A Full Physics Real-Time Solver for Simulating Arrhythmias in the Human Heart

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Introduction: For simulating human cardiac electrophysiology (CEP) the bidomain model is considered the gold standard, as its ability to replicate experimental observations with high fidelity has been demonstrated. However, owing to its reaction-diffusion nature and associated constraints on spatiotemporal discretization, computational costs are significant, hampering its adoptions in industrial and clinical applications. Eikonal-based models are computationally more efficient but limited in their ability of simulating cardiac arrhythmias.

Objective: Development of a real-time eikonal-based CEP model for simulating activation and repolarization patterns at fast rates, including reentrant patterns, that match solutions obtained with a full physics reaction-diffusion bidomain model.

Methods: We present a CEP-informed reentrant eikonal model (REK) that combines an eikonal solver with a finite state machine to track action potential phases. The model incorporates physiological restitution, curvature and diffusion effects as measured in a high fidelity reference bidomain model. Local activation times (LATs) and conduction velocities (CVs) predicted by the REK model were compared to a reference bidomain model under resting and stress conditions. Transmembrane voltages were recovered from LATs and local repolarization times to reconstruct the spatiotemporal dynamics of cardiac sources for reentrant activations and compared against solutions of a bidomain model.

Results: Under resting and stress conditions, the REK model matches LATs and CVs of the bidomain model with small root mean squared errors of 0.29 ms and 0.22 m/s respectively. When simulating a sustained spiral wave pattern, the REK solver agrees quantitatively in terms of cycle and wave length with the bidomain solution, while offering a speedup of a factor of ~ 160. Our novel REK solver is able to simulate cardiac arrhythmias with close to real-time performance that approximate very closely full physics bidomain solutions.