Reconstruction of Coronary Vessels from Angiographic Data using a Convolutional Neural Network

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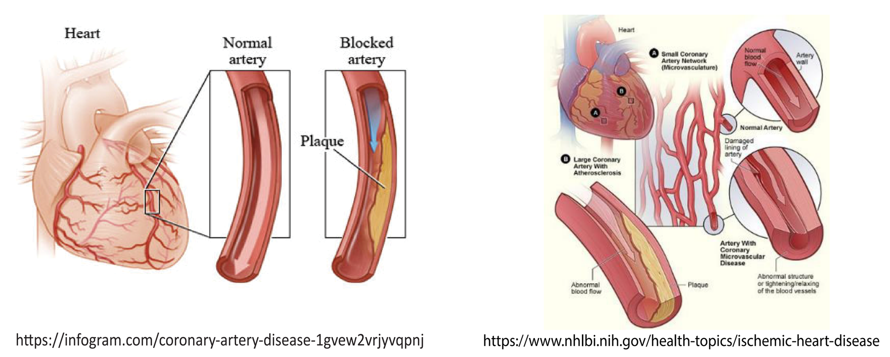
Introduction

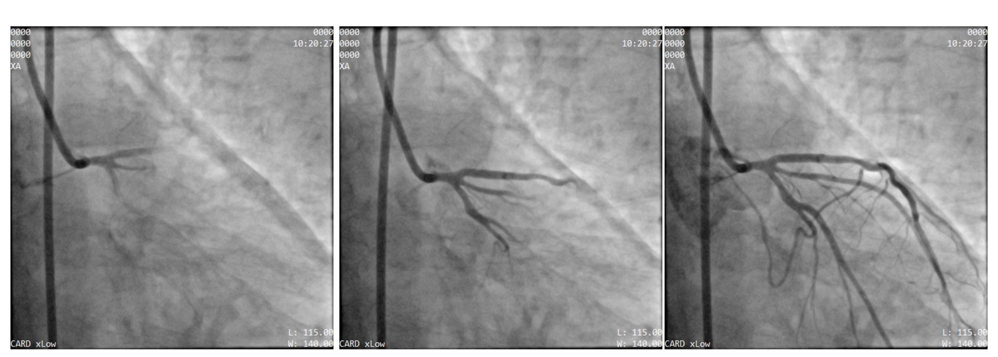
Coronary Artery Disease (CAD)

CAD is characterized by plaque build-up in the coronary arteries, leading to a narrowing known as stenosis [1]. Severe stenosis can lead to ischemia in the heart muscle. Stenosis can also cause microvascular remodeling, further increasing the risk of ischemia [2].



Coronary X-Ray Angiography

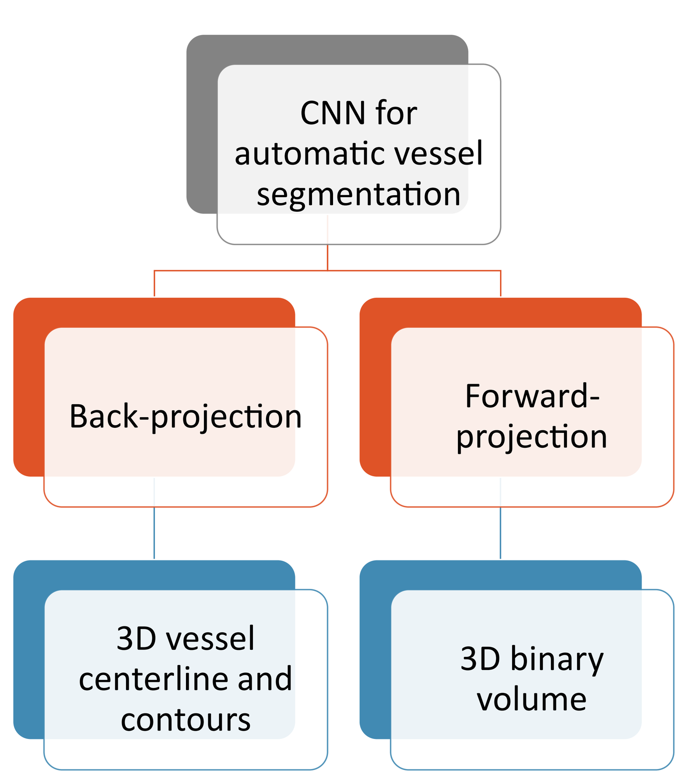
The gold standard diagnostic method for CAD is X-ray angiography. A catheter is inserted into the patient and positioned in the aortic sinus. Radio-opaque dye is injected via catheter into the coronary arteries, and X-ray images are taken as the dye flows through the vessel.



