

# Segmentation of Heart Ventricles Using Skeletal Representations

Hasana Chaudry, Toshiro Kubota

Department of Computer Science, Susquehanna University, Selinsgrove, PA 17870



## Abstract

The objective of the project is to develop practical algorithms to segment the human heart's left and right ventricles from isotropic Magnetic Resonance Imaging (MRI). An advanced algorithm that allows for efficient analysis of the ventricles in 3D or 4D would help diagnose and treat numerous cardiac diseases and illnesses. The left ventricle is a convex-like structure whereas the right ventricle has a relatively more abstract shape. The constant blood flow in and out of the ventricles causes them to look different at any given time. Therefore, our data set is in 4D where the fourth dimension is time.

We designed two algorithms; both use a 1D skeletal representation of the volume. We tested the algorithms on 4 data sets provided by the Fornwalt Lab at Geisinger Hospital. Each data contains manual annotations of both left and right ventricles at end-systolic and end-diastolic phases. The experiments were run on a laptop with 1.80 GHz CPU with 8 GB RAM. For the first algorithm, the average Intersection over Union (IoU) and run-time was 68% and 26 seconds respectively for the left ventricle and 52% and 30 seconds respectively for the right ventricle at the end-diastolic. For the second algorithm, the average Intersection over Union (IoU) and run-time was 78% and 1.322 seconds respectively for the left ventricle and 55% and 1.83 seconds respectively for the right ventricle at the end-diastolic.

## Algorithms

Our algorithms take a 3D MRI volume and first reduces it to a 1D skeletal representation with figure-ground separation followed by morphological analysis. We think the skeletal representation is rich enough to keep the important structural information of ventricles while small enough to scale it to the 4D volume. The complete description of the reduction is beyond the scope of this poster.

The first algorithm (Algorithm I) further reduces the skeleton into a minimum spanning tree and asks a user for an edge that can separate the ventricle from the rest of the foreground. When the ventricle exhibits near convex-shape, a single skeletal branch connects the ventricle and the rest. Then, the user will be able to select the edge to separate the ventricle. However, when the ventricle is non-convex, there can be multiple skeletal branches that connect the ventricle to the rest. Then, three won't be a single edge that can clearly separate the ventricle.

The second algorithm (Algorithm II) circumvents the problem by asking the user for two points inside the ventricle: one near the atrium and the other near the apex. With these two points, the algorithm derives a shortest path tree from the atrium point. The path to the apex point defines the main skeleton of the ventricle. The algorithm uses the main skeleton to distinguish branches running closely with it and those deviating significantly from it. The former branches are considered intra-ventricle branches and used to segment the ventricle.

