Modeling and simulating two-compartment neuron model with NESTML on NEST GPU

Pooja Babu(1,3), Charl Linssen(1,3), Elena Pastorelli(4), Pier Stanislao Paloucci(4), Gianmarco Tiddia(5), Bruno Golosio(5), Abigail Morrison(2,3)

(1)Simulation and Data Laboratory Neuroscience, Jülich Supercomputer Centre, Forschungszentrum Jülich GmbH, (2)Institute for Advanced Simulation IAS-6, Computational and Systems Neuroscience, Forschungszentrum Jülich GmbH, (3)Software Engineering, Faculty of Computer Science, RWTH Aachen University, Germany (4)Istituto Nazionale di Fisica Nucleare, Sezione di Roma, Rome, Italy, (5)Department of Physics, University of Cagliari, Monserrato, Italy

NESTML is a domain-specific language for spiking neuron models and synaptic plasticity rules. It is designed to support researchers in computational neuroscience by allowing them to specify models in a precise and intuitive way [1]. These models can subsequently be used in dynamical simulations of small- or large-scale spiking neural networks using high-performance simulation code generated by the NESTML toolchain [2]. With NESTML, neuroscientists can write the model code once and have the same models run on multiple target platforms, without needing to create additional low-level code. Code can be generated for a variety of hardware platforms, including CPU (NEST) [3], GPU (NEST GPU) [4], and neuromorphic hardware (SpiNNaker) [5]. This capacity for multiplatform code generation supports validation workflows for neuromorphic platforms.

In this work, we demonstrate the capabilities of the NESTML toolchain for generating GPU-based CUDA/C++ code of neuron models for the NEST GPU target platform. We illustrate these capabilities by implementing the two-compartment spiking neuron model, called the Ca-AdEx model [6], using NESTML. The Ca-AdEx model extends the Adaptive Exponential Integrate and Fire (AdEx) neuron model by incorporating apical dendritic Ca^{2+} dynamics. The NESTML model defines the dynamics of two compartments: the somatic compartment and the apical compartment with Ca^{2+} concentration dynamics. The non-linear dynamics of the Ca-AdEx model are solved using a numerical solver, and the required solver expressions are automatically generated using ODE-toolbox [7]. We validate the generated model code against the pulse protocol described in [6] and compare the results against the same model using NEST Simulator as a reference.

NESTML enhances the findability, accessibility, interoperability, and reusability of models, following the "FAIR" principles. Owing to these principles, NESTML's CUDA/C++ code generation for GPU hardware removes the barrier of having to learn CUDA programming, enabling researchers to focus on conceptual development rather than implementation. The GPU support enables researchers to accelerate large-scale simulations of complex neuron models by leveraging GPU parallelism.

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[4] Golosio et al., Frontiers in Computational Neuroscience, 2021

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[6] E. Pastorelli et al., Frontiers in Computational Neuroscience, 2025

[7] Blundell et al., Frontiers in Neuroinformatics, 2018