Emory REU Cardiology Project, Comparison of Segmentation Techniques

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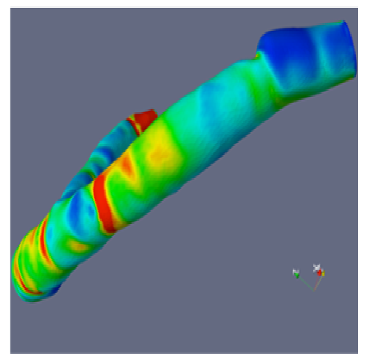
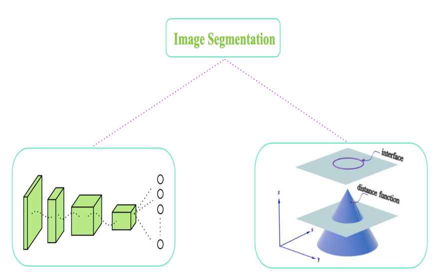
Introduction



- **Imaging** has been revolutionizing medical research and clinical practices for decades.
- **Segmentation** is the image processing step to identify a region of interest (an artery, a bone, etc.) in an image.
- Here, we focused on **Optical Coherence Tomography (OCT)** of Coronaries.
- We analyzed two segmentation approaches: the **Level-Set Method** and **Machine Learning based on Convolutional Neural Networks**.

Level Set Methods & VMTK Results

The **Level Set Method** utilizes implicit functions to identify the region of interest in an image, where the implicit function is the numerical solution of a Partial Differential Equation (PDE) that is defined on the image that is being segmented. The level set function ϕ is evaluated by



$$\frac{\partial \phi}{\partial t} + \nabla \bullet (\mathbf{u}\phi) = 0$$

where the vector $\mathbf{u}$ depends on the grey levels of the image.
The solution ϕ describes the time-dependent position of the interface $\Gamma(t)$

$$\Gamma(t) = \{x \in \Omega : \phi(x,t) = 0\}$$

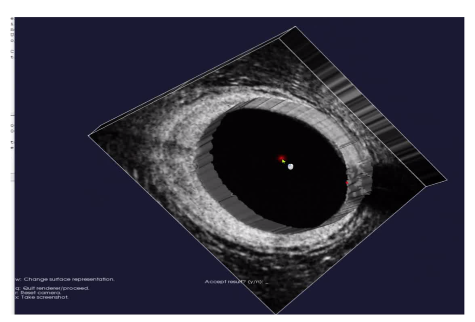


Figure 1: VMTK Result

The basic idea of the Level Set is to correlate the velocity to the gray level of the image in such a way that the gray level of the image is driving the evolution of the ϕ close to the boundary. The Level Set is a very powerful method that extracts the border of a region or image, and it can handle changing topology well. It is also a great tool because it utilizes physical concepts, such as velocity, mean curvature, and elastic energy for image segmentation problems. We used the image segmentation software, Vascular Modeling ToolKit (VMTK), that is based on the Level Set. VMTK is a collection of tools and libraries for image-based modeling of medical images. This segmentation method is model-driven, meaning that the technique is established on physical concepts of the problem.

FEniCS and MATLAB

The **FEniCS Project** is a research and software project, which is effective to generate mathematical methods and software to solve computational mathematical modeling problems. As the implicit function, the numerical solution of a PDE, is involved in our project, we tried to use **FEniCS** in **Python** for solving PDEs using finite element methods.
For **MATLAB**, our group used **Image Segmenter App** under **Image Processing Toolbox** and applied Thresholding, Active Contours, Graph Cut, Auto Cluster, etc. to segment 2-D images.For 3-D volumetric images, we used **Volume Segmenter** to create and refine binary or semantic segmentation masks to segment the images by means of automated, semi-automated, and manual techniques.

