Please provide a short title for your overall project

Enabling high-performance simulation of the versatile “AMAT” spiking neuron model through NESTML

Please provide a short abstract (approx. 100-300 words).

Describe the scientific field the student will work in and the problem at hand.

High-performance computing (HPC) enables large-scale simulations of the human brain. However, in order to harness the full computational power of HPC, a training in computing science and a dedication to hardware and software implementation details is generally required, creating a barrier for neuroscience researchers. In order to break down this barrier, NESTML [1] was created as a modelling language (domain-specific language or DSL) for neurons and synapses, and combined with a code generation toolchain, which takes the model, expressed by the researcher in the DSL syntax, and automatically generates high-performance simulation code. The code then runs inside the kernel of an existing simulation platform, in particular, NEST Simulator [2]. This approach allows the end user (the neuroscience researcher) to interact with the system only in terms of the user-friendly NESTML DSL syntax, while implementation details are taken care of by the automated toolchain.

At present, several canonical (industry-standard) spiking neuron models are included with NESTML [3]. In particular, the Izhikevich [4] model is very popular in the scientific literature. However, it suffers from ambiguities in the original formulation as well as a dynamical formulation which is nonlinear, making it challenging to numerically integrate. A favourable alternative is provided by the “AMAT” model [5], which can be analytically integrated and captures a wide range of neuronal responses.

In this project, we will implement the AMAT model in the NESTML DSL, making the model available for other researchers to use and thereby bolstering findability, accessibility, interpretability and reprodicibility of models in computational neuroscience.

[1] Linssen C, Babu PN, Eppler JM, Koll L, Rumpe B and Morrison A (2025) NESTML: a generic modeling language and code generation tool for the simulation of spiking neural networks with advanced plasticity rules. Front. Neuroinform. 19:1544143. doi: 10.3389/fninf.2025.1544143

[2] Gewaltig M.-O.DiesmannM. (2007). NEST (NEural Simulation Tool). Scholarpedia2:1430. 10.4249/scholarpedia.1430

[3] https://nestml.readthedocs.io/en/latest/models_library/index.html

[4] Izhikevich, Simple Model of Spiking Neurons, IEEE Transactions on Neural Networks (2003) 14:1569-1572

[5] Heiberg T, Kriener B, Tetzlaff T, Einevoll GT, Plesser HE (2018). Firing-rate model for neurons with a broad repertoire of spiking behaviors. J Comput Neurosci, 45:103. DOI: https://doi.org/10.1007/s10827-018-0693-9

Please provide information about the required programming skills. Also, indicate the level of proficiency.

Intermediate to good Python programming skill is required. The student will work with and extend an existing Python codebase (that of NESTML; https://github.com/nest/nestml).

Beginner to intermediate C++ programming skill is required. The generated code will be in C++ as NEST Simulator is written in that language. However, a template is already in place and at most will need fine-tuning (see e.g. https://github.com/nest/nest-simulator/blob/master/models/amat2_psc_exp.cpp)

Experience working with a Linux shell and basic Linux tools is required.

Please provide a short workplan.

week 1: training (no workplan required here)
week 2: training (no workplan required here)
week 3: generating and running Izhikevich neuron on HPC
week 4: running Izhikevich neuron benchmarks on HPC with NEST (establishing a baseline)
week 5: running Izhikevich neuron benchmarks on HPC with NESTML (establishing a baseline)
week 6: implementation of AMAT neuron model in NESTML
week 7: numerical validation and parameter space exploration of AMAT neuron model in NESTML
week 8: benchmarking of AMAT neuron model in NEST and NESTML
week 9: optimisation of code generation for AMAT model in NESTML
week 10: creating documentation of the model and tutorial notebook as a GitHub Pull Request

What will the students learn? What tasks do they have to tackle? What software do they have to use?

The expected output of the project is:
- AMAT model implementation in NESTML including model documentation (see https://nestml.readthedocs.io/en/latest/models_library/izhikevich_neuron.html for an example).
- Runtime performance and memory benchmarks for the AMAT model running on NEST Simulator on HPC, especially in comparison to the Izhikevich model
- Jupyter Notebook with a tutorial on how to use the model, including parameter exploration and characterisation of spiking responses, including transfer function, stimulus frequency locking metrics

Please provide requirements that are mandatory for project.

Knowledge of any specific tool, a certain scientific background, etc.

An affinity with computational neuroscience and knowledge of neuroscientific concepts (spike generation, synaptic transmission, etc.) are required.