Numerical analysis of Poisson-Nernst Planck system of equations to study the propagation of a transient signal in neurons.

Keywords: Numerical analysis, Finite volume methods, Poisson-Nernst Planck.

Skills: Numerical simulations, Finite volume methods, parabolic system.

Description: The goal of the present internship is to build numerical simulations of a parabolic system of equations with a finite volume method, to study the propagation of a transient signal in thin neuronal sections.

Introduction:

The classical model to study voltage propagation in neurons, the cable theory, has been responsible for many advances in neuroscience, as it accurately describes the electrical activity in large axons. However, this 1D model neglects the spatial variation of ionic concentration, and its effect on the electric field, even though this electric field is generated by the ions.
To investigate such an effect, we will consider a two-dimensional domain representing the small neuronal compartments. We will describe the variations of the electrodiffusion of ions and the electric field after a transient influx of charges using a parabolic system called the Poisson-Nernst Planck system of equation. This system is highly non-linear, which makes its resolution challenging. It will be solved using the DDFV solver [Can], which solves numerically 2D problems while naturally enabling the mesh to be locally refined in specific areas.

Project:

This project aims to investigate the effects of the electric field and the electrodiffusion of ions on signal propagation. In a first stage, the student will have to familiarize himself/herself with the Poisson-Nernst Planck system and the DDFV method. In a second step, the student will have to implement the 2D numerical solver starting from an existing code. Then, the student will investigate the effects of modifying specific parameters (such as the neuronal membrane permitivity) on signal propagation. We will study in particular signal velocity and attenuation.

Prerquisites: Minimal knowledge of Finite volume methods. Some coding skills are welcomed.

References:

[Can] Cancès C, Chainais-Hillairet C and Krell S, *"Numerical analysis of a nonlinear free-energy diminishing Discrete Duality Finite Volume scheme for convection diffusion equations"* Comp Meth in Appl Math, Vol 18(3), 2018.

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