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# A NEST-based framework for the parallel simulation of networks of compartmental models with customizable subcellular dynamics

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The human brain computes in a massively parallel fashion, not only at the level of the neurons, but also through complex subcellular signaling networks which support learning and memory. Therefore, it's desirable to utilize the parallelization capabilities of modern supercomputers to simulate the brain in a massively parallel fashion. The NEural Simulation Tool (NEST) [1] enables massively parallel spiking network simulations, being optimized to efficiently communicate spikes across MPI processes [2]. However, so far, NEST had limited options to simulate subcellular processes as part of the network. We have extended the NESTML modeling language [3] to support multi-compartment models, featuring user-specified dynamical processes (Fig 1A-C). These dynamics are compiled into NEST models, which optimally leverage CPU vectorization. This adds a deeper, subcellular level of parallelization, allowing individual cores to parallelize multiple compartments. Furthermore, we leverage the Hines algorithm [4] to achieve stable and efficient integration of the system. Overall we gain single-neuron speedups compared to the field-standard NEURON simulator [5] of up to a factor of four to five (Fig 1D). Thus, we enable embedding user-specified dynamical processes in large-scale networks, representing (i) ion channels, (ii) synaptic receptors that may be subject to a-priori arbitrary plasticity processes, or (iii) slow processes describing molecular signaling or ion concentration dynamics. With the present work, we facilitate the creation and efficient, distributed simulations of such networks, thus supporting the investigation of the role of dendritic processes in network-level computations involving learning and memory.

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## References

References
[1] M.-O. Gewaltig and M. Diesmann, "NEST (NEural Simulation Tool),"Scholarpedia, vol. 2, no. 4, p. 1430, 2007, doi: 10.4249/scholarpedia.1430.
[2] S. Kunkel et al., "Spiking network simulation code for petascale computers,"Front. Neuroinformatics, vol. 8, Oct. 2014, doi: 10.3389/fninf.2014.00078.
[3] I. Blundell, D. Plotnikov, J. M. Eppler, and A. Morrison, "Automatically Selecting a Suitable Integration Scheme for Systems of Differential Equations in Neuron Models,"Front. Neuroinformatics, vol. 12, p. 50, Oct. 2018, doi: 10.3389/fninf.2018.00050.
[4] M. Hines, "Efficient computation of branched nerve equations,"Int. J. Biomed. Comput., vol. 15, no. 1, pp. 69–75, 1984.
[5] N. T. Carnevale and M. L. Hines, The NEURON book. 2004.
[6] M. E. Larkum, J. J. Zhu, and B. Sakmann, "A new cellular mechanism for coupling inputs arriving at different cortical layers.,"Nature, vol. 398, no. 6725, pp. 338–41, Mar. 1999, doi: 10.1038/18686.
[7] E. Pastorelli et al., "Two-compartment neuronal spiking model expressing brain-state specific apical-amplification, -isolation and -drive regimes,"Mar. 26, 2024, arXiv: arXiv:2311.06074. doi: 10.48550/arXiv.2311.06074.

References (DOI)
[1] 10.4249/scholarpedia.1430
[2] 10.3389/fninf.2014.00078
[3] 10.3389/fninf.2018.00050
[4] 10.1017/CBO9780511541612
[5] 10.1016/0020-7101(84)90008-4
[6] 10.1038/18686
[7] 10.48550/arXiv.2311.0607

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