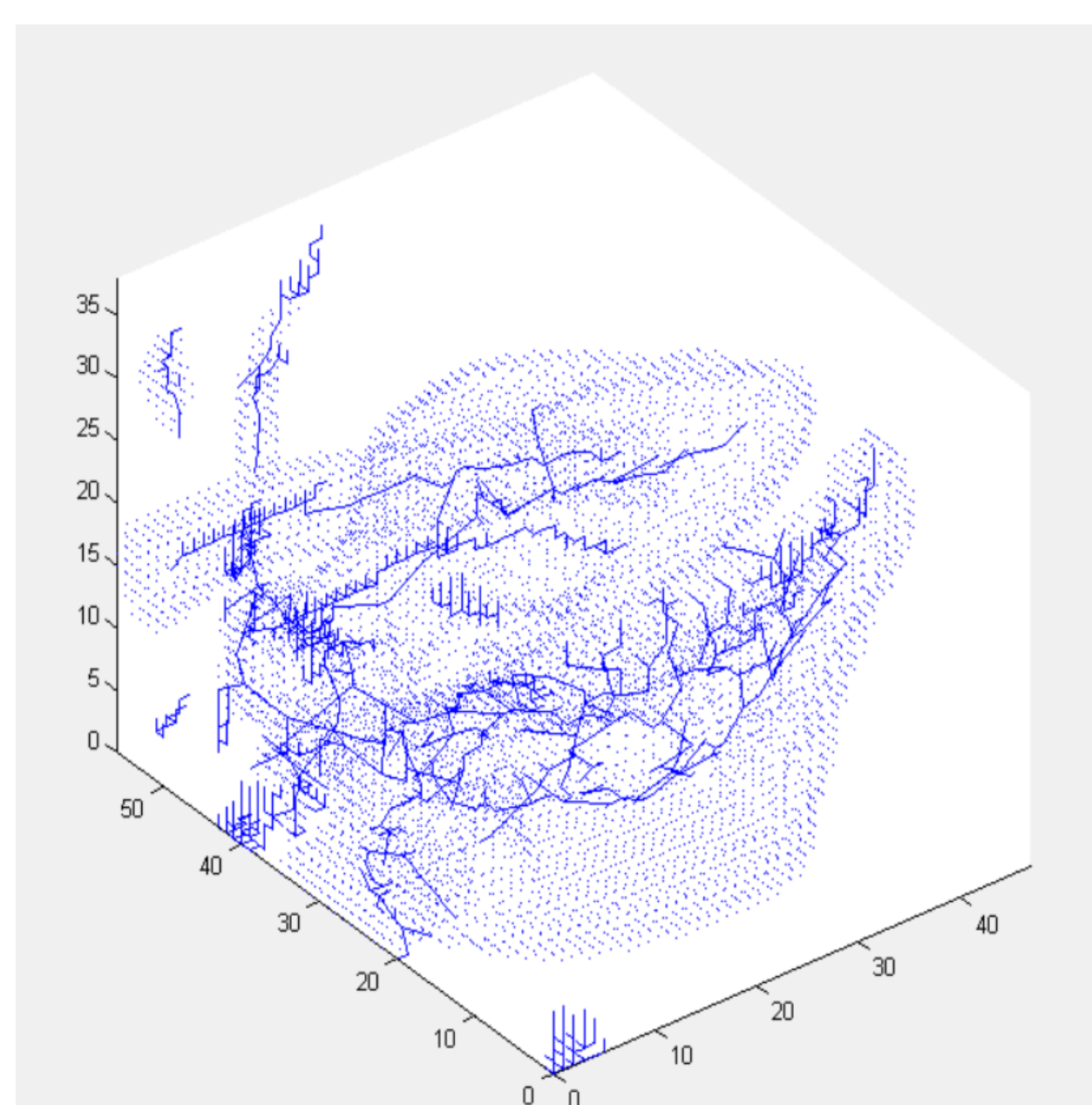


Figure 1

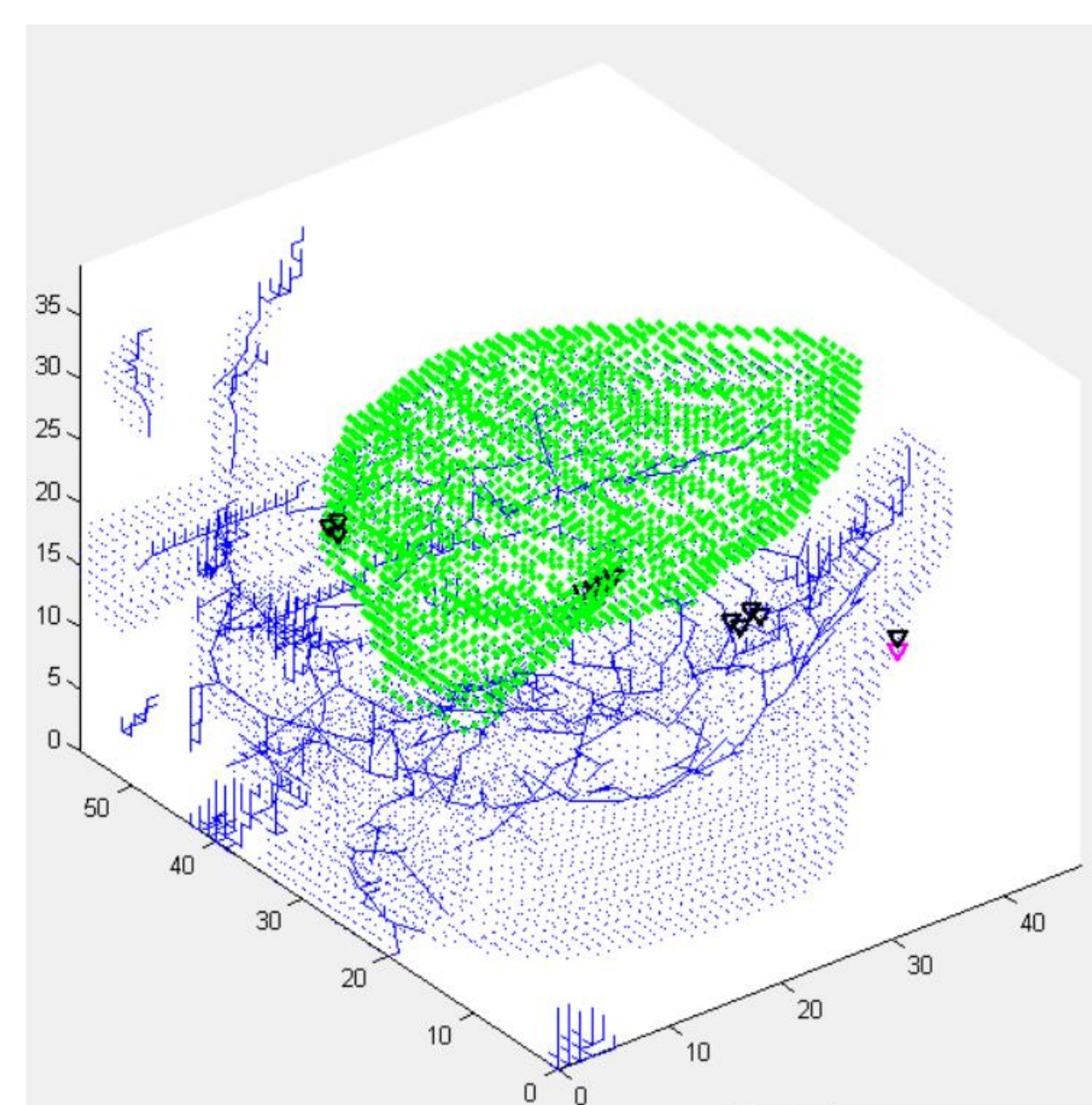


Figure 2

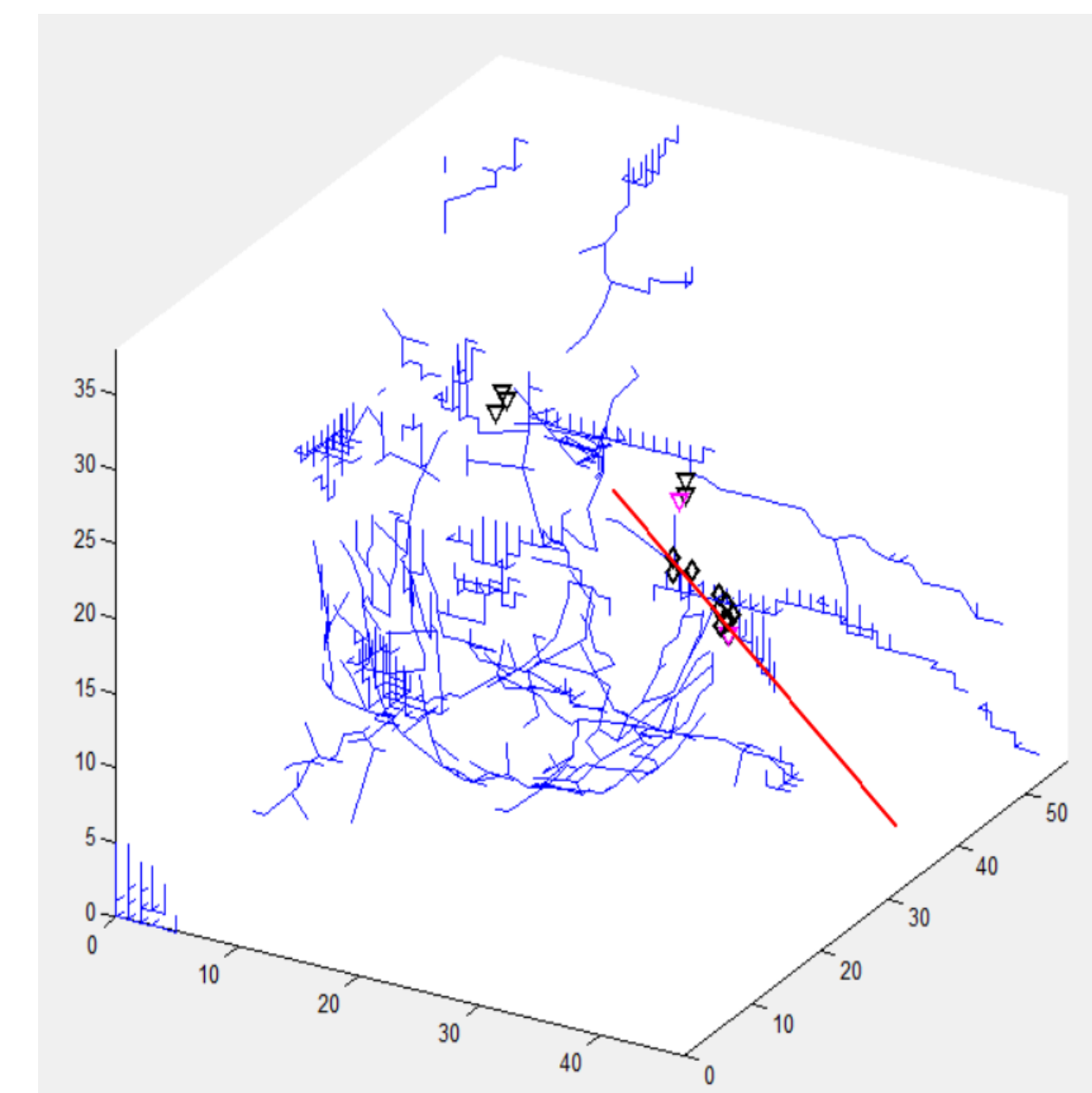


