A Convex Max-Flow Segmentation of LV Using Subject-Specific Distributions on Cardiac MRI

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Abstract. This work studies the convex relaxation approach to the left ventricle (LV) segmentation which gives rise to a challenging multi-region separation with the geometrical constraint. For each region, we consider the global Bhattacharyya metric prior to evaluate a gray-scale and a radial distance distribution matching. In this regard, the studied problem amounts to finding three regions that most closely match their respective input distribution model. It was previously addressed by curve evolution, which leads to sub-optimal and computationally intensive algorithms, or by graph cuts, which result in heavy metrization errors (grid bias). The proposed convex relaxation approach solves the LV segmentation through a sequence of convex sub-problems. Each sub-problem leads to a novel bound of the Bhattacharyya measure and yields the convex formulation which paves the way to build up the efficient and reliable solver. In this respect, we propose a novel flow configuration that accounts for labeling-function variations, in comparison to the existing flow-maximization configurations. We show it leads to a new convex max-flow formulation which is dual to the obtained convex relaxed sub-problem and does give the exact and global optimums to the original non-convex sub-problem. In addition, we present such flow perspective gives a new and simple way to encode the geometrical constraint of optimal regions. A comprehensive experimental evaluation on sufficient patient subjects demonstrates that our approach yields improvements in optimality and accuracy over related recent methods.

1 Introduction

Left ventricle (LV) segmentation of 2D cardiac magnetic resonance (CMR) is one of the fundamental steps to diagnose coronary heart disease characterized by heart wall motion abnormalities, ventricular enlargement, aneurysms, scars (it occurs only on the myocardium region), strain, EF and etc.
Manual segmentation of CMR images is extremely tedious and time-consuming. As such, automatic or semi-automatic algorithms are highly desired. Despite so many studies in the literature allocated to the task, challenges inherent to CMR images such as including papillary muscles in blood cavity within endocardial region, and presence of noise and artifacts prevented the algorithms to sufficiently address the problem for routine clinical use.

The problem of myocardial segmentation is commonly formulated as an optimization of a cost functional of the image features, which typically are solved using active contours or discrete graph-cut methods. Active contours have been the prevalent choice in medical image analysis as they are able to introduce a wide range of photometric and geometric constraints. Generally, these constraints use pixel-wise penalties learned from image models in the training set that suffer from inability to distinguish between connected cardiac regions with almost the same intensity profile. Also, such choice suffers from local optima, slow convergence, high sensitivities to initialization, and numerical complexity as well.

Training-based algorithms have several drawbacks including the difficulty in capturing the inter- and intra-subject variations and pathological characteristics. They further need a large amount of training dataset. The recent active curve studies in advanced it by building subject-specific models of a manually segmented frame in the current cardiac sequence.

In the discrete setting, although graph cut guarantees convergence to a global optima in nearly real time, it is unable to support global functionals that arise in our problem. Nevertheless, the recent works use relaxations via bounds or approximations of the energy functional. Although these works led to substantial improvements over active contours in terms of speed, optimality, and accuracy, they still suffer from metrization errors.

Alternatively, continuous convex relaxation approaches share the advantages of both active curves and graph cuts, which recently have attracted a significant research attention in image segmentation problems. Some current studies based on convex optimization have shown its potential in solving the classical piecewise constant Mumford-Shah segmentation model, and its multiphase (multiregional) variant.

In this study, segmentation of the LV endo- and epicardial boundaries in a CMR sequence is formulated in an iterative convex max-flow relaxation approach with two original discrete cost functions. We solve a sequence of sub-problems which results in an algorithm robust to initial conditions. Unlike active contours, it also does not require a large number of iterative updates of the labeling and the time-consuming kernel density estimates (KDEs). The proposed formulation avoids a complex training process and the need for tremendous amount of training data. It leads to a segmentation faster than level-set methods and improvements in optimity and accuracy of the results. We further prove that the novel convex max-flow formulation obtains accurate and global solutions to the original, nonconvex sub-problems. Moreover, the proposed method is

\footnote{Almost over 200 2D images per subject.}