Activity Report 2011

Team CARMEN

Modélisation et calculs pour l'électrophysiologie cardiaque

RESEARCH CENTER
Bordeaux - Sud-Ouest

THEME
Observation, Modeling, and Control for Life Sciences

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Team CARMEN

Keywords: Models, Numerical Methods, Scientific Computation, Simulation

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Administrative Assistant
Chrystel Plumejeau [Shared with other teams]

2. Overall Objectives

2.1. Overall Objectives

The team Carmen plans to develop some models and numerical methods in order to simulate the propagation of the cardiac action potential, from the cellular scale to the scale of the body. It aims at improving:

- our knowledge and the treatment of electrical cardiac pathologies;
- the exploitation of all available electrical signals.

Therefore, we want to incorporate the heterogeneities and coupling processes from the intermediate scales into the macroscopic PDE models. They play a primary role in the cardiac electrical arrhythmias. Meanwhile, we want to use the models to solve the inverse problems related to non-invasive electrical imaging of the heart.

The mathematical fields involved in our research are: PDE modeling and in particular reaction-diffusion equations, inverse problems, numerical analysis and scientific computing.

A main goal of the team is to contribute to the work-packages defined in the IHU LIRYC, which focuses on electrical arrhythmias and heart failure related to electrical disorders.

A cooperation with physiology, physiopathology and medicine is being developed. the team will build new models and powerful simulation tools that will help to understand the mechanisms behind cardiac arrhythmias and to establish personalized and optimized treatments. A particular challenge consists in making the simulations reliable and accessible to the medical community.

2.2. Highlights

- The team was created on October 14th, 2011.

3. Scientific Foundations

3.1. Fondation 1

The foundations of research project are as follows.

- Mathematical analysis of the reaction-diffusion systems of equations called the monodomain and bidomain models [2], [1] and [5].
- Numerical schemes to simulate cell models of cardiac electrophysiology and the monodomain and bidomain systems of equations [3], [4] and [7], [6].

A list of detailed objectives is:

- Enhance the the fundamental understanding of the models used in cardiac electrophysiology.
- Take into account two kinds of heterogeneities from intermediate scales: coupling between 0D, 1D, 2D and 3D systems of differential equations; model the multiscale behavior of a 3D tissue through asymptotic or multiscale analysis (for example involved in infarct modeling).
- Derive intermediate models based on a simplified description of the physics, in particular to account efficiently for the various measures and stimulation electrodes used for catheterization.
- Improve the numerical techniques that discretize these equations, guarantee their accuracy and robustness, search for high-order robust schemes (space and time).
- Make use of high performance computing technical possibilities in order to explore the behavior of the models. Collaborate therefore with our colleagues from the IHU LIRYC in order to identify the mechanisms of the cardiac electrical pathologies.
- Solve some inverse problems of different nature.
  - data assimilation or parameter identification-like problems with two objectives,
    * build specific models from experimental data;
    * build personalized models from clinical data, including non-invasive electrical recordings (see next item).
  - reconstruction of cardiac electrical signals, either from experimental data (catheter, optical mapping...) or from clinical data (catheter, ECG recordings,...).

4. Application Domains

4.1. Application Domains

Our fields of application are naturally: electrophysiology and cardiac physiopathology at the tissue scale on one side; medical and clinical cardiology on the other side.

The team's research project is part of the IHU LIRYC project, initiated by Pr. M. Haissaguerre. It is concerned by the major issues of modern electrocardiology: atrial arrhythmias, sudden death due to ventricular fibrillation and heart failure related to ventricular dyssynchrony.

We aim at bringing applied mathematics and scientific computing closer to biomedical research applied to cardiac rhythmology and clinical cardiology. It aims at enhancing our fundamental knowledge of the normal and abnormal cardiac electrical activity, of the patterns of the electrocardiogram; and we will develop new simulation tools for training, biological and clinical applications.

5. New Results

5.1. New result 1

In [5], we explain the links between the solutions of the bidomain and monodomain models using some analytical arguments. The result is partially based on the theory of the bidomain operator explained in [2]. We can imagine several consequences to this general results, like improving the preconditionner proposed by C. Pierre [7] or derive some intermediate models.

5.2. New result 2

We computed some bidomain solutions for use by M. Pop and M. Sermesant in the STACOM'11 challenge from the MICCAI 2011 conference. They are the only bidomain simulations presented within this collaborative challenge. A collaborative paper will be published, see [8].

6. Partnerships and Cooperations

6.1. National Initiatives

The ANR project MOMME, coordinated by Y. Coudière ended on November, 14th, 2011. It involved two partners, the Université de Nantes (Laboratoire de Mathématique Jean Leray – LMJL) and the ASCLEPIOS team.

6.2. European Initiatives

6.2.1. Major European Organizations with which you have followed Collaborations

Partner 1: CNR, IMATI (Italie) – G. Manzini.

Finite volume discretization on general, distorted meshes, for second order operators with anisotropy and discontinuities.

6.3. International Initiatives

We collaborate with Y. Bourgault from the Department of Mathematics and Statistics, University of Ottawa, Canada. It has been supported by the ANR MOMME, the Université de Nantes, the Région des Pays de la Loire and the Natural Sciences and Engineering of Research council of Canada.

7. Dissemination

7.1. Teaching

Licence : probabilités et statistique, IUT Hygiène, Sécurité, Environnement, Université Bordeaux 1, France.

PhD in progress : Simon Labarthe, « modélisation de l'activité électrique dans les oreillettes et les veines pulmonaires », started on 10/1/2010, supervized by Jacques Henry and Yves Coudière.

8. Bibliography

Major publications by the team in recent years

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[3] Y. COUDIÈRE, C. PIERRE. *Stability And Convergence Of A Finite Volume Method For Two Systems Of Reaction-Diffusion Equations In Electro-Cardiology*, in "Nonlinear Anal. Real World Appl.", 2006, vol. 7, n^{o} 4, p. 916–935, http://hal.archives-ouvertes.fr/hal-00016816/fr.

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Publications of the year

Research Reports

[5] Y. COUDIÈRE, Y. BOURGAULT, M. RIOUX. *Optimal monodomain approximations of the bidomain equations used in cardiac electrophysiology*, INRIA, November 2011, n^{o} RR-7810, http://hal.inria.fr/hal-00644257/en.

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[8] M. POP, M. SERMESANT, T. MANSI, E. CRYSTAL, S. GHATE, J. RELAN, C. PIERRE, Y. COUDIÈRE, J. BARRY, I. LASHEVSKY, B. QIANG, ELLIOT R. MCVEIGH, N. AYACHE, GRAHAM A. WRIGHT. *EP challenge - STACOM'11: forward approaches to computational electrophysiology using MRI-based models and in-vivo CARTO mapping of swine hearts*, in "MICCAI'2011", under publication in Lecture Notes in Computer Science, Springer, 2012, vol. 7085, p. 1-12.