Figure 3

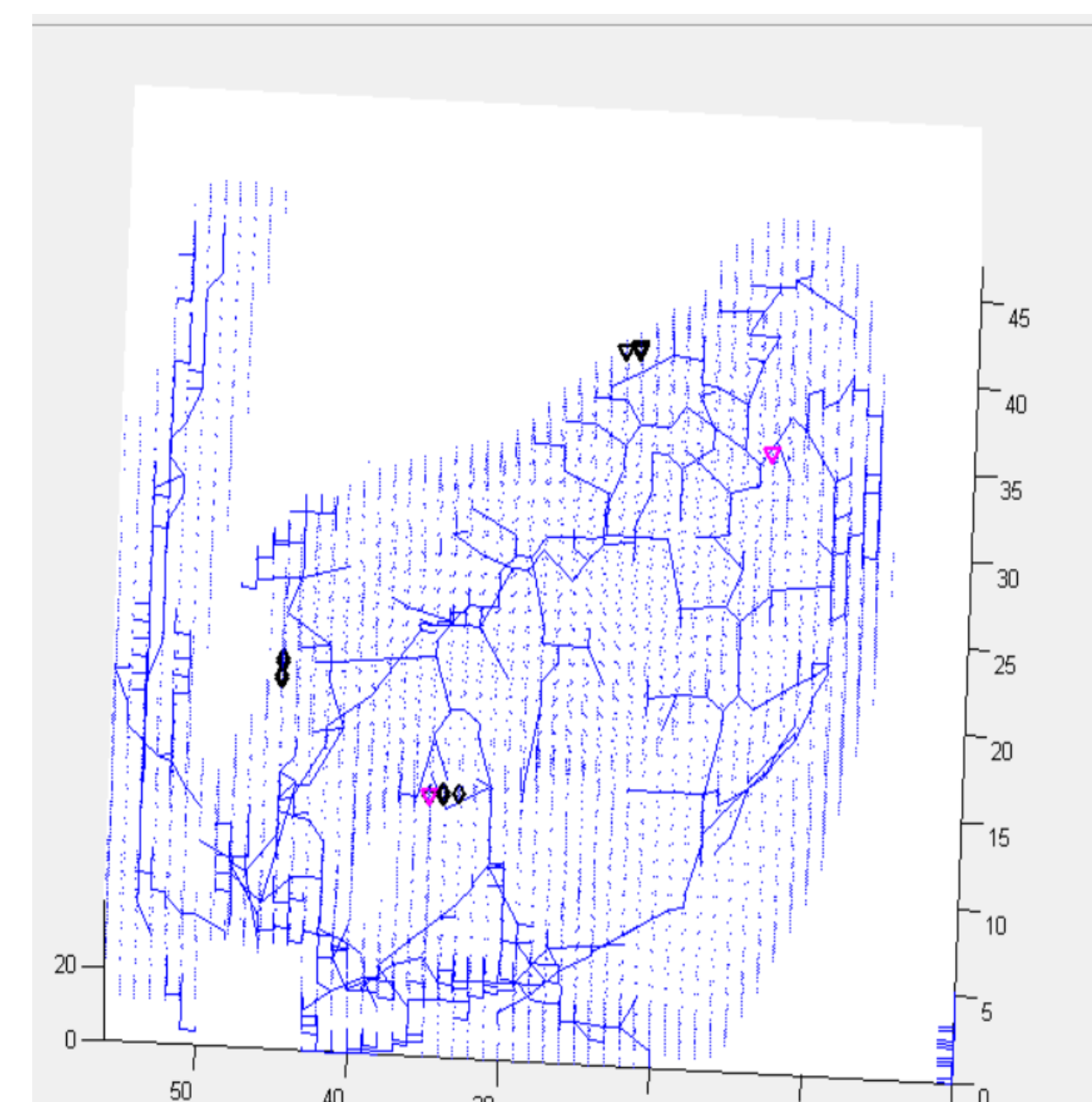


Figure 4

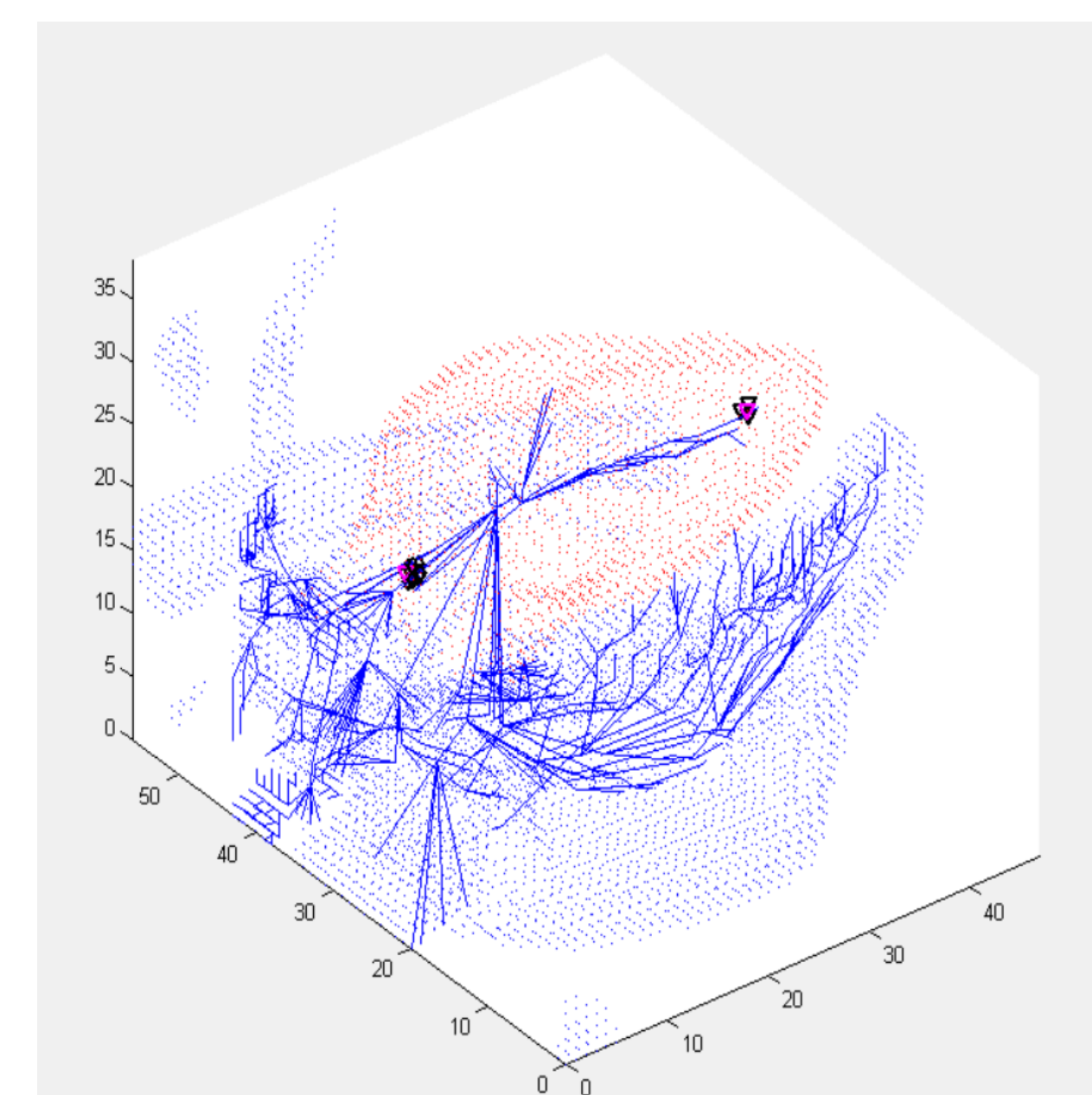


Figure 5

