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# Bulk-surface evolving FEM setup for the simulation of dendritic spines growth on realistic geometries

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## Abstract

In the landscape of synaptic plasticity, small protrusions called dendritic spines are thought to play a key role in the mechanisms underlying learning and memory formation. The reason is that their size can be directly correlated with synaptic strength; an increase in spine size due to biophysical processes leads to an increase in synaptic strength. A recent paper by (Bonilla-Quintana M., Rangamani P., 2023) proposed an experimentally-informed 3D computational model to investigate how cytoskeletal forces can alter spine size and shape. In this model, bulk reactions describing internal reconfiguration are coupled to surface dynamics in a moving domain framework. Here, we propose to develop a full finite element (FEM) setup to solve this complex numerical problem. By doing so, we will alleviate some of the numerical difficulties of the previous scheme and enable the addition of additional physics. Ultimately, our purpose is to use this algorithm in different biologically plausible scenarios including realistic geometries reconstructed from electron microscopy to gain more insight into the underlying mechanics and to generate testable predictions. Various challenges arise from the implementation of these bulk and surface equations and their coupling. For the bulk part, the actin spine cytoskeleton is modeled using purely advective-reactive equations coupled through non-linear terms and evolving in a moving domain. We exploit classical techniques to stabilize the convection term, such as continuous interior penalty, and insert them in the context of evolving meshes. For the surface part, the elastic membrane follows the gradient flow of a Willmore energy. Its velocity is also perturbed by the nearby barbed ends which are known to generate active forces on it. We exploit recent advances in evolving surface FEM for geometrical flows to accommodate as much generality as possible with focus on: developing a stable algorithm, avoid remeshing, including the influence of the internal species, accommodate membranes with open boundaries.

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