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Using the Finite Element method to solve the Poisson Nernst-Planck equations in neural structures

Systems of ordinary differential equation are often used in models of computational neuroscience. While this is appropriate when the spatial dimension is neglected or when the geometry is greatly simplified, this formalism is not well suited to describe complex spatial structures in which case one has to rely on systems of partial differential equations.

In neural structures, the concentration of ionic species and the electric potential evolve in an intertwined manner according to the Poisson-Nernst-Planck system of equations. Solving this system provides the evolution of the distribution of the electric field and ionic concentrations without having to rely on oversimplifying assumptions. However, solving these equations poses many methodological challenges as there is a trade-off between computational cost and accuracy.

Except for very simple geometries, the spatial domain has to be divided into a mesh or a grid on which an approximate solutions can be computed. However, to best way to do this is unclear as many numerical approaches are available. We apply the finite element method with second order elements to two typical structures: a single node of Ranvier and a dendritic spine. We show that this improves the quality of the solution when compared to simpler approaches and that the solutions can be computed at a reasonable numerical cost.