Convolutional Neural Networks & PyTorch

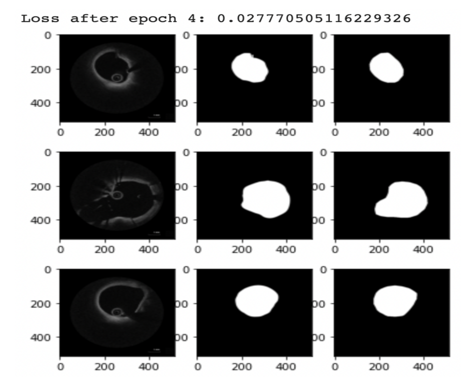
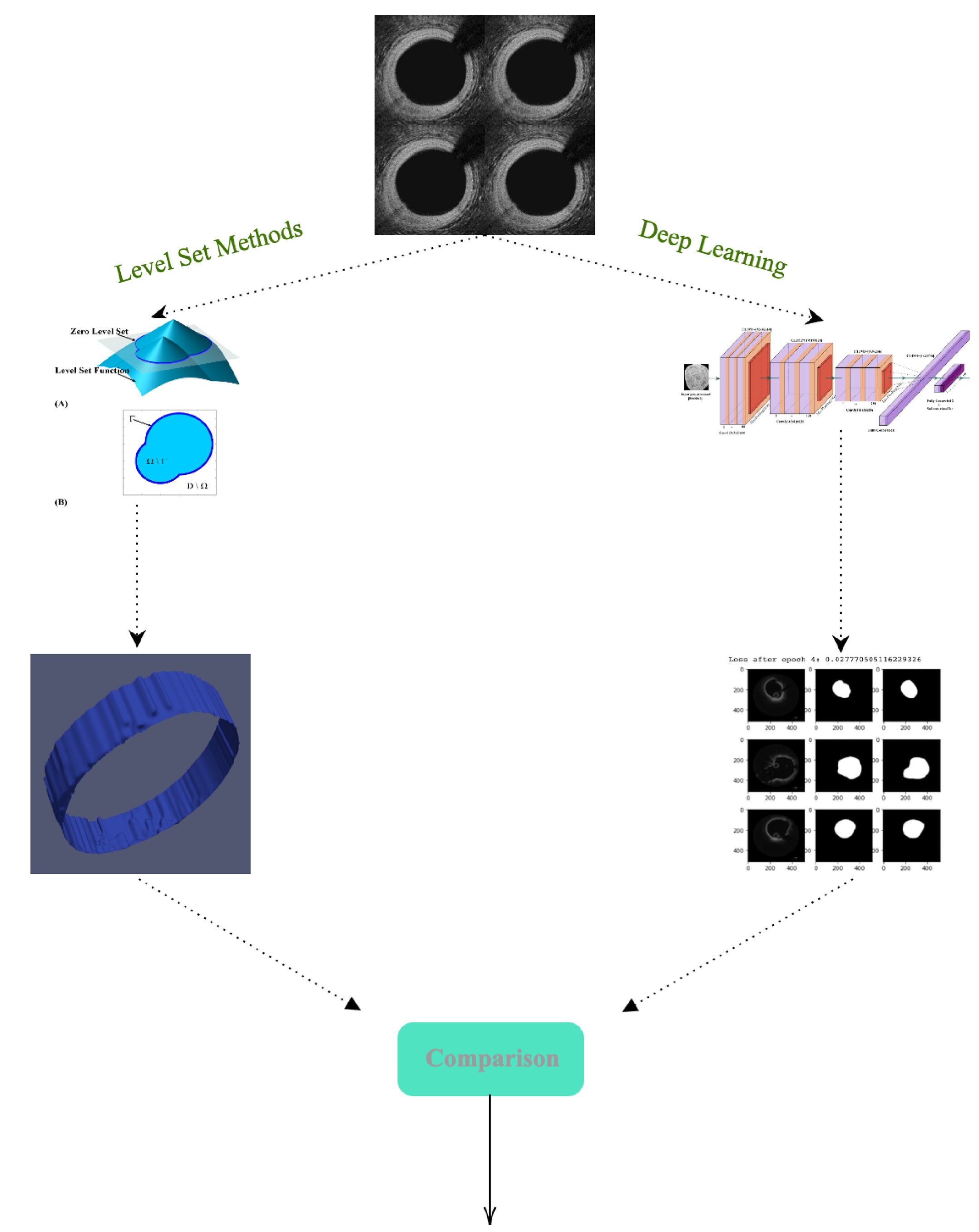


Figure 2: PyTorch Results

Convolutional Neural Networks are a deep learning algorithm for image classification. The CNN's convolutional layer parameters comprise of filters, where the values of the filters are learned during the training phase. The layers are for feature learning and classification, specifically for classifying the pixels in an image with respect to a background or vessel. We used the image processing software, PyTorch. The deep learning (DL) based method involves using training data from a database of images to train the algorithm in PyTorch.

Our Activities/Experiences



$$J(A,B) = \frac{|A \cap B|}{|A \cup B|}$$

The Jaccard Index

Acknowledgements

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- The National Science Foundation

Comparison

- **Which method was faster?** The deep learning method was much faster than VMTK, but it still required a waiting period to complete the epochs.
  - ➔ Our training and development data was relatively small.
  - ➔ Limitation of the DL approach:
  labeled large data sets are required for preventing CNN overfitting and increasing accuracy.
- **Which method required more human intervention?** VMTK segmentation required far more human intervention than the DL.
  - ➔ With VMTK, we had to initialize the image by selecting an initialization type, identifying a lower and upper threshold of pixel values, and placing seeds that identified the region we planned to segment.
  We also selected the coefficients for the Level Set equation.
  We actively supervised the segmentation to accept or reject the results.
  - ➔ The DL method required much less decision making.
  We empirically set a few parameters associated with training the CNN (training rate and number of epochs).
  The DL algorithm trained itself and segmented the OCT images without user participation.
- **Other advantages and limitations?** PyTorch is better at handling noise suppression than VMTK.
  On the other hand, VMTK handles the data normalization, contrast enhancement, and conversion of color images to grayscale better.

Results/Conclusions

Instead of preferring one method over the other, we can combine the two for better results: we could train a CNN for an optimal parameter selection to use in VMTK segmentation for setting the parameters. This could help since we encountered a set-back in determining the initialization type, thresholds, and parameters to set for the best segmentation result in VMTK: we combine the strengths/benefits of both **model-driven** and **data-driven** approaches.
➔ **Future works**: focus on improved segmentation using unsupervised DL where the machine uses image-derived features, or supervised learning that requires Gold Standard segmentation to train it.
The DL based algorithm demonstrated high accuracy based on Jaccard Index.
We should look into Edge-based deformable models, and approaches using blood vessel tracking algorithms and seeding points to find the minimum path according to image-derived metrics.

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