NEST Conference 2021

28-29 June 2021

Collage from virtual NEST Conference 2020

NEST Conference 2021 — Program

Monday, 28 June (all times CEST)

Morning

08:45	Registration
09:00	**Welcome & Introduction** Hans Ekkehard Plesser

Session 1	Chair: Hans Ekkehard Plesser
09:15	Keynote **Embedding memories in a network with excitatory and inhibitory plasticity leaves a spiking regularity trace** Julia Gallinaro
10:00	**Short break**
10:15	Talk **NEST Desktop: A web-based GUI for the NEST Simulator** Sebastian Spreizer
10:35	Talk **Multi-scale brain co-simulation in the Human Brain Project: EBRAINS tools for in-transit simulation and analysis** Muhammad Fahad
10:55	Talk **EBRAINS Scientific Liaison Unit** Claudia Bachmann
11:15	**Short break**
11:30	Workshop **Structural plasticity** Sandra Diaz
12:30	**Lunch break**

Afternoon

Session 2	Chair: Johanna Senk
13:30	Session Introduction
13:35	Keynote **Structured Information Representation with Assemblies of Spiking Neurons** Michael Günther Müller
14:20	**Short break**
14:30	Flash talk **Sequence learning, prediction, and generation in networks of spiking neurons** Younes Bouhadjar
14:40	Talk **Event-driven implementation of eligibility propagation** Agnes Korcsak-Gorzo
15:00	Flash talk **Activity simulations in random networks subject to neurodegradation** Sylvain Casteilla
15:10	**Short break**
15:30	Poster session
16:00	Keynote **NEST for Associative Memory with Winner Take All Nets** Christian Huyck
16:45	Group photo

17:30 NEST Initiative General Assembly: Closed session for all NEST Initiative members and official yearly assembly for reports, elections and decisions.

18:30 Social gathering (open end): Meet all the other conference participants in an informal setting at the GatherTown beach, chat, play games and get to know the NEST community members around you. Don't hesitate to bring your favorite drink and lunch/dinner/snack adequate for your timezone. This is of course an optional offering and you can also reduce your screen time and go for a *real* walk to regenerate (without the community though). We'll hopefully see each other again tomorrow.

NEST Conference 2021 — Program

Tuesday, 29 June (all times CEST)

Morning

Session 3	Chair: Markus Diesmann
09:15	Session Introduction
09:25	**Talk** **Towards a systematic understanding of deep-sleep-like activity effects on the network working points during learning cycles** Chiara De Luca
09:45	**Workshop** **Modeling and simulation of synaptic plasticity using NESTML and NEST Simulator** Charl Linssen, Pooja Babu
10:45	**Short break**
11:05	**Flash talk** **Spiking model of the head direction cell system for orientation estimation** Rachael Stentiford
11:15	**Keynote** **Conditions for wave trains in spiking neural networks** Johanna Senk
12:00	**Lunch break**

Afternoon

Session 4	Chair: Abigail Morrison
13:00	Session Introduction
13:05	**Keynote** **Dynamics of multiple interacting excitatory and inhibitory populations with delays** Christopher Kim
13:50	**Short break**
14:00	**Talk** **Compartmental models with user-defined trans-membrane currents through NESTML** Willem Wybo
14:20	**Flash talk** **Combining NEST Simulator and Python Modules in Parallel HPC Implementation** Petia Koprinkova-Hristova
14:30	**Flash talk** **Sub realtime simulation of a full density microcircuit model on a single compute node** Anno Kurth
14:40	**Short break**
15:00	**Poster session**
15:30	**Wrap-up** Abigail Morrison
15:45	**Community Discussions***
17:00	**End of Day 2**

* This slot will be filled during the conference and is intended for dedicated in-depth discussions of interesting topics that came up in the sessions. Topic suggestions are collected openly at the white board in the Gathertown main room and selected by the community towards the end of the conference.

