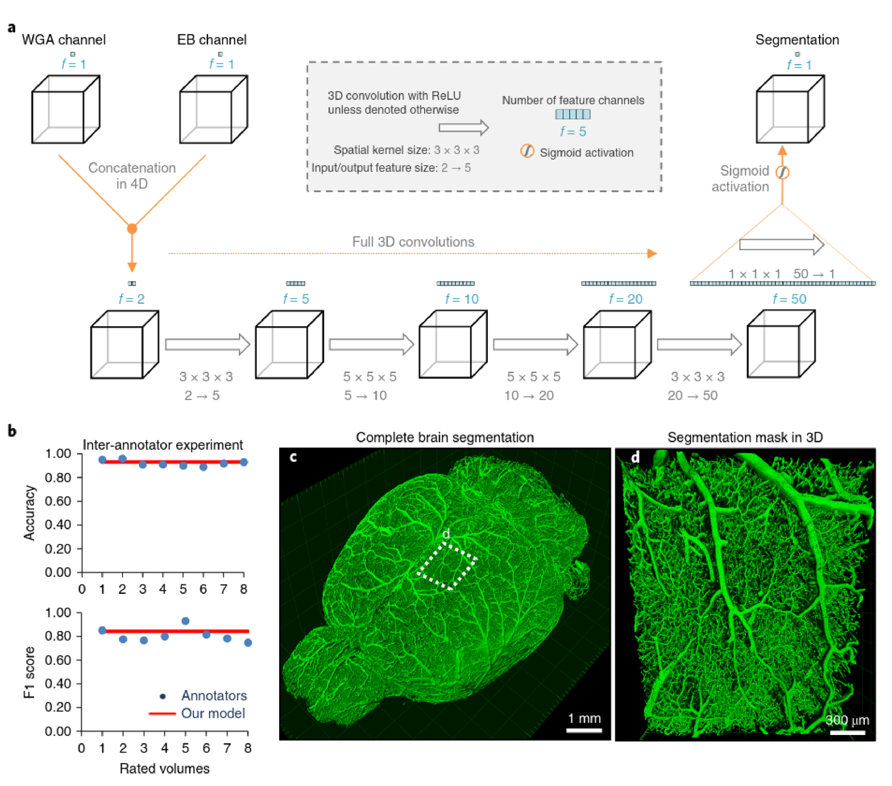

Fig. 3: Vessap Architecture [3].

Evaluation metrics of the different segmentation approaches for 75 volumes of 100 × 100 × 50 pixels (s:seconds).

Segmentation model	CI-F1	Accuracy	F1-Score	Jaccard	Parameters	Speed
VesSAP CNN	**0.93 ± 0.02**	**0.94 ± 0.01**	**0.84 ± 0.05**	**0.84 ± 0.04**	**0.0587 m**	**1.19 s**
VesSAP CNN, trained from scratch	**0.93 ± 0.02**	**0.94 ± 0.01**	**0.85 ± 0.04**	**0.85 ± 0.04**	**0.0587 m**	**1.19 s**
VesSAP CNN, synthetic training data	0.87 ± 0.02	0.90 ± 0.05	0.72 ± 0.07	0.70 ± 0.05	**0.0587 m**	**1.19 s**
3D U-Net	**0.93 ± 0.02**	**0.95 ± 0.01**	**0.85 ± 0.03**	**0.85 ± 0.03**	178.4537 m	61.22 s
V-Net	**0.94 ± 0.02**	**0.95 ± 0.02**	**0.86 ± 0.07**	**0.86 ± 0.07**	88.8556 m	26.87 s
Frangi Vesselness	0.84 ± 0.03	0.85 ± 0.03	0.47 ± 0.19	-	-	117.00 s
Markov Random Field	0.86 ± 0.02	0.85 ± 0.03	0.48 ± 0.04	-	-	24.31 s

Fig. 4: Vessap Results [4].

Transfer Learning

We perform transfer learning as a method to solve the unavailability of manually annotated images. This approach allows us to start with learned features before adjusting these features to suit the specific segmentation task we want to carry out instead of starting the process all over from scratch.

