Dissertation Defense

Parameter Estimation and Reduced-order Modeling in Electrocardiology

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Abstract: Computational modeling of healthy and diseased electrocardiology (EC) has a great potential for use in improved diagnosis and prognosis of cardiac arrhythmia and also better therapy planning. However, recent computational methods in electrocardiology usually suffer from three major limitations that hinder their use in the clinic: lack of efficient model personalization strategy; high computational demand from the EC solver; lack of good trade-off between the simplification of cellular ionic models and the demand on keeping sufficient biophysical details. The work in this thesis aims at solving these challenging issues.

The principal part of the work is on the estimation of cardiac conductivities that parameterize the bidomain/monodomain modelthe current standard model for simulating cardiac potential propagation. We consider a variational data assimilation approach by regarding the parameters as control variables to minimize the mismatch between computed and measured potentials. The existence of a minimizer of this misfit function is proved. We significantly improve the numerical approaches in the literature by resorting to a derivative-based optimization method with the settlement of some challenges due to discontinuity. The core of our numerical results is in 3D, on both idealized and real geometries. The reliability and stability of the conductivity estimation approach are demonstrated in presence of noise and with an imperfect knowledge of other model parameters.

We then focus on the computational cost reduction for the inverse conductivity problem. The Proper Orthogonal Decomposition (POD) approach was taken for forward model reduction, along with the Discrete Empirical Interpolation Method (DEIM) for tackling nonlinearity. The POD-DEIM combination is finally applied for the inverse problem of conductivity estimation. In this application, we obtain a very small set of samples by sampling the parameter space using the polar coordinates and densifying the boundary layer utilizing Gauss-Lobatto nodes. In usage of the POD-DEIM reduced order model, the computational effort can be reduced to up to 10estimation. The last part of the work is on the development of a data-driven approach to the reduction of state-of-the-art cellular models used for atria simulation. The reduced model predicts cellular action potentials (AP) in a simple form but is effective in capturing the physiological complexity of the original model. We start from an AP manifold learning, and continue with a regression model construction to predict few leading components in the reduced AP manifold. The reduced cellular model drastically improves the performance of atrial tissue-level electrophysiological modeling (up to two order of magnitudes) and enables almost real-time computations. The same modeling technique can be extended to the study of other excitable myocardial tissues.

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