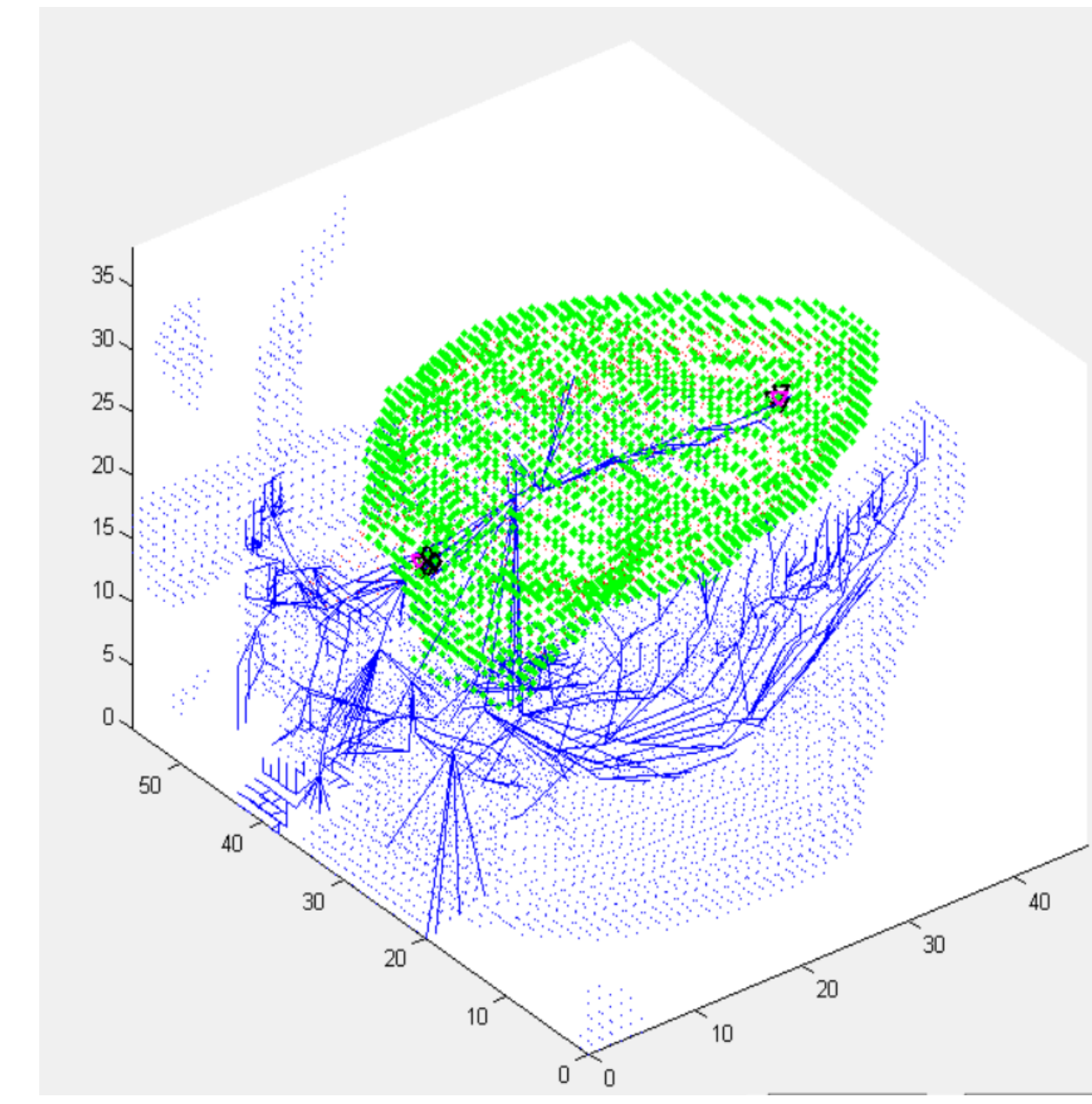


Figure 6

## User Interface

The algorithms developed for this research project use the user's click points to guide the segmentation process. To facilitate the experiments, an intuitive and simple graphical user interface is essential.