NEST Conference 2021
Abstracts

Embedding memories in a network with excitatory and inhibitory plasticity leaves a spiking regularity trace

Júlia V. Gallinaro[1], Claudia Clopath[1]

[1] Bioengineering Department, Imperial College London, London, United Kingdom

Email: j.gallinaro@imperial.ac.uk

Cortical synapses are plastic, allowing sensory experience to be stored in the network connectivity. Theoretical studies have shown that neuronal assemblies can form upon stimulation in networks with multiple forms of plasticity [1, 2, 3, 4]. In some of these studies [3,4], the resulting network activity reflects previous experiences, with assemblies transitioning between periods of high and low activity. In the others [1, 2], inhibitory plasticity counteracts the effect of excitatory potentiation, leading to the formation of cell assemblies in which excitatory neurons receive increased excitatory and inhibitory currents (EI assemblies). Such EI assemblies could implement inhibitory engrams [5], which allow memories to be stored in a quiescent state, from where they canbe recalled for example through disinhibition [6]. Here we show that, also in EI assemblies, the previous experience may be reflected on spontaneous activity, and information about the assembly may be encoded on the regularity of spike trains. We perform simulations of recurrent networks of excitatory and inhibitory leaky integrate-and-fire neurons, in which excitatory-to-excitatory connections follow the triplets STDP rule [7], and inhibitory-to-excitatory connections are subjectto iSTDP [1]. We show that, after stimulation, excitatory neurons belonging to the EI assembly can be distinguished from the other excitatory neurons in the network based on the coefficient of variation of their inter-spike-intervals. We also show how information about irregularity of spike trains can be readout with the support of short-term plasticity, and how this irregularity leads to a slower decay of excitatory weights within the EI assembly.

References

1. T. P. Vogels, H. Sprekeler, F. Zenke, C. Clopath, and W. Gerstner (2011**), Inhibitory plasticity balances excitation andinhibition in sensory pathways and memory networks**, *Science, vol. 334, no. 6062*, pp. 1569–1573
2. G. K. Ocker and B. Doiron (2019), **Training and spontaneous reinforcement of neuronal assemblies by spike timingplasticity**, *Cerebral Cortex, vol. 29, no. 3*, pp. 937–951.
3. A. Litwin-Kumar and B. Doiron (2014), **Formation and maintenance of neuronal assemblies through synaptic plasticity**,*Nature communications, vol. 5, no. 1*, pp. 1–12
4. F. Zenke, E. J. Agnes, and W. Gerstner (2015), **Diverse synaptic plasticity mechanisms orchestrated to form and retrievememories in spiking neural networks** *Nature communications, vol. 6, no. 1*, pp. 1–13
5. H. C. Barron, T. P. Vogels, T. E. Behrens, and M. Ramaswami (2016), **Inhibitory engrams in perception and memory** *Proceedings of the National Academy of Sciences, vol. 114, no. 26*, pp. 6666–6674
6. H. Barron, T. Vogels, U. Emir, T. Makin, J. O'shea, S. Clare, S. Jbabdi, R. J. Dolan, and T. Behrens (2016), **Unmasking latent inhibitory connections in human cortex to reveal dormant cortical memories** *Neuron, vol. 90, no. 1*, pp. 191-203
7. J.-P. Pfister and W. Gerstner (2006), **Triplets of spikes in a model of spike timing-dependent plasticity** *Journal of Neuroscience, vol. 26, no. 38*, pp. 9673–9682

NEST Desktop: A web-based GUI for the NEST Simulator

Sebastian Spreizer[1,2,3], Jens Buchertseifer[1], Johanna Senk[2], Stefan Rotter[3], Markus Diesmann[2,4,5],Benjamin Weyers[1]

[1] Department IV - Computer Science, Human-Computer Interaction, University of Trier, Trier, Germany
[2] Institute of Neuroscience and Medicine (INM-6) and Institute for Advanced Simulation (IAS-6) and JARA-InstituteBrain Structure-Function Relationships (INM-10), Jülich Research Centre, Jülich, Germany
[3] Bernstein Center Freiburg & Faculty of Biology, University of Freiburg, Freiburg, Germany
[4] Department of Psychiatry, Psychotherapy and Psychosomatics, School of Medicine, RWTH Aachen University,Aachen, Germany
[5] Department of Physics, Faculty 1, RWTH Aachen University, Aachen, Germany

Email: spreizer@uni-trier.de

NEST Desktop [1] comprises graphical elements for creating and configuring network models, running simulations, visualizing and analyzing the results. It allows students to explore important concepts in computational neuroscience without the need to learn a simulator control language before. In this contribution we demonstrate how NEST Desktop gives neuroscientists access to the features of NEST 3 and the European EBRAINS infrastructure [2].

