Domain Decomposition for Multiscale Cardiac Electrophysiology Model Coupling

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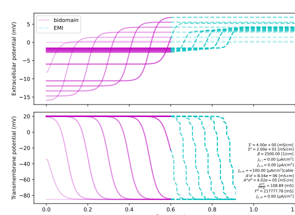
Background. Homogenized models such as the bidomain and monodomain systems are widely used for organ-scale cardiac simulations. However, their averaging nature makes them inadequate for investigating pathologies driven by microstructural changes. In this context, extracellular-membrane-intracellular (EMI) models are more appropriate, but their high computational cost limits their use to small domains, making them impractical for whole-heart simulations.

Methods. This scenario motivates a multiscale modeling strategy: using an EMI model only where spatial resolution is required, while retaining a coarser bidomain model in the surrounding healthy tissue. To couple the EMI and bidomain models across different regions of the computational domain, a domain decomposition approach was employed. At each time step, the subdomains were solved independently, and the solutions were coupled through Dirichlet–Neumann interface conditions enforcing continuity of both the solution and the flux. The approach was also compared with an overlapping strategy and a monolithic approach used as a reference.

Results. Cable simulations were performed using both the EMI and bidomain models, with consistent parameters yielding similar propagation velocities. The numerical results demonstrate that the wave propagates smoothly across the interfaces without noticeable artifacts. For overlapping methods, the size of the overlap influences the quality of the coupling, affecting the agreement between the solutions at the interface.



Time evolution of spatial bidomain–EMI solution.

Conclusions. Future work will focus on extending the framework to a non-overlapping domain decomposition method, with the aim of simplifying the formulation and facilitating its extension to higher-dimensional problems.