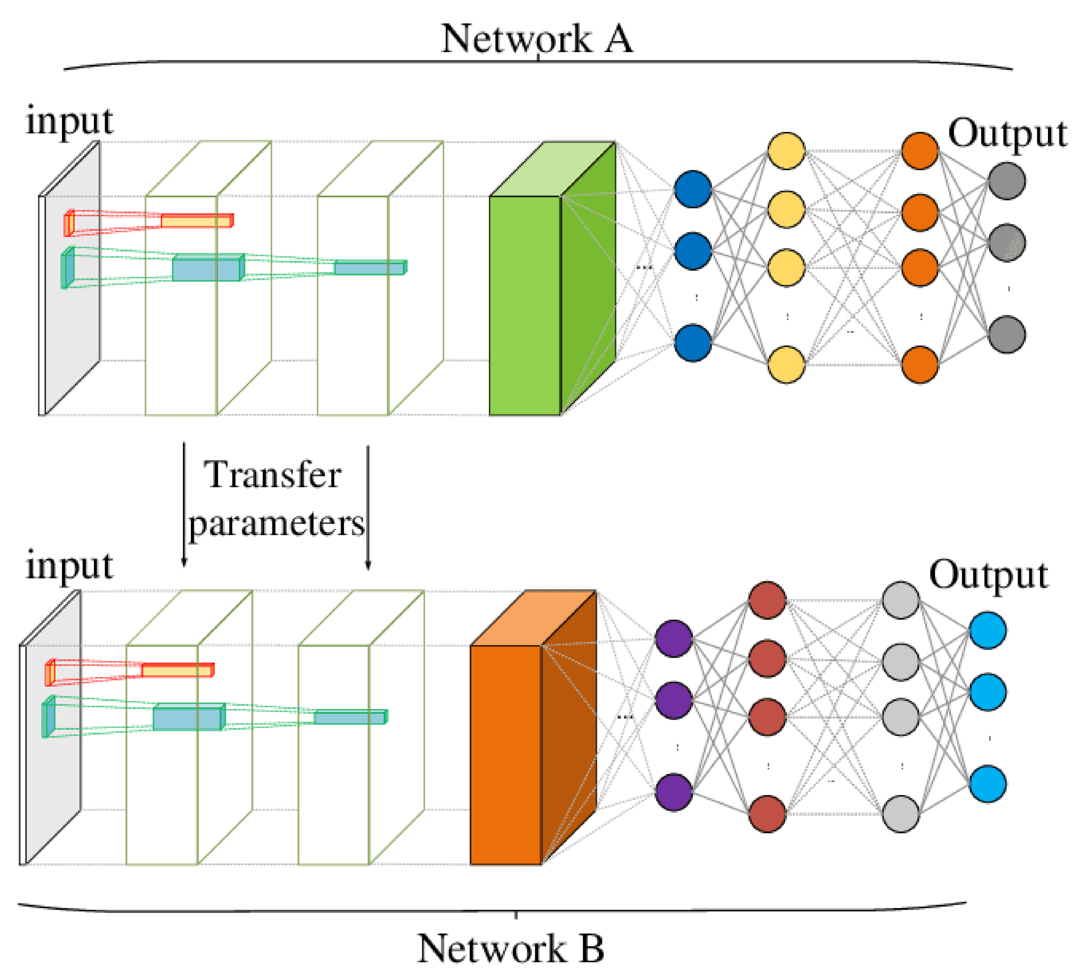

Fig. 5: Illustration of transfer learning [5].

Our approach mainly involved hyper-parameter tuning to enable the deep learning architecture to work on our task of human brain segmentation

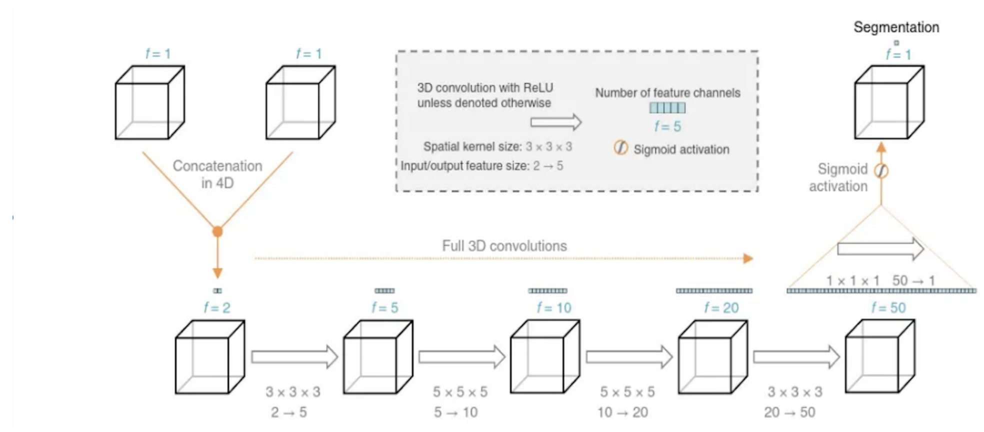

Fig. 6: Illustration of pre-trained model

Vessap Model Vs Fine-tuned Model		
Data	Volumes of Mouse Brain	Volumes of Human Brain
Input	Images stained with dye	Low contrast MRA images concatenated
Execution time	5 minutes execution time	4 minutes execution time
Crosshair filters	False	True
Normalize Data	Max	Max
Input Channel	2	1
Batch size	10	12
learning rate	0.01	1
Cube size	64	32
Threshold	0.5	0.6
Optimizer	Adam	SGD

Evaluation

We evaluate the performance of the model on the datasets mentioned in the previous section. Metrics used to measure predictions are Accuracy, F1-score, Precision and Recall. These metrics are calculated in terms of TP, TN, FP and FN.