Figure 1 shows a 3D plot of one of the study areas. The surface of the foreground volume is shown with dots while a minimum spanning tree used in Algorithm I is shown with lines. The user can rotate, zoom-in, and zoom-out to locate an edge to cut. The user can also set the visibility of the ground-truth annotation on, as shown in green in Figure 2.

To locate a point on the volumetric data via mouse click, we consider a line that is perpendicular to the screen and incident at the mouse click point. Figure 3 shows the line at a rotated view. For Algorithm I, the edge closest to the line is selected. For Algorithm II, surface voxels that are within a few voxels away from the line are selected as candidates. The user then uses an arrow key to loop through the candidates and pick the most appropriate one. In Figure 4, a first click point selected candidates shown in diamond markers, and a second click point selected candidates shown in triangle markers. Those shown in magenta color are the current choice.

Once, the user is satisfied with the selection, the segmentation process can be run and the result will be superimposed on the plot, as shown in Figure 5. The user can again set visibility on to compare it against the annotation, as shown in Figure 6.

## Acknowledgements

This research was supported by NSF grant CCF-1421734. We are also grateful for the help from Dr. Brandon Fornwalt, Dr. Jonathan Suever and Mr. David Vanmaanen from the Fornwalt Cardiac Imaging Lab at the Geisinger Health System.

## Results and Discussion

Multiple trials were conducted throughout our experiments in order to characterize the algorithm performance with enough statistics. The "2016 Algorithm" in the figures represent the segmentation data from the very original form of this research's algorithm. It is noticeable that although the IoU for both ventricles is relatively satisfactory, the runtime isn't favorable at all. The segmentation data collected during a stage of improvements this year is under "2017 Algorithm I". Here the algorithm has become much faster and time efficient, but the IoU scores have dropped considerably and are no longer close enough to the preferable 80%.

In "2017 Algorithm II", the final and current stages of this project's development, favorable IoU scores and reasonable time efficiency were both achieved. The segmentation scores achieved were higher than ever before and closest to the target 80% IoU. Comparing and tracking the scores throughout the research ensured that accuracy and efficiency was preserved while achieving the desirable results.

