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Finite element implementation of Poisson Nernst Planck equations in models of neural structures

Signaling in neural structures is determined by the movement of ions subjected to an electrical field which is best described by the Nernst Planck partial differential equations. The distribution of ionic concentrations in turns determines the electric field through the Poisson equation. The coupling of these equations gives rise to the Poisson Nernst-Planck (PNP) system of partial differential equations. To complete the picture, the opening of transmembrane channels describing the boundary conditions are often given by systems of ordinary differential equations involving the electrical field. In this talk, we present a model describing the evolution of ionic concentrations in a node of Ranvier using PNP equations together with Hodgkin-Huxley equations describing dynamics of transmembrane voltage-gated channels. Solving this model give rise to many numerical difficulties. For one, small imbalances in ionic concentrations can have a huge impact on the electrical field making it difficult to treat the problem as a fully coupled one. Second, the elongated geometries of structures such as axons or nodes of Ranvier makes difficult the construction of an efficient spatial mesh. Finally, the presence of a mostly impermeable membrane leads to solutions being non differentiable and exhibiting steep variations near the membrane cytosol interface. We will see how to tackle some these difficulties in particular by using automatic mesh adaptation. We will also discuss the relevance of related models and how they can be used in other contexts such as the description of cardiac cells and presynaptic vesicles.