Ph.D. research topic

- Title of the proposed topic: **“Novel tensor decompositions for atrial fibrillation analysis”**
- Research axis of the 3IA: IA for integrative computational medicine
- Supervisor (name, affiliation, email): Vicente Zarzoso, I3S Laboratory, UCA, CNRS vicente.zarzoso@univ-cotedazur.fr
- Potential co-supervisor (name, affiliation): Rodrigo Cabral Farias, I3S, UCA, CNRS
- The laboratory and/or research group: Signals, Images, Systems (SIS) Team, I3S Lab.

Apply by sending an email directly to the supervisor.
The application will include :

- Letter of recommendation of the supervisor indicated above
- Curriculum vitæ.
- Motivation Letter.
- Academic transcripts of a master’s degree(s) or equivalent.
- At least, one letter of recommendation.
- Internship report, if possible.

- Description of the topic:

Background
Atrial fibrillation (AF) is the most common sustained arrhythmia encountered in clinical practice, especially affecting the elderly and held responsible of up to 25% of strokes. With the ageing of the Western population, this arrhythmia is becoming a major public health concern taking epidemic proportions: between 6 and 12 million people will be affected in the USA in 2050, and up to 18 million in Europe in 2060 [MOR17]. AF is indeed “the last great frontier of cardiac electrophysiology” as it continues to puzzle cardiologists [JAN14]. Physiological signal analysis and machine learning arise a key tools to improve the understanding and management of this challenging cardiac condition. Despite its cost and risk of complications, catheter ablation is currently the most attractive therapeutic option in terms of long-term recurrence rate for the treatment of persistent AF. However, this therapy depends heavily on the practitioner’s subjectivity, with rather variable protocols and success rates reported by different centers. The development of robust, widely accepted intervention protocols is still an open challenge.

The noninvasive analysis of AF can be carried out by processing cardiac signals recorded by electrodes located on the patient’s skin, giving rise to the surface electrocardiogram (ECG), a low-cost noninvasive clinical tool in cardiology. Recent research has shown the benefits of arranging ECG data in the form of three-dimensional arrays or *tensors*, which are then decomposed using suitable tensor factorizations. This approach has proven particularly useful for atrial activity extraction from the surface ECG [MAR19, MAR20, MAR21, GOU20]. Nevertheless, the clinical power of tensor tools and their usefulness to derive markers of AF characterization and aid in the therapeutic gesture remain mostly unexplored.

Goals

Taking a step forward towards a patient-tailored management of persistent AF, the present thesis aims at developing new tensor data analysis techniques to aid in the characterization of this cardiac disturbance, particularly in the context of the catheter ablation therapy. Emphasis will be laid on the recent ablation protocol developed at Nice Pasteur University Hospital (CHU) [SEI17] based on multi-spline catheters. The thesis will consist of three axes:

- *Novel quantitative measures of AF complexity:* Despite the growing interest in noninvasive methodologies to assess the complexity of persistent AF, their use in the characterization of the ablation therapy is still rather limited [MEO18]. To fill this gap, this part of the project aims to explore the power of tensor techniques to derive novel noninvasive measures of AF complexity that may accurately reflect the global evolution of the atrial substrate during catheter ablation procedures. The local complexity of intracardiac atrial electrograms recorded by multi-spline catheters will also be analyzed. The tensor model structure estimated by suitable optimization algorithms, such as that recently developed in [GOU20], will be considered as a starting point.

- *Exploiting data multimodality and multiple tensor modeling:* Several data modalities, including invasive (intracardiac electrograms, electroanatomic maps) and noninvasive (ECG, echocardiography), are acquired in the management of persistent AF patients. This part of the project will study how to exploit such modalities simultaneously in a robust manner by means of coupled tensor factorizations. Encouraging preliminary results have recently been obtained to deal with multiple time segments of a single data modality for blind separation of nonstationary data (AF ECG) [MAR20]. Extensions to multimodal observations will be considered in the thesis. Moreover, even in the case of a single modality, signals related to different cardiac activities may be best modeled by using different constructions of the tensor from ECG data [GOU20, MAR21]. One of the challenges to be solved in this thesis will be to propose methods that analyze the different tensors simultaneously. These methods are expected to result in improved extraction of atrial activity.

- *Dealing with high dimensionality:* Computational difficulties linked to the high dimensionality of the underlying tensor approach have been tackled in [GOU20] by undersampling the measured AF ECG signals. Although this approach has been successful, other approaches that do not discard part of the samples can also be considered. For example, by using tensor versions of principal component analysis [DEL00] to reduce the dimensionality of the data prior to its analysis. An issue with such an approach is that the resulting tensor cannot be analyzed with the same methods as in [GOU20]. One of the objectives of this thesis will be to propose specialized tensor decomposition methods that can be applied for AF ECG signal analysis after tensor dimensionality reduction. Extensions of the methods will also be considered in the multimodal setting, where dimensionality reduction is applied jointly to the tensors arising from different modalities.

The above goals will require the development of novel tensor decomposition models and algorithms in the challenging scenarios of non-stationary, multimodal, noisy observations with possibly missing data, often encountered in AF ablation procedures. Recent results [MAR20, MAR21] show the performance gains brought forth by adapted tensor decompositions in this context. The thesis will deepen this fruitful line of research. The impact of these theoretical results will likely extend beyond the medical application motivating this work.

Collaborations
This interdisciplinary thesis will be carried out in close collaboration with cardiologists from Nice CHU and Monaco Princess Grace Hospital (CHPG), and could attract industrial partners.

Pre-requisites
Prospective candidates must hold an MSc diploma or equivalent in data science, signal processing or applied mathematics and will require a strong background in theoretical as well as computational aspects of linear algebra, optimization and signal processing. Previous experience with biomedical signals and familiarity with cardiac electrophysiology will also be interesting assets.

Bibliography

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