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An Isogeometric Analysis Computational Platform for Material Transport Simulation in Complex Neurite Networks

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Abstract: Neurons exhibit remarkably complex geometry in their neurite networks. So far, how materials are transported in the complex geometry for survival and function of neurons remains an unanswered question. Answering this question is fundamental to understanding the physiology and disease of neurons. Here, we have developed an isogeometric analysis (IGA) based platform for material transport simulation in neurite networks. We modeled the transport process by reaction-diffusion-transport equations and represented geometry of the networks using truncated hierarchical tricubic B-splines (THB-spline3D). We solved the Navier-Stokes equations to obtain the velocity field of material transport in the networks. We then solved the transport equations using the streamline upwind/Petrov-Galerkin (SU/PG) method. Using our IGA solver, we simulated material transport in three basic models of the network geometry: a single neurite, a neurite bifurcation, and a neurite tree with three bifurcations. In addition, the robustness of our solver is illustrated by simulating material transport in three representative and complex neurite networks. From the simulation we discovered several spatial patterns of the transport process. Together, our simulation provides key insights into how material transport in neurite networks is mediated by their complex geometry.

Keywords: Material transport; neurite network; isogeometric analysis; streamline upwind/Petrov-Galerkin method; variational multiscale method

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