Earlier versions of NEST Desktop required a NEST installation on the user's machine which limited not only the uptake by a non-expert audience but also the network models studied to what can be simulated on a laptop or desktop computer. To ease the use of the app and increase the rangeof possible simulations, we have separated the GUI from the simulation kernel: the web browser renders the GUI while the simulation kernel runs on a centrally maintained server. Furthermore, we discuss the potential of using an in-situ pipeline to enable the app to receive larger data sets from anongoing NEST simulation. This enhances the interactivity of NEST for large simulations on HPC facilities.

In order to give students, teachers, and researchers installation-free access to the compute resources being built up by the European Union, we integrated NEST Desktop into the EBRAINS infrastructure also facilitating long-term sustainability. The same code remains available as a stand- alone version of NEST Desktop [3] for applications in teaching and training and installations at other sites.

Acknowledgements

This project has received funding from the European Union's Horizon 2020 Framework Programme for Research and Innovation under Specific Grant Agreement No. 785907 (Human Brain Project SGA2) and 945539 (Human Brain Project SGA3) and the Helmholtz Association Initiative and Networking Fund under project number SO-092 (Advanced Computing Architectures,ACA).

References

1. Documentation [https://nest-desktop.readthedocs.io]
2. EBRAINS [https://ebrains.eu/service/nest-desktop]
3. Source code [https://github.com/nest-desktop/nest-desktop]

Multi-scale brain co-simulation in the Human Brain Project: EBRAINS tools for in-transit simulation and analysis

Muhamad Fahad[1], Kim Sontheimer[1], Cristian Jimenez-Romero[1], Rolando Ingles Chavez[1], Sandra Diaz[1], Wouter Klijn[1], Abigail Morrison[1,2,3]

[1]Forschungszentrum Jülich GmbH, Institute for Advanced Simulation, Jülich Supercomputing Centre (JSC), Simulation& Data Lab Neuroscience, JARA, 52425 Jülich | Germany
[2]Forschungszentrum Jülich, GmbH, Institute of Neuroscience and Medicine (INM-6) and Institute for AdvancedSimulation (IAS-6), 52425 Jülich | Germany
[3]Software Engineering, Department of Computer Science 3, RWTH Aachen University, Ahornstraße 55, 52074 Aachen | Germany

Email: m.fahad@fz-juelich.de

An important capability build by The Human Brain Project (HBP) is brain simulations of large- and multiscale experimental and clinical data sets with integrated analysis toolkits. This results in workflows with multiple components to be run in parallel and in coordination with each. How to develop an end-user friendly production system capable of running these workflows is an open question, and introduces several scientific, engineering, and execution challenges: Parallel execution in a distributed environment. Data-flow and transformation between different scales, as well as error propagation related to the model complexity. Tolerance to network isolation/failure, the identification of communication/computation bottlenecks, and the growing probability of the fault condition as a multiplicative function of the number of applications in a workflow and their individual failure probabilities.
To address these challenges, the multi-scale co-simulation framework, based on the Modular Science approach [1], connects at runtime the needed simulation engines, analysis tools and visualization engines. The Modular Science runtime execution system augments the science functionality with engineering and deployment functionality providing a handle on the complexity of the system.
This talk will introduce the multi-scale co-simulation framework and the Modular Science approach to address the challenges with a focus on two-driving use-cases containing a NEST model. Firstly, a TVB[2] and NEST co-simulation with dedicated transformation modules connecting a spiking network with a neural mass model. The second use-case is a co-simulation setup connecting NEST to the multi-agent simulation environment NetLogo[3], where a small point neuron network simulation controls agents interacting in a simple world.

