Cardiac Trabeculae Segmentation: an Application of Computational Topology

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Abstract

In this video, we present a research project on cardiac trabeculae segmentation. Trabeculae are fine muscle columns within human ventricles whose both ends are attached to the wall. Extracting these structures are very challenging even with state-of-the-art image segmentation techniques. We observed that these structures form natural topological handles. Based on such observation, we developed a topological approach, which employs advanced computational topology methods and achieve high quality segmentation results.

1998 ACM Subject Classification F.2.2 Geometric Problems and Computations

Keywords and phrases image segmentation, trabeculae, persistent homology, homology localization

Digital Object Identifier 10.4230/LIPIcs.SoCG.2017.65

Category Multimedia Contribution

1 Problem

The interior of a human cardiac ventricle is filled with fine structures including the papillary muscles and the *trabeculae*, i.e., muscle columns of various width whose both ends are attached to the ventricular wall (Figure 1). Accurately capturing these fine structures are very important in understanding the functionality of human hearts and in the diagnostic of cardiac diseases. These structures compose 23% of left ventricle (LV) end-diastolic volume in average and thus is critical in accurately estimating any volume-based metrics, e.g., ejection fraction (EF) and myocardial mass; these measures are critical in most cardiac disease diagnostics. A detailed interior surface model will also be the basis of a high quality ventricular flow simulation [10], which reveals deeper insight into the cardiac functionality of patients with diseases like hypokinesis and dyssynchrony.

With modern advanced imaging techniques, e.g., Computed Tomography (CT), we can capture details within cardiac ventricles (Fig. 1(left)). However, most state-of-the-art cardiac analysis methods [13, 12], although very efficient, can not accurately capture these complex

* Chao Chen's research is partially supported by PSC-CUNY-69844-00-47.

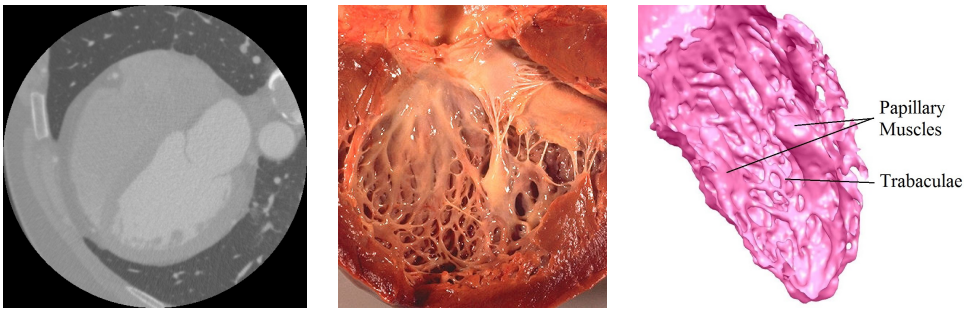

Figure 1 Left: our input CT image. Middle: interior of LV [7]. Right: our result (a 3D triangle mesh) successfully captures the trabeculae.

structures. The challenge is twofold. First, large variation of geometry and intensity of trabeculae makes it difficult to distinguish them from noise. Second, most segmentation models, e.g., region competition [14] and Markov random field [1], employ global priors, which tend to work against fine structures. A prior is certain function that measures the certain quality of the segmentation results. By optimizing such prior while fitting the segmentation result to the data, we achieve a segmentation with certain desired properties. In most segmentation models, a smoothness prior is employed, which prefers a simplified segmentation result and thus removes fine structures that we want to capture.

2 A Topological Approach

We exploit novel global information which is more suitable for the extraction of trabeculae, namely, the *topological prior*. A trabeculae is naturally a *topological handle*; both of its ends are attached to the wall, while the intermediate section is freely mobile. We propose a topological method that explicitly computes topological handles which are salient compared with their surrounding regions. The saliency is measured based on the theory of *persistent homology* [6] and can be computed efficiently. To improve the quality of the extracted handle, we further optimize the cycle representing such handle. The optimization is based on the previous methods from homology localization [3, 5, 8, 4, 2]. We propose an A$*$ search strategy to further improve the practical performance of the method.

Our system has the following modules. First, we localize the location of the left ventricle and enhance the image. This way our method could be more focused and more efficient. Second, we extract the interior surface model using traditional image segmentation methods, in particular, region competition. As show in Figure 2 Middle-Left, such method will give us a reasonable result but missing most trabeculae structures. Third, our system identifies topological handles by computing persistence homology using the intensity function of the image. Persistent dots on the diagram with high persistence (based on hand-selected threshold) are chosen as hypothetical trabeculae structures. We also filter these structures using a classifier trained on the geometric features. Fourth, we extract cycles representing these topological structures. We compute the optimal representative cycle, namely, the shortest cycle (Figure 2 Middle-Right). The remaining structures are considered the true signal and are included in the final segmentation (Figure 2 Right).

The related publications include [11, 9]. Source code for computing the shortest 1D cycle representing each persistent dot can be found at the first author's webpage: `http://eniac.cs.qc.cuny.edu/cchen`.

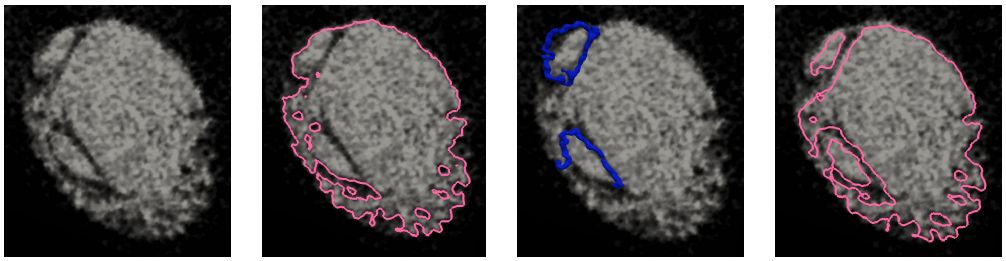

Figure 2 Left: a 2D slice of the intensity function, shaded bridges through the white regions are trabeculae. Middle-left: existing methods will miss the trabeculae completely. Middle-right: our method recovers missed trabeculae using persistent homology. Right: including these trabeculae in the final segmentation gives a better quality segmentation.

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