Once the dye has perfused the entire vessel, the cardiologist will perform a visual inspection of the angiography images to identify stenosis and estimate the percent cross-sectional area reduction of the vessel. If the stenosis is severe (% diameter reduction > 70%), coronary revascularization is recommended.

Since this method uses 2D projections to estimate the flow in the 3D vessel and does not take into account pressure or flow information, it often leads to over-estimation of disease severity. A system to reconstruct the 3D geometry of the vessels would lead to more accurate diagnostic decisions, and could be used in further analyses such as Fractional Flow Reserve (FFR) computation.

3D Reconstruction of Coronary Geometry



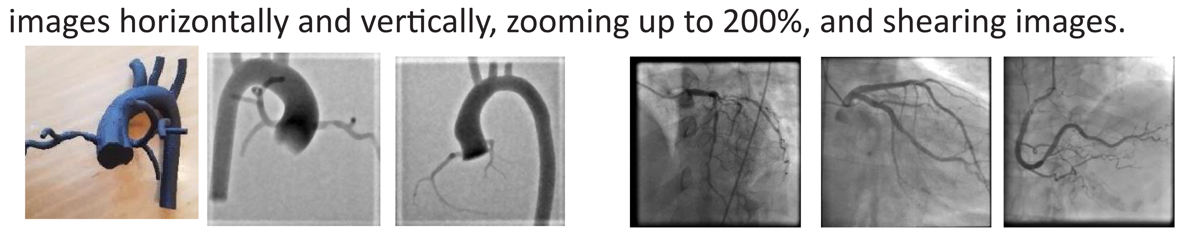
The workflow for generating a 3D reconstruction of the coronary geometry from angiography images is given above. A convolutional neural network, or CNN, will be trained to automatically identify the vessel in the angiography image. Two methods of 3D reconstruction will be explored: back-projection and forward-projection. In both cases, the segmented images will be used as an input to the algorithm and a 3D model of the coronaries will be the output.