Acknowledgements

This project has received funding from the European Union's Horizon 2020 research and innovationprogramme under grant agreement No 785907 (HBP SGA2), from the European Union's Horizon 2020 Framework Programme for Research and Innovation under the Specific Grant Agreement No. 945539 (HBP SGA3) and from the European Union's Horizon 2020 Framework Programme for Research and Innovation under the Specific Grant Agreement No. 945539 (Human Brain Project SGA3)

References

1. W. Klijn, et. al (2019), **Staged deployment of interactive multi-application HPC workflows**, *HPCS*
2. P. Sanz Leon, et. al (2013), **The Virtual Brain: a simulator of primate brain network dynamics** *Frontiers in Neuroinf. Volume 7*,
3. Wilensky, U. (1999). **NetLogo Home Page** http://ccl.northwestern.edu/netlogo/.

EBRAINS Scientific Liaison Unit

Claudia Bachmann[1], Wouter Klijn[1]

[1] Jülich Supercomputer Centre (JSC), Institute for Advance Simulation (IAS), Jülich Research Centre, Jülich, Germany

Email: c.bachmann@fz-juelich.de

The Human Brain Project (HBP) is developing and providing a European Brain Research Infrastructure (EBRAINS), which offers NEST as a service component. EBRAINS provides digital tools and services for brain research, aiming for a concerted usage of the different tools. This allowsresearchers to simulate, visualize, analyze, and compare brain activity at different spatial and temporal scales (e.g. TVB-NEST multiscale simulation tool). EBRAINS comprises more than 130 European research organizations, each with a large number of scientists, programmers and technicalcoordinators. On top of this, it also entails divisions responsible for management, outreach, communication, education, ethics and, of course, the director's board. The Scientific Liaison Unit (SLU) was founded in order to reconcile the different needs and viewpoints resulting from the complexity of developing and operating this immense EBRAINS infrastructure.
In my talk, I will give an overview of the different areas of responsibility that the SLU has. In particular, I will explain our strategies for identifying and prioritizing the needs of the scientific community and their formulation into technical requirements based on scientific showcases [1]. In this context, I will also demonstrate how we present the content of the showcases in a very systematicand standardized way, which helps researchers to structure their work and to identify potential challenges as well as opportunities for extension and interaction early on.

Acknowledgements

This research was supported by the EBRAINS research infrastructure, funded from the European Union's Horizon 2020 Framework Program for Research and Innovation under the Specific GrantAgreement No. 945539 (Human Brain Project SGA3).

References

1. https://drive.ebrains.eu/f/2d30a9a6284f4cc0b8c9/

Workshop: Structural plasticity

Sandra Diaz[1]

[1]Forschungszentrum Jülich GmbH, Institute for Advanced Simulation, Jülich Supercomputing Centre (JSC), Simulation& Data Lab Neuroscience, JARA, 52425 Jülich | Germany

Email: s.diaz@fz-juelich.de

In this session we will cover the state of the art research and future directions of simulation and modeling of structural plasticity and generative connectomics. We will examine modeling and simulation of connectivity generation from two perspectives:
1. Neural development and structural plasticity in biological neural networks
2. Generation of connectivity for biological and artificial neural networks

In specific we will discuss about different models of structural plasticity, the current available implementation in NEST and other simulation / emulation platforms as well as the intersections among them. We will also cover implementation details such as: identification of data and computing requirements, separation between simulation of activity and structural dynamics, management of computing resources, and implementation of interfaces. Discussion will also focus on how to collectively move forward in this field in order to provide more flexibility to modelers and researchers while preserving computational efficiency and a standard language which allows sharing and comparing among platforms.
Potential participants to this session would be modelers, computational and experimental neuroscientists, developers, experts in simulation interfaces, and experts in interactive data analysis and visualization.

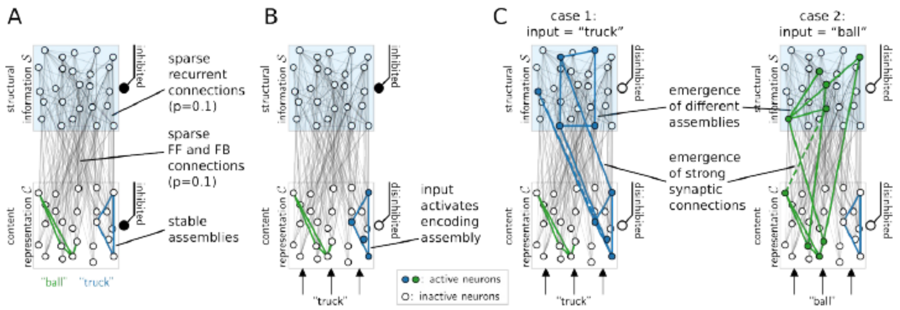
Structured Information Representation with Assemblies of Spiking Neurons

