

Title:

Toward a Functional Model of the Mitral Valve

- **Location:** INRIA Nancy-Grand Est research center, Nancy France
- **Research theme:** Vision, perception and multimedia interpretation

- **Project-team:** MAGRIT (Nancy, France)

- **Scientific Context:**

The mitral valve of the heart ensures one-way flow of oxygenated blood from the left atrium to the left ventricle. However, many pathologies damage the valve anatomy producing undesired backflow, or regurgitation, decreasing cardiac efficiency and potentially leading to heart failure if left untreated. Such cases could be treated by surgical repair of the valve. However, it is technically difficult and outcomes are highly dependent upon the experience of the surgeon. A solution could be to use computer-based simulations to predict the result of the surgical procedures. The mitral valve is composed of leaflets that are maintained by chordae during peak systole. The Magrit Inria team has previously worked on extracting the chordae in the context of the associate team CURATIVE (<https://team.inria.fr/curative>). The topic of this PhD is to continue this research with the aim to develop a functional model of the mitral valve that is physically valid and replicates real measurements.

- **Missions:** (objectives, approach, etc.)

State-of-the-art mitral valve simulation researches either focus on one unique data that has been manually segmented or acquired in special in-vivo conditions [Tom17, Kha19] or focus on simplified chordae sets [Feng18]. On the contrary, our aim is to be able to perform simulation with a realistic model build from images of any patient.

Previous works in the team [Pani19a, Pani19b] have allowed to automatically extract chordae from CT scanner images represented as a graph of centerlines, including bifurcations. However, some chordae may be missing or incorrectly detected which may lead to an incorrect physical behavior of the valve. In addition, there is a dense set of small chordae near the leaflets which cannot be properly detected from images. One of the main goal of the PhD will be to develop a simplified model of the valve from patient data which does not consider too small chordae and gives an equivalent functional result.

To reach this objective, improvements are expected both on the segmentation and on the mechanical side:

- For the segmentation process, focus will be made on enforcing structural constraints on the chordae arborescence and on identification of parts (bifurcations or centerlines) that are less reliable than others. This reliability could be included in the global optimization process that is currently used to refine the arborescence from the initial graph. As the shape of the chordae are not perfect elliptical cylinders, we also intend to investigate the use of convolutional-network techniques to learn how chordae shapes differ from a mathematical cylinder and improve their detection
- Based on typical chordae arborescence, mechanical simulations will be realized in order to understand how the upper dense part of the arborescence could be simplified to give a similar mechanical behavior. The PhD student will first use an existing mechanical framework [Ham11] for simulation and improvements on that aspect could take place with P. Hammer (BioRobotic Labs) in the context of the team CURATIVE. Besides the definition of strategies for simplification, one of the challenges will also consist in defining when the simulation reaches a steady state and in comparing two simulations. Indeed, considering the average motion is not appropriate since the motion of the leaflet may be local.
- Strategies for finding the simplified tree that is in good agreement with the image and physically coherent, should be defined. In particular, the extracted structures could have some slack (leading to errors in the valve modeling). Ways to reduce this slack while giving an equivalent mechanical behavior will be developed.

The student will evaluate the proposed functional models with different typical mitral valve states: healthy pathology and after surgical repair. The challenge will be to set properly the mechanical parameters, the boundary conditions, the resolution numerical method and its convergence so that the model is robust and predictive.

It must be noted that the leaflets and the chordae are required for mechanical simulation. However, the detection of the leaflets in closed images of the valve seems currently not accessible by automatic means. During the PhD, semi-automatic tools for helping the extraction of the leaflet will be

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designed. The idea is not to write a software but rather to use existing tools and to design specific steps dedicated to valve segmentation. Technical challenges in segmenting the valve at the closed state include detecting the “Coaptation” surface. They are other irregularities in the leaflet surface such as other wrinkles and surface indentations due to chordae pulling down the structure. In order to detect them, thickness measurement from a Laplace-based method [Yez03] will be used to infer connections between leaflets and chordae.

- Bibliography: (if any)

[Feng18] Liuyang Feng, Nan Qi, Hao Gao, Wei Sun, Mariano Vazquez, Boyce E Griffith, Xiaoyu Luo, On the chordae structure and dynamic behaviour of the mitral valve, IMA Journal of Applied Mathematics, Volume 83, Issue 6, December 2018, Pages 1066–1091

[Ham11] Peter E Hammer, Simulating heart valve mechanical behavior for planning surgical repair, Tufts University, 2011.

[Kha19] A .Khalighi and B. V. Rego and A. Drach and R.C. Gorman and J.H. Gorman and M. S. Sacks, Development of a Functionally Equivalent Model of the Mitral Valve Chordae Tendineae Through Topology Optimization, Annals of Biomedical Engineering 47 (2019), no. 1, 60–74.

[Pani19a] Daryna Panicheva, Pierre-Frederic Villard, Marie-Odile Berger, Toward an automatic segmentation of mitral valve chord, SPIE Medical Imaging, 16-21 February 2019, San Diego.

[Pani19b] Daryna Panicheva, Pierre-Frederic Villard, Peter E. Hammer, Marie-Odile Berger, Physically- coherent Extraction of Mitral Valve Chordae, IEEE Computing in Cardiology, Volume 46 September 2019, Singapore.

[Tom17] M. Toma and D. Einstein and C. Bloodworth IV and R. Cochran. and A.P. Yoganathan and K.S. Kunzelman, Fluid–structure interaction and structural analyses using a comprehensive mitral valve model with 3D chordal structure, International Journal for Numerical Methods in Biomedical Engineering 33 (2017), no. 4.

[Yez03] A.J. Yezzi and J.L. Prince, An Eulerian PDE Approach for Computing Tissue Thickness, IEEE Transactions on Medical Imaging 22 (2003), no. 10, 1332–1339, DOI 10.1109/TMI.2003.817775.

- Skills and profile:

Required qualification: Master (in applied mathematics or computer science).

We are looking for a highly motivated student with strong inclination for interdisciplinary research.

Candidates must have a solid background both in mathematics (modeling, optimization, numerical simulations), image processing (segmentation), and some knowledge in mechanics. Some acquaintance with medical imaging techniques will be appreciated.

- Additional information:

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Additional links: Magrit team: <https://magrit.loria.fr/index.en.html>

Duration: 3 years

Starting date: between Oct. 1st 2020 and Jan. 1st 2021

Salary: 1 958 euros gross monthly (about 1 580 euros net) during the first and the second years. 2 059 euros the last year (about 1 661 euros net). Medical insurance is included.

The required documents for applying are the following :

- CV;
- a motivation letter;
- your degree certificates and transcripts for Bachelor and Master (or the last 5 years if not applicable).
- Master thesis (or equivalent) if it is already completed, or a description of the work in progress, otherwise;
- all your publications, if any (it is not expected that you have any).

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- At least one recommendation letter from the person who supervises(d) your Master thesis (or research project or internship); you can also send at most two other recommendation letters. The recommendation letter(s) should be sent directly by their author to the prospective PhD advisor.

All the documents should be sent in at most 2 pdf files; one file should contain the publications, if any, the other file should contain all the other documents. These two files should be sent to your prospective PhD advisor (in addition to the application on the web).

Help and benefits :

- Possibility of free French courses
- Help for finding housing
- Help for the resident card procedure and for husband/wife visa
- Lunch cost at Inria is 2,72 €