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Internship Report
Left Atrial Contraction Patterns

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1 Acknowledgement

First of all, I would like to thank my internship tutors Katharina Vellguth and Lukas Obermeier for giving me the chance to work with them within the Institute of computer-assisted cardiovascular medicine of Charité – University Medicine Berlin. It was a really enriching and challenging opportunity in my studies because I discovered how computer science can be used in medicine.

Furthermore, I would also like to thank my school, ENSEEIHT, for giving me the opportunity to do a technical internship in computer science for my first year of engineering school. It was a really instructive year that gave me the ability to adapt easily to a new tool of data analysis during the internship.

2 Abstract

With digital transformation, computer science has a key role in predicting cardiovascular outcomes. Innovation in this area is leading to faster diagnosis and potential treatment of pathologies. Furthermore, left atrial geometry has a decisive impact in a healthy oxygen and blood filling. Thus, I established a new workflow to process patient specific left atrial geometries with the Python package Deformetrica in the context of geometry registration, time series registration, and shape atlas construction. In the end, after performing simulations on simple and complex cases, and discussing different estimation methods, I achieved to find a 3D dynamic model of the geometry of the left atrium.

3 Introduction

Today, computer tools allow us to study and predict the health behaviour of individuals. This is currently a research topic in full development thanks to the digital transformation, particularly in cardiovascular medicine. Data processing and simulations are improving knowledge of the heart and its behaviour in healthy and pathological cases. This knowledge would ultimately make it possible to anticipate malfunctions and treat the patient in time. This is why researchers are interested in an advanced model of the heart. Therefore, I did an 8-week internship in Berlin at the Institute of Computer-assisted Cardiovascular Medicine of Charité. I joined the Cardiovascular modeling and simulations research team at the beginning of June 2022. My goal was to answer the following question:

How to model the behaviour of the left atrium in 3D?

In order to do this, I read the literature on the left atrium (LA, fig.1) and I familiarised with the mathematical Python package Deformetrica on 2D examples. Then, I worked in 3D with a simple and a complex model and finally I went from static to dynamic modelling.

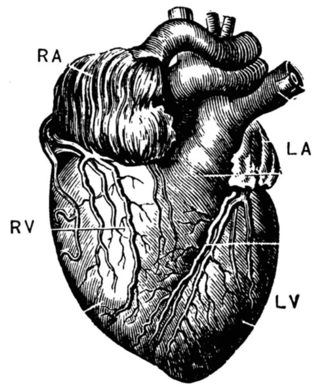

Figure 1: Heart anatomy

4 Description of the internship

4.1 Charité

Charité is the Berlin University of Medicine, built in 1710, it is one of the best research medical institution and hospital in the world. Charité is internationally renowned for its excellence in teaching and training. For 10 years, it is the best hospital in Germany. And since 4 years Charité is ranked as 5º best hospital in the world and best in Europe.

The Institute of Computer-assisted Cardiovascular Medicine (ICM) works on novel clinical solutions for diagnostics, decision support and therapy planning. The ICM is thus an important innovation driver of the digital transformation of cardiac medicine in Berlin. An important focus of the ICM is the combination of modern multimodal imaging methods with innovative methods of data science and biophysical modeling. At the ICM, an interdisciplinary team of physicians, mathematicians, computer scientists, physicists, and engineers work on both basic science and clinical solutions.

4.2 Internship activities

I joined the team of Katharina Vellguth and Lukas Obermeier, who were working on an advanced heart model that they wanted to extend by a left atrium (LA) behavior simulations. Indeed, LA has a special role in circulatory system : in late diastole (beating heart relaxing), the LA contracts and accelerates blood to the left ventricle. Pathological LA movements may lead to unfavorable left ventricular flow fields and may result in thrombus formation inside the LA. Therefore, my mission was to map patient specific LA geometries. The goal was to retrieve 3D deformation fields on atrial surfaces.

First of all, I documented on Left Atrium, about the role it plays in cardiovascular system and for the heart filling [2]. The idea was to familiarize with the anatomy of LA [1] and to study the LA movement in healthy and diseased (atrial fibrillation) state [3].