bloodflow.engin.umich.edu

Methods

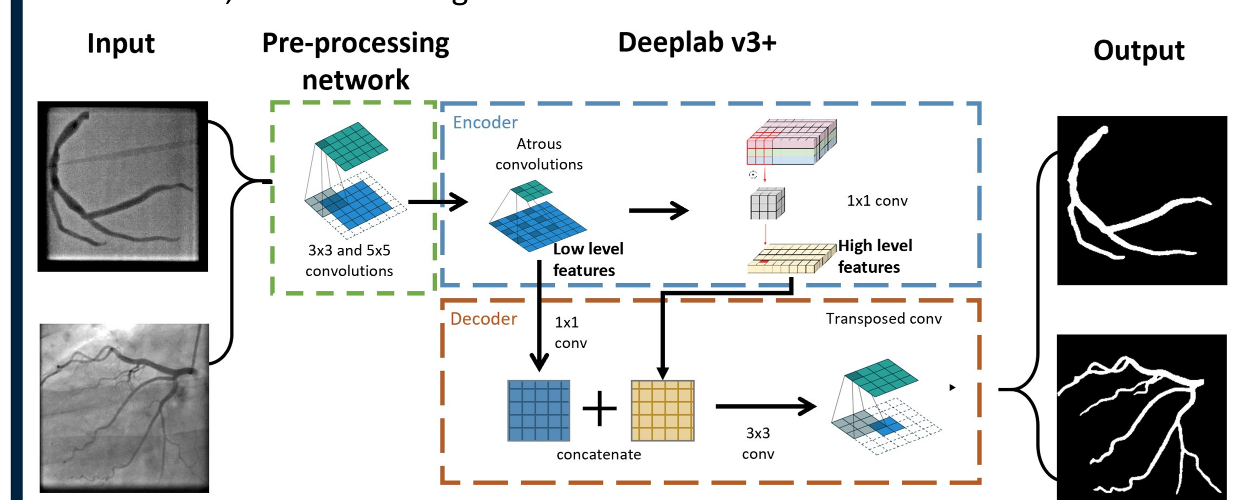
Automatic Vessel Segmentation

A convolutional neural network (CNN) was used for segmentation of synthetic and clinical biplane angiograms. The synthetic dataset was created by imaging 3D printed phantom models of the coronary tree, while clinical data was obtained from the University of Michigan hospital. Datasets were augmented by flipping images horizontally and vertically, zooming up to 200%, and shearing images.



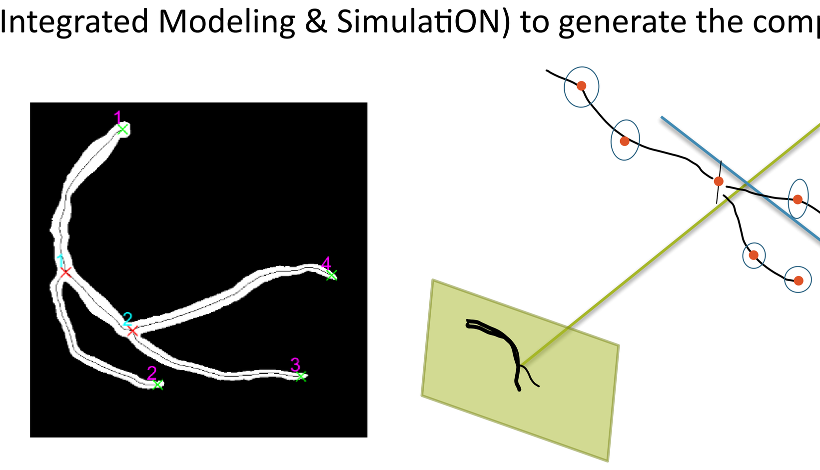
Synthetic angiograms **Clinical angiograms**

A pre-processing neural network was trained to mimic several unsharp mask filters in order to improve boundary sharpness and local contrast. The pre-processing network was then combined with the Deeplab v3+ network [3,4] to produce an end-to-end semantic segmentation network that can accommodate noisy, low-contrast, real world image data.



Back-projection

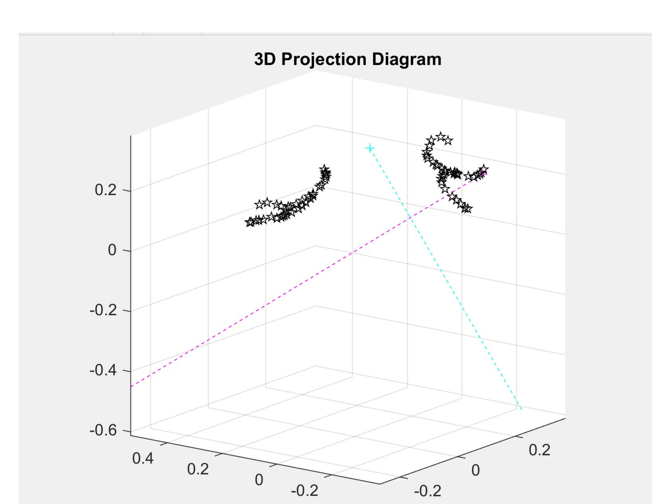
A segmented pair of biplane images were input into a skeletonization algorithm [4] to identify the centerline. Epipolar line geometry was used to match at least 30 points along the vessel centerline in each image. A back-projection algorithm was then used to reconstruct the 3D vessel centerline and radius contours from the skeletonized biplane 2D image data. The output of the back-projection algorithm was lofted in our lab's hemodynamic modeling software, CRIMSON (CardiovasculaR Integrated Modeling & SimulatiON) to generate the complete 3D vessel geometry.



