Strongly Coupling the Electrical and Mechanical Dynamics of the Heartbeat in a Diffuse Interface Model

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Cardiac arrhythmias are the leading cause of death in the U.S. and the developed world but remain poorly understood. Mathematical models of the heart have proven essential to their study, but while existing models provide an unobstructed view of the heart's electrical activity on both the surface and interior, they have not been able to efficiently incorporate the beating motion of the heart due to the difficulty in handling the moving boundaries of the domain of the governing partial differential equation system. Here, I develop a novel method for strongly coupling mechanical contraction from beating with electrical propagation in a diffuse interface model. I represent the geometry of the heart with a diffuse domain approximation and model the soft-tissue mechanics by considering the heart to be a fluid with an elastic boundary. I couple local contraction of the domain with the Calcium power stroke of the action potential and evolve the shape through a Cahn-Hilliard type equation. I validate my algorithm by demonstrating its convergence, and I show that the model captures the differences in electrical wave propagation due to shape, evidence of successful strong coupling. The algorithm is also found to be 300 times faster than those of existing strongly coupled models. By avoiding the need to explicitly track the boundary of the evolving domain, my work makes comprehensive simulations of total heart function tractable. The theory developed here efficiently facilitates more realistic simulations of the heart, thus giving drug developers a more complete tool in designing therapies for heart conditions, yielding critical insight on the underlying mechanisms of fatal conditions like fibrillation, and enabling dramatic improvements in their treatment and prevention.

Awards Won:

American Mathematical Society: Second Award of $1000

Third Award of $1,000