Secondly, I discovered the Python package Deformetrica. It is a powerful mathematical tool for statistical shape analysis of 2D and 3D shape data using optimisation methods. In my context, the issue was to obtain the best modelling of the 3D geometry of the left atrium. So, I started using it on 2D examples and then on a 3D simple mapping of two shapes (small sphere onto large sphere).

After that, I was able to start working on real 3D data, i.e. a more complex model. So, I mapped a surface mesh of sphere, first onto a closed (at the arteries) geometry of LA (fig. 2), and then onto opened LA geometry (fig. 3).

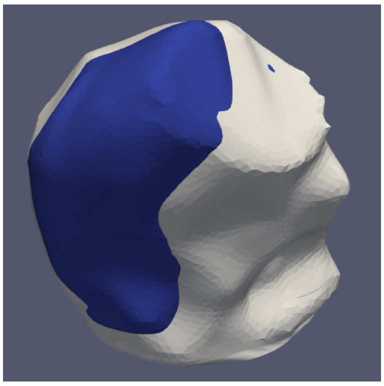

Figure 2: Simple geometry of Left Atrium (LA data in blue, estimation model in white)

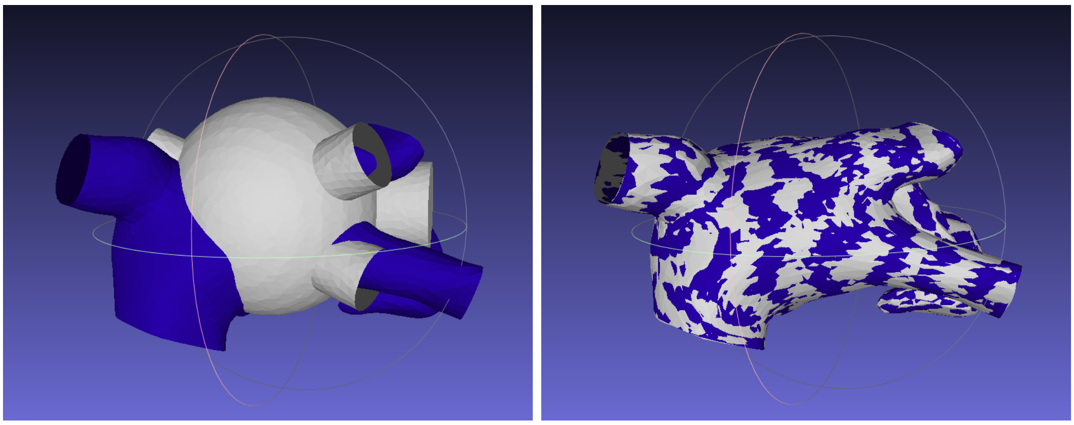

Figure 3: Complex geometry of Left Atrium (input - left : LA data in blue, sphere template in white; output - right : LA data in blue, estimation in white)

With this satisfying result for one LA data, I could start to work on several data in order to find a reasonable general representation of left atrial movement (fig.4). In this atlas construction, Deformetrica is not using the classical (i.e. Euclidean) mean but it estimates an "geodesic" average object configuration from a collection of object sets, and the deformations from this average to each sample in the collection.