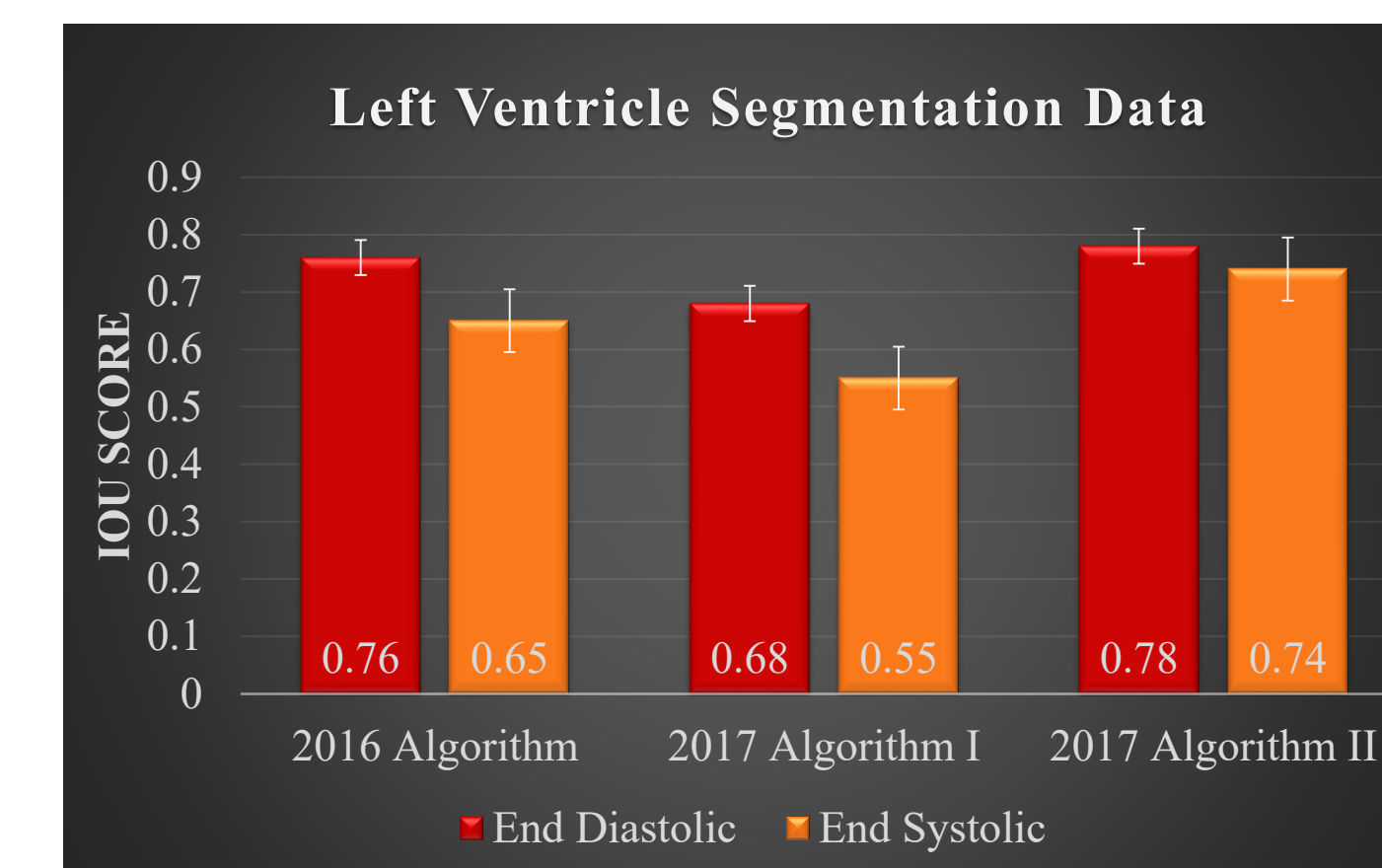


Figure 1: Left Ventricle Segmentation Scores

Figure 2: Algorithm Runtime

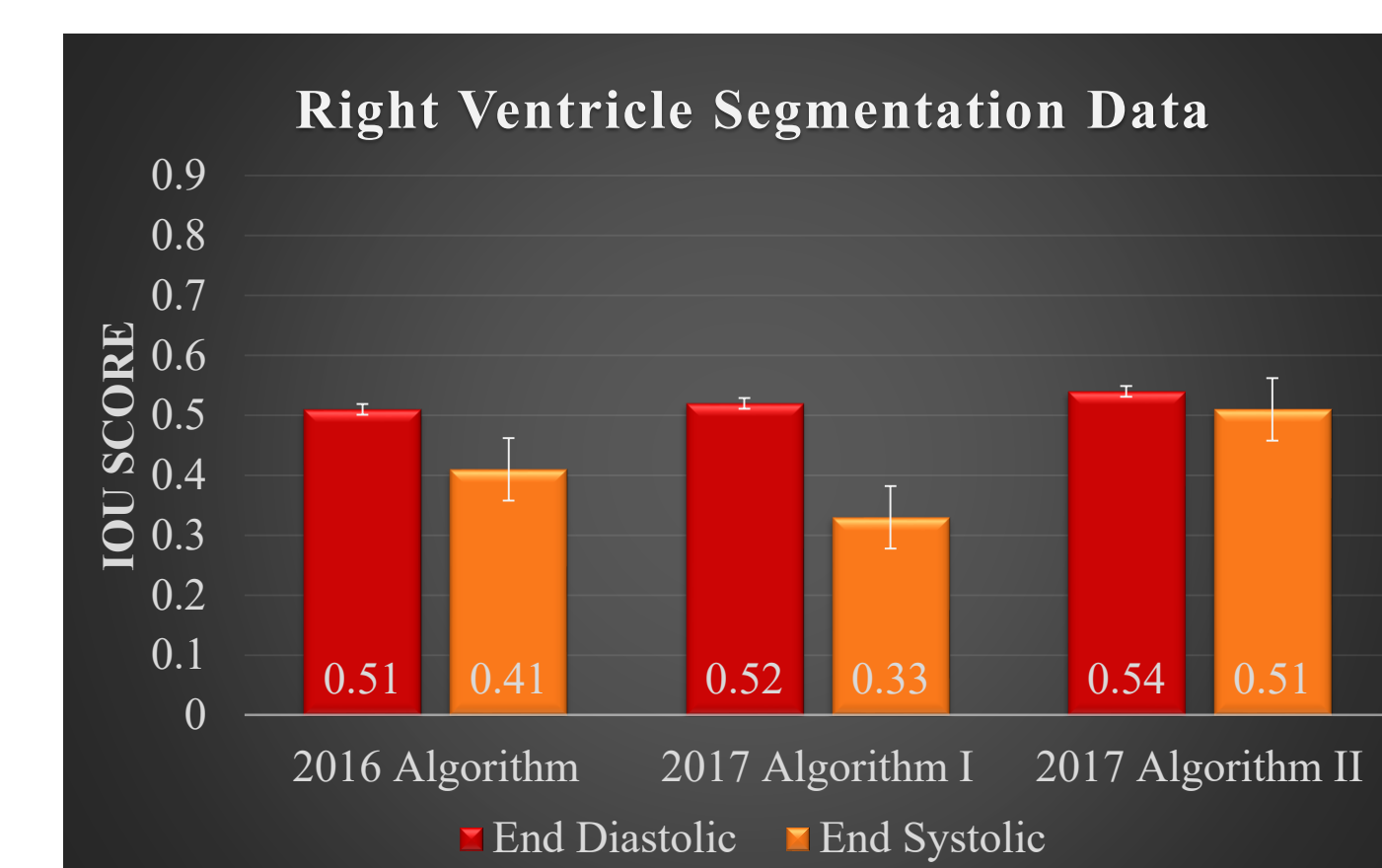
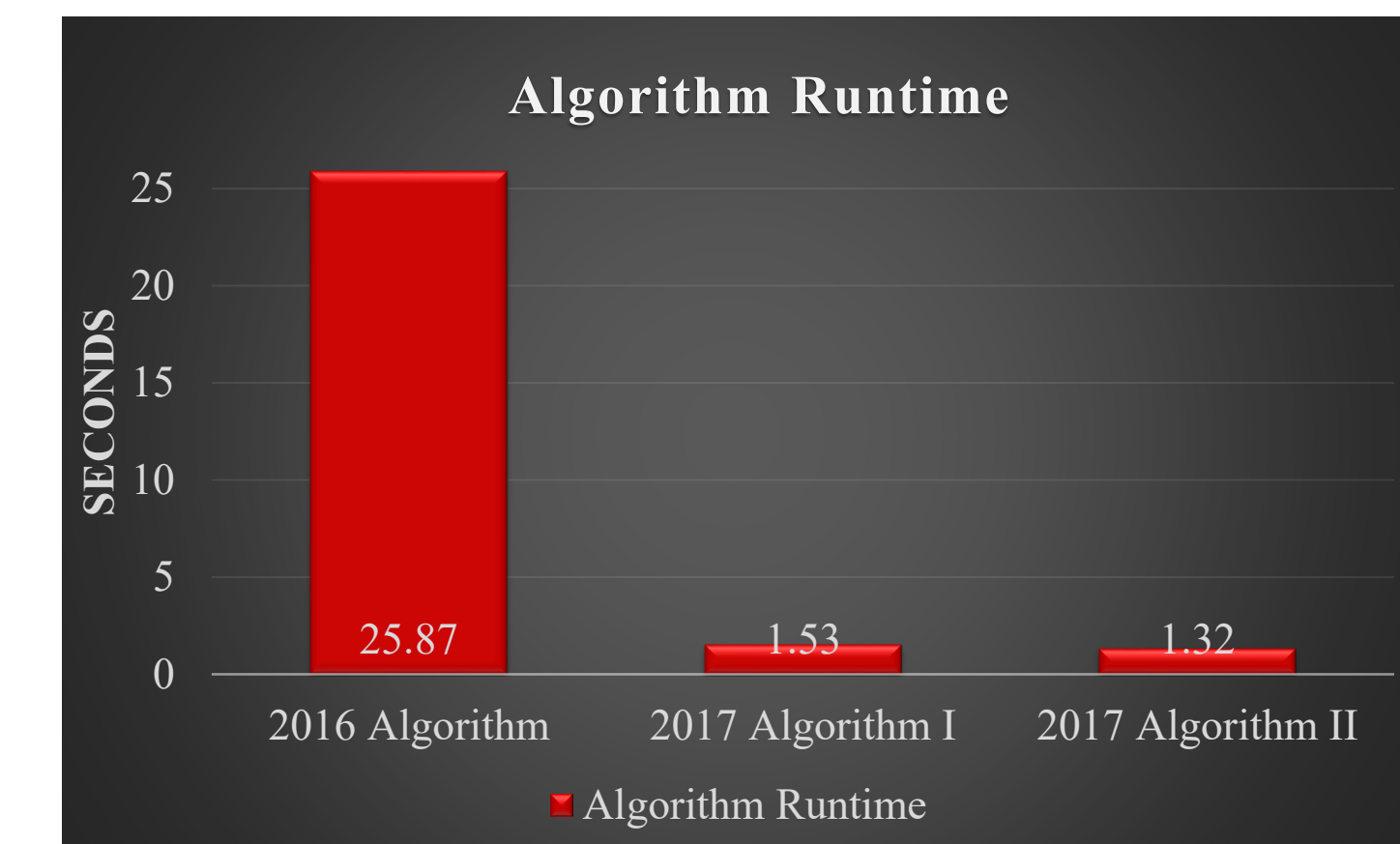


Figure 3: Right Ventricle Segmentation Scores

## Conclusions

Further measures can be taken to improve the segmentation scores even more. The desired time efficiency has been achieved. The results show a promising future for the development of a time oriented, four dimensional algorithm using MRI scan's data. This will be most useful for physicians diagnosing illnesses and diseases in the cardiology department. The current algorithm provides a foothold to build up the volumetric analysis of both of the heart's ventricles.

## References

- "Ventricles of the Heart." *Kenhub*. N.p., n.d. Web. 21 July 2017.
- "Ventricle (heart)." *Wikipedia*. Wikimedia Foundation, 16 July 2017. Web. 21 July 2017.
- "Paul Mennen (view Profile)." *MATLAB Central*. N.p., n.d. Web. 21 July 2017.
- "Heart-Disease." Digital image. N.p., n.d. Web.
- "Magnetic Resonance Imaging." *Wikipedia*. Wikimedia Foundation, 13 July 2017. Web. 21 July 2017.