Numerical Modeling and Large–Scale Simulation of the Cardiac Electromechanics

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Abstract

Simulating the whole cardiac function represents a challenging task from the mathematical, numerical, and computational standpoints. This is mainly due to the fact that a full cardiac model should exploit the multiphysics nature of the problem, which is indeed comprised of several core models, namely electrophysiology, mechanics (both in its passive and active components), valve dynamics, and fluid dynamics. Each of these models is intrinsically complex and features a wide range of spatial and temporal scales along the heartbeat; these need to be suitably captured to correctly represent the mutual interactions of the heart components [6]. Notable examples are the study of blood flows in the heart [5, 7] and through the valves [3].

In this talk, we consider the mathematical and numerical modeling of the left ventricle by integrating state–of–the art models for the electrophysiology of the tissue, mechanical activation at the cellular level [1], and the passive mechanical response of the muscle, thus yielding a coupled electromechanical problem [4]. We consider its spatial approximation by means of the Finite Element method and we propose a fully coupled approach with an implicit scheme for its time discretization based on BDF formulas. We solve the corresponding discrete, large–scale problem by means of the GMRES method with a newly proposed physics–based preconditioner that exploits the coupling of the core models [2, 4]. We present and discuss numerical results – obtained in the high performance computing framework – for the electromechanical problem applied to patient–specific geometries of the left ventricle.

Keywords: Cardiac modeling, mathematical and numerical modeling, electromechanics, Finite Element method, preconditioning.

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