CRIMSON
www.crimson.software

Forward-projection

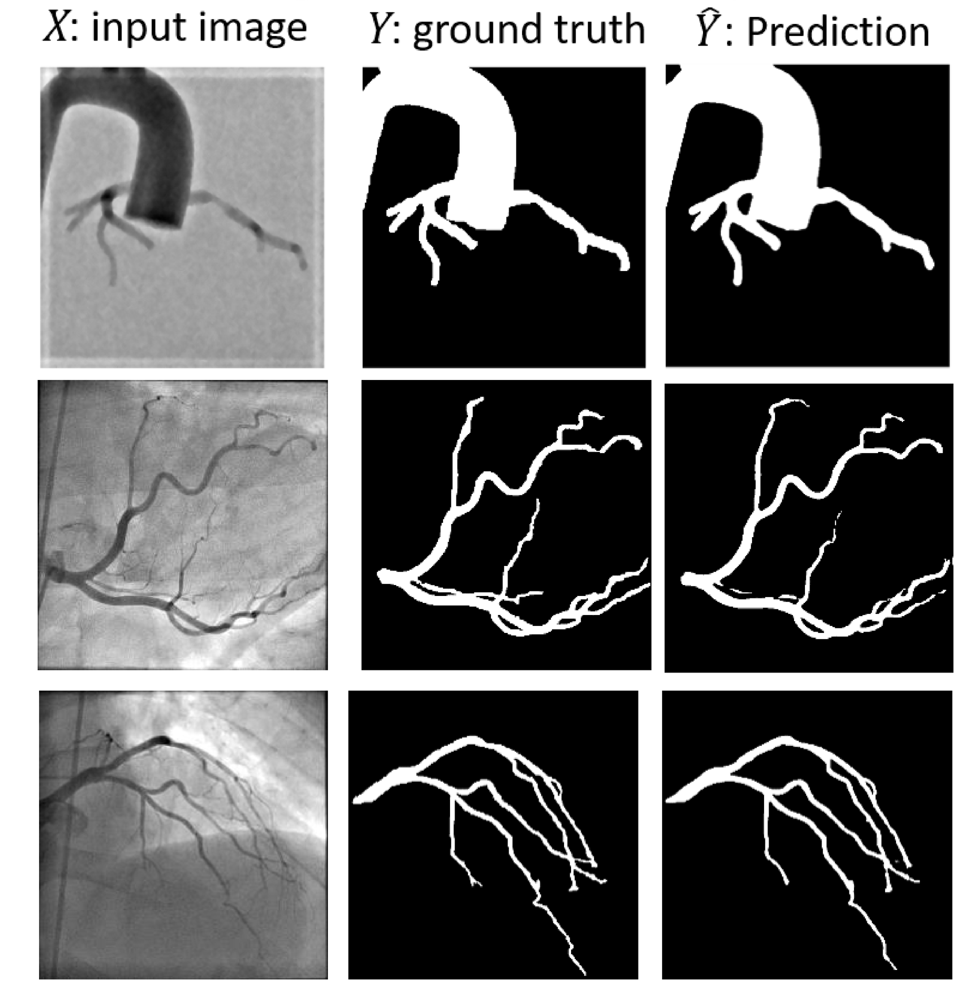
A 3D volume centered at the imaging isocenter was subdivided into voxels of dimension 0.3mm. Each voxel was projected onto the 2D segmented angiography images; if the voxel projected onto a vessel pixel in all images, the voxel was classified as a vessel. Once the binary 3D volume was generated, a smoothing algorithm was applied to ensure vessel wall smoothness.



