

# Extracting Lagrangian Coherent Structures from three-dimensional, three-component, time-resolved phase contrast magnetic resonance images

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## Background

Cardiac blood flow is highly complex and not yet fully understood. Using three-dimensional, three-component, time-resolved phase contrast magnetic resonance imaging (4D PC-MRI), new understanding of flow dynamics may be obtained. However, the 4D data is too complex to visualize directly. One method to visualize flow is Lagrangian Coherent Structures (LCS). LCS show division between different flow patterns, where blood on each side of the structure belongs to a different flow pattern.

## Purpose

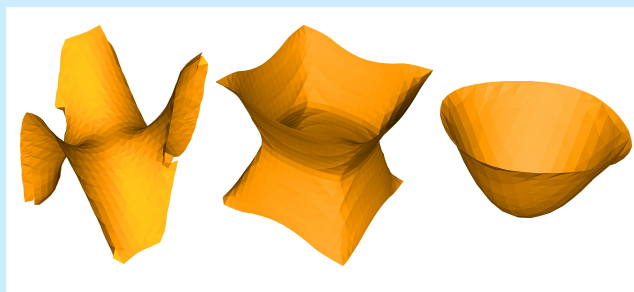
The aim of the study was to develop an algorithm able to extract LCS from measured flow and investigate if LCS appear in cardiac blood flow.

## Methods

4D PC-MRI was used to measure velocity fields over the whole heart. To extract potential LCS surfaces an extended version of the Marching Ridges algorithm was used. Due to low signal-to-noise ratio and limited resolution Marching Ridges was extended with new heuristics and support for more complex geometries to get robust results.

## Results

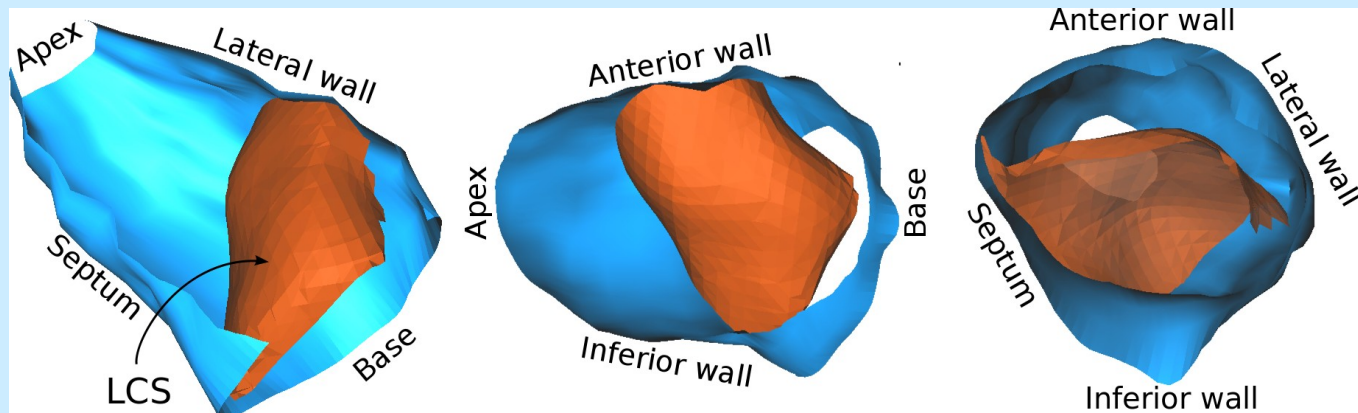
The developed algorithm was tested with both synthetic (Figure 1) and measured (Figure 2) 4D PC-MRI data. The algorithm was able to extract LCS in both types of data.



**Figure 1:** Three LCS extracted from synthetic flow data used to test the algorithm.

## Conclusion

An algorithm able to extract LCS from measured flow was developed. Initial experiments on data from healthy volunteers show that LCS appear in cardiac blood flow. LCS visualization can be used to give an overview of the different flow patterns in cardiac blood flow.



**Figure 2:** LCS surface inside the left ventricle of a healthy volunteer. The LCS show division between different flow patterns. The blue and orange surfaces represent the endocardial wall and the LCS surface respectively. All images show the same LCS for the same volunteer viewed from different angles with the endocardial wall sliced open differently. The middle image is oblique to more clearly indicate the LCS. Blood on the apical side of the LCS belongs to a different blood flow pattern as opposed to the blood on the basal side.