Alya Red: A computational simulation of the heart coupling electrophysiology and cardiac mechanics

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Abstract

A multiscale, coupled electromechanical model is presented as a tool to simulate a heart beat. The objective of this work is to reproduce the dynamics of the heart in a computer with the best degree of accuracy and test some properties, using large scale computational resources. In this work, the geometry of a rabbit heart has been used. The information of the fiber architecture has been incorporated into the model using a rule-based approach preserving tissue anisotropy.

1 Computational Framework

We present a model to reproduce the dynamics of the heart in a computer and use it as a tool to test some properties of cardiac tissue. The computational framework used, Alya, is a code developed to solve partial differential equations preserving parallel efficiency. Large scale computational problems are simulated using the code (fluids, metheorology..). Regarding the simulation of the heart, first electrical activity spreads through the tissue and activates the cardiac cells. Secondly, mechanical contraction is calculated and coupled to the electrical activity through the calcium concentration of the cells and the stretch of the muscle fibers. Electrical propagation and mechanical contraction have been computed as separate modules in Alya code:

1.1 Electrophisiology

Electrical propagation is modeled using a reaction-diffusion equation, [1]. The diffusion term is governed by the diffusion tensor D_{ij} which represents the cardiac tissue orientation. The diagonal components are the axial and crosswise fiber diffusion. Due to the anisotropy of cardiac tissue, crosswise diffusion is equal and typically one third of axial diffusion. Finally, the non-linear term of the equation corresponds to the cell model for the ionic current I_{ion} (FitzHugh-Nagumo, Fenton-Karma, Ten Tusscher).

1.2 Mechanical Deformation

Mechanical part includes passive and active properties of the myocardium, [2]. The passive filling of the ventricles is governed by a transverse isotropic exponential strain energy function W. Active contraction is modelled by coupling the heart model to close-looped systemic and pulmonary Windkessel models of circulation the fibre strain scaling coefficients.

1.3 Paralelization

Fully implicit and explicit schemes are implemented using Finite Element space discretization. The automatic mesh partition tool, METIS divides the original mesh in sub-domains. Parallelization follows a multi-level strategy, with an outer level based in MPI and automatic mesh partition for distributed memory. The resulting code is able to run using elements of different space order (P1, P2, Q1, Q2) and higher order time schemes with good scalability.

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