Results

Segmentation Accuracy

X: input image Y: ground truth $\hat{Y}$: Prediction



Segmentation accuracy was measured using Mean Intersection Over Union (MIOU) and the Dice score. The formulas and accuracy metrics are given below.

$$IOU = \frac{|Y \cap \hat{Y}|}{|Y \cup \hat{Y}|}$$

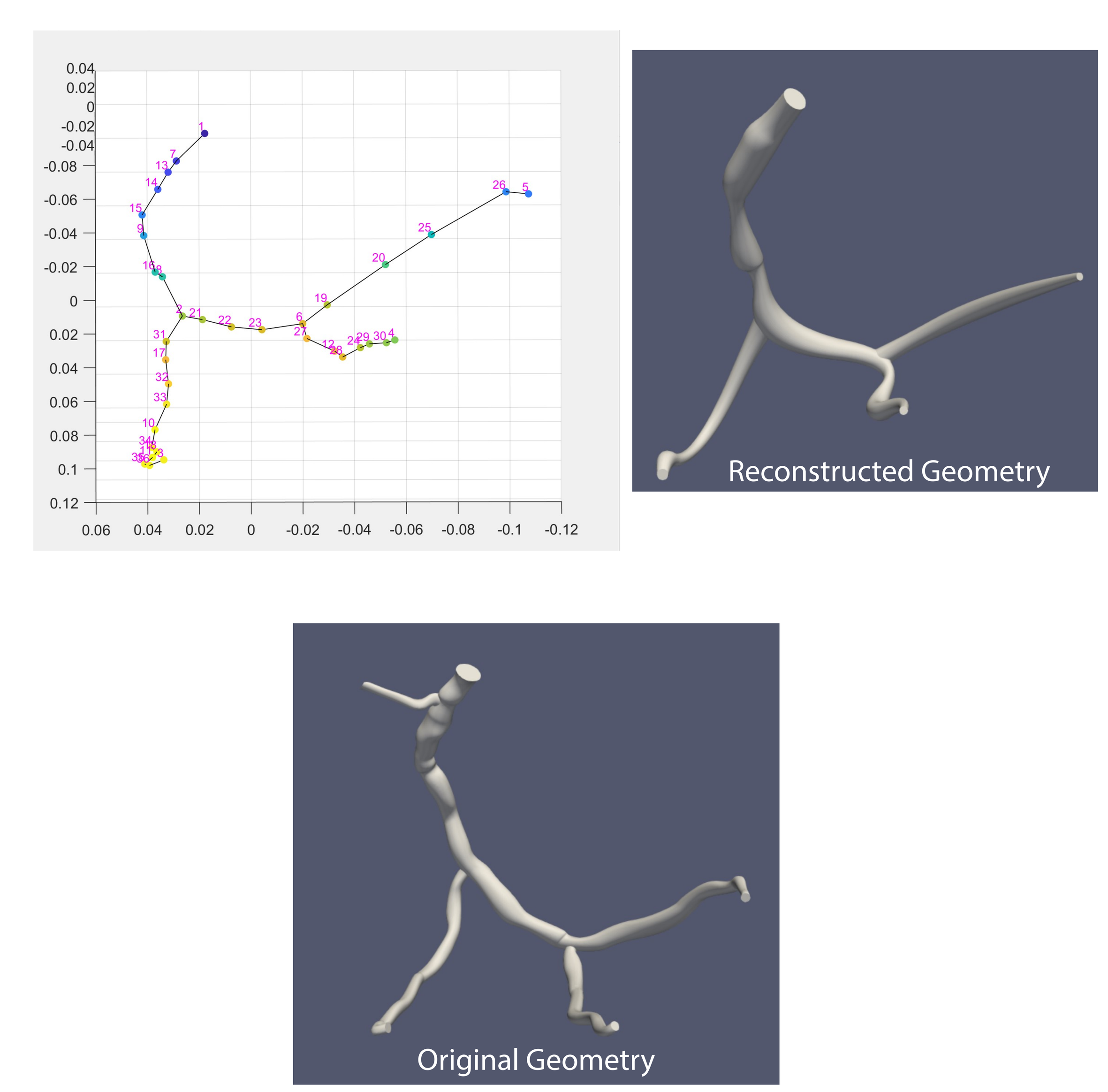
MIOU is the average of IOU for each class