- Accuracy is expressed as
$$A = \frac{TP + TN}{TP + TN + FP + FN};$$
- Precision is expressed as
$$P = \frac{TP}{TP + TN};$$
- F1score is expressed as
$$P = \frac{2TP}{2TP + FN + FP};$$

The class balancing loss function with stable weights is implemented to account for general class imbalances.

$$L(W) = L(W_1) + L(W_2)$$
$$L_1(W) = -\frac{-1}{|Y_+|}\sum_{j\in Y_+} logP(y_j = 1|X;W) - \frac{1}{|Y\_|}\sum_{j\in Y\_} logP(y_j = 0|X;W)$$
$$L_2(W) = -\frac{\gamma_1}{|Y_+|}\sum_{j\in Y_{f+}} logP(y_j = 0|X;W) - \frac{\gamma_2}{|Y\_|}\sum_{j\in Y_{f\_}} logP(y_j = 1|X;W)$$

$$\gamma_1 = 0.5 + \frac{1}{Y_{f+}}|\sum_{j\in Y_{f+}} P(y_j = 0|X;W) - 0.5|$$

$$\gamma_2 = 0.5 + \frac{1}{Y_{f\_}}|\sum_{j\in Y_f} P(y_j = 1|X;W) - 0.5|$$

Qualitative Results

VesSAP enables reliable segmentation and feature extraction (bifurcation points, radius and centerlines) down to the capillary-level from the imaging data. We provide results of the segmentation of the Vessap Model as well as results of our pre-trained model.

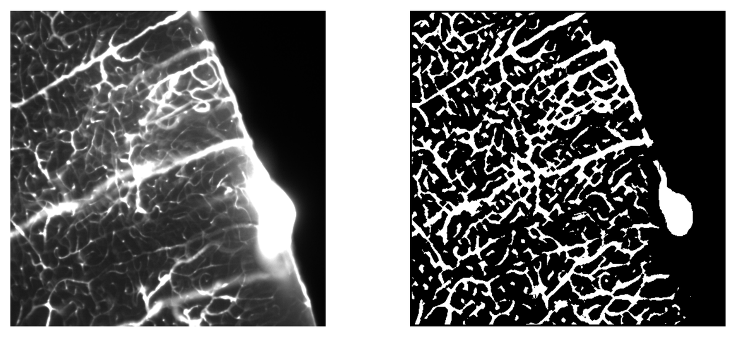

Fig. 7: Original and Segmented Slices of Vessap Segmentation

Fig. 8: Original and Segmented Slices of ABDIV Data

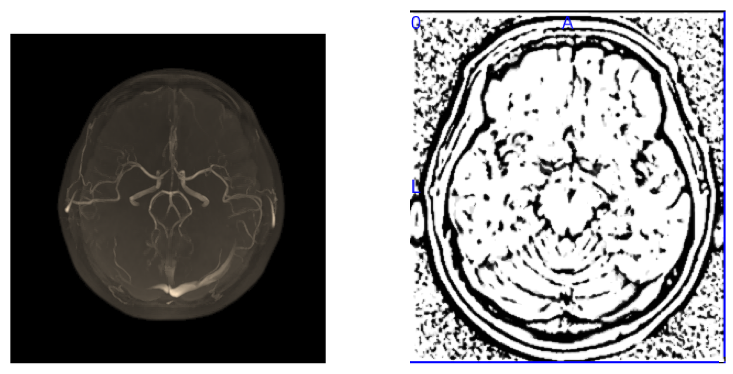

Fig. 9: Original and Segmented Slices of MRA Data

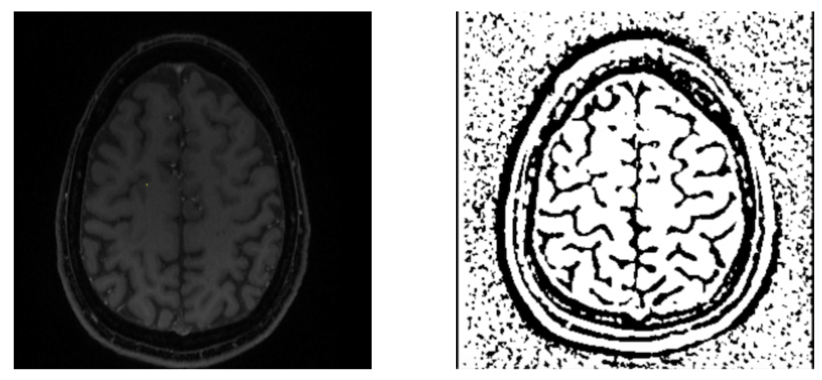

Fig. 10: Original and Segmented Slices of IXE Data

Metrics and Features Extracted		
Features/Metric	MRA Data	IXE Data
Loss	7.9870e-07	6.9870e-07
Metric	0.9	0.8
Centerlines	True	True
Max Radius	18.98	17.42
Min Radius	3.82	2.96
Skeleton Length	63934	43934
Bifurcations	9725	8742

Remarks

We presented automated method of brain vessel segmentation with deep learning architectures. This method required lesser resources and time as compared to manual vessel segmentation. We used a transfer learning approach with deepvesselnet to segment and extract features on volumes of the human brain. Due to lack of annotated ground-truth images, feature extraction yielded low performance.

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