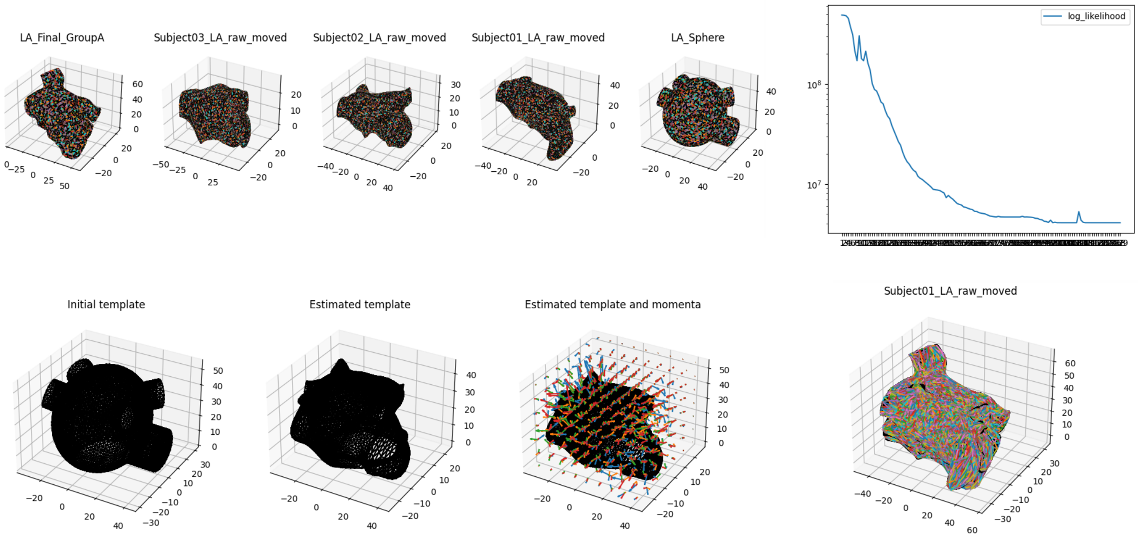

Figure 4: Left Atrium - Atlas construction

The last goal was to make a video of the movement over time in 3D. At the institute we only had data time series for Left Ventricle so we did it for it (fig.5).

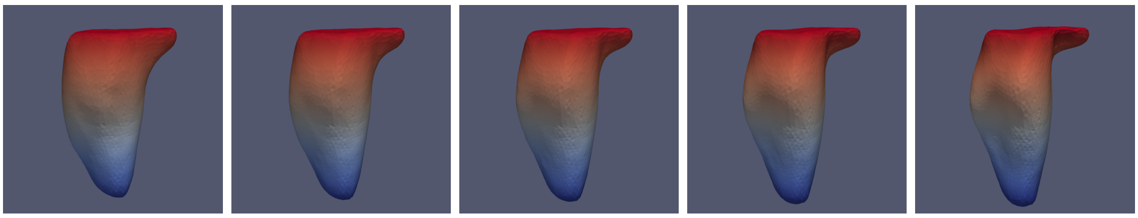

Figure 5: Left Ventricle - Time Series

4.3 Results

The calculated geometries were close to reality despite the complexity of the data. I tested several estimation methods for minimizing the loss functions of the different models such as a simple gradient ascent, the L-BFGS algorithm from Scipy, and a stochastic version of the EM algorithm. I also varied various parameters such as kernel type and width, factor of convergence tolerance and noise. I was able to evaluate the results, using the 3D display softwares Paraview and Meshlab, by comparing the Hausdorff distance for each case. Also, I did a detailed documentation of code and of the steps and results.

4.4 Knowledge

I acquired new skills and knowledge during this 2-month internship especially in Data Analysis and Visual Computing, with a focus on medicine and more specifically on cardiology. It was a perfect opportunity to experience team work in professional environment while being very independent and at the same time improving my English.

5 Conclusion

This internship in Berlin was the opportunity for me to discover a new field of application of computer science and a new country. It was really challenging and I managed to established a new workflow to process the deformation of left atrium geometry using the toolbox of statistical shape analysis Deformetrica. It was a very relevant internship for my professional project.

References

[1] Doctor of Medicine Brian D. Hoit. "State-of-art paper, Left Atrial Size and Function, Role in Prognosis"". In: *Journal of the American College of Cardiology (ISSN 0735-1097)* 63.6 (2014).

[2] Mayo Clinic. *The Heart and Circulatory System - How They Work*. Youtube. 2013. URL: https://www.youtube.com/watch?v=CWFyxn0qDEU.

[3] Paul S. Pagel et al. "Review article, Mechanical Function of the Left Atrium - New Insights Based on Analysis of Pressure–Volume Relations and Doppler Echocardiography". In: *American Society of Anesthesiologists* 98.4 (2003), pp. 975–994.