$$Dice = \frac{2|Y \cap \hat{Y}|}{|Y| + |\hat{Y}|}$$

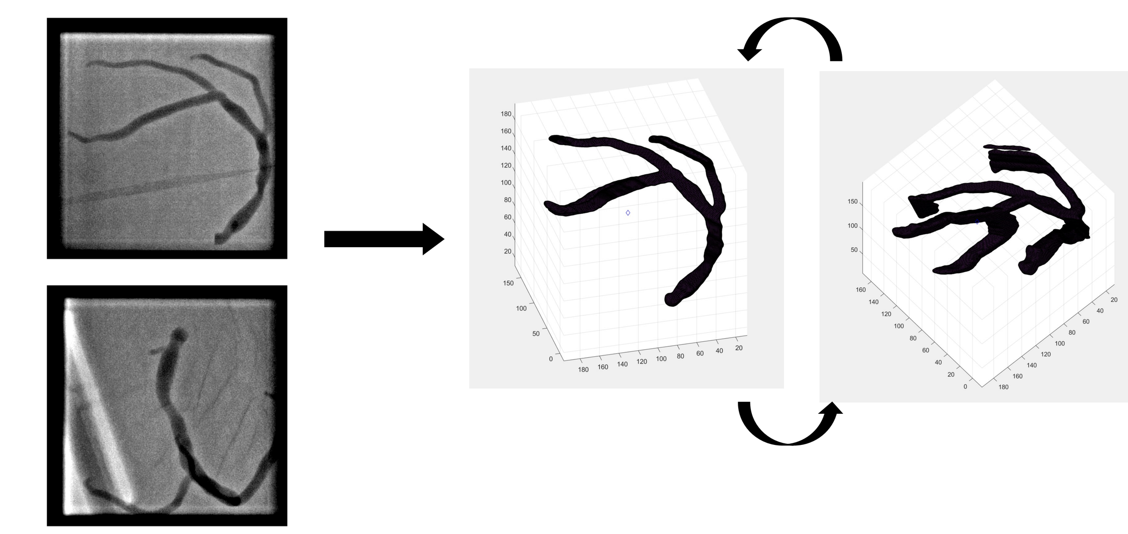
	Synthetic Data	Clinical Data
MIOU	0.975	0.917
Dice	0.980	0.916
Sensitivity	0.980	0.952
Specificity	0.994	0.995

Skeletonization results on synthetic data is shown below. 36 points were co-located in the two planes and used to reconstruct the 3D centerline. The complete reconstructed 3D geometry is shown above the original 3D printed model.

Back-projection



Forward Projection



Forward projection with two biplane images led to a non-unique 3D reconstruction. In order to improve the reconstruction, more images must be added to the reconstruction algorithm, requiring algorithms to account for patient table motion during angiography acquisition.

Future Directions

1) Incorporate more angiography images to improve 3D reconstruction instead of using biplane angiography images

2) Explore other methods of 3D reconstruction, such as deformable models

3) Use 3D reconstructions of coronaries for computational analysis, such as FFR computation

Acknowledgments

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