Michael G. Müller[1], Christos H. Papadimitriou[2], Wolfgang Maass[1], Robert Legenstein[1]

[1] Institute of Theoretical Computer Science, Graz University of Technology, Graz 8010, Austria
[2] Computer Science Department, Columbia University, New York, NY 10027

Email: mueller@igi.tugraz.at

High-level cognition requires structured representations of information in which abstract categories are linked to content. Experimental data point to specific subareas of the temporal lobe from which categorical information (like agent or patient in a sentence) can be decoded [1]. We present assembly projections [2], a general mechanism for attaching structural information to content based onassemblies of spiking neurons. We assume that content is encoded by sparse assemblies (similar to the concept cells [3] found in the medial temporal lobe, Fig. A). When activated by input (Fig. B), content can be attached to semantic variables through the formation of a linked assembly in a separatepopulation (Fig. C-D). This link allows structural information to be read out at a later time, leading to the reactivation of the content assembly. Assembly projections emerge through STDP in randomlywired spiking neural networks with divisive inhibition where the different populations are controlledby disinhibition. This models thus provides a very general mechanism for binding (i.e., tying togetherpieces of information) without relying on assumptions made by many classical models of binding like specific connectivity or special circuitry. As assembly projections also support a number of elementary symbolic computations (e.g., comparing contents linked to different structural categories),they can serve as a building block for models capable of solving more demanding cognitive tasks.



Acknowledgements

This work was supported by the Austrian Science Fund (FWF) projects I 3251-N33 (SASNN) and I4670-N (SMALL) and by the European Union projects 785907 (HBP) and 824162 (SYNCH).

References

1. Frankland SM and Greene JD (2015) **An architecture for encoding sentence meaning in left mid-superiortemporal cortex.** *Proc Natl Acad Sci USA,* 112(37), 11732-11737. doi: 10.1073/pnas.1421236112
2. Müller MG, Papadimitriou CH, Maass W, and Legenstein R (2020). **A model for structured information representation in neural networks of the brain.** *eNeuro*, 7(3). doi: 10.1523/ENEURO.0533-19.2020
3. Quian Quiroga R (2016) **Neuronal codes for visual perception and memory.** *Neuropsychologia,* 83 (2016): 227-241. doi: 10.1016/j.neuropsychologia.2015.12.016

Sequence learning, prediction, and generation in networks of spiking neurons

Younes Bouhadjar[1,2], Markus Diesmann[1,3], Dirk J. Wouters[4], and Tom Tetzlaff[1]

[1] Institute of Neuroscience and Medicine (INM-6), & Institute for Advanced Simulation (IAS-6), & JARA BRAINInstitute Structure-Function Relationships (INM-10), Jülich Research Centre, Jülich, Germany
[2] Peter Grünberg Institute (PGI-7-10), Jülich Research Centre and JARA, Jülich, Germany
[3] Department of Physics, Faculty 1, & Department of Psychiatry, Psychotherapy, and Psychosomatics, Medical School,RWTH Aachen University, Aachen, Germany
[4] Institute of Electronic Materials (IWE 2) & JARA-FIT, RWTH Aachen University, Aachen, Germany

Email: y.bouhadjar@fz-juelich.de

Sequence learning, prediction and generation has been proposed to be the universal computation performed by the neocortex. The Hierarchical Temporal Memory (HTM) algorithm [1] realizes this form of computation. It learns sequences in an unsupervised and continuous manner using local learning rules, permits a context-specific prediction of future sequence elements, and generates mismatch signals in case the predictions are not met. While the HTM algorithm accounts for a number of biological features such as topographic receptive fields, nonlinear dendritic processing, and sparse connectivity, it is based on abstract discrete-time neuron and synapse dynamics, as well as on plasticity mechanisms that can only partly be related to known biological mechanisms. Here, we devise a continuous-time implementation of the temporal-memory (TM) component of the HTMalgorithm [2], implemented in NEST, which is based on a recurrent network of spiking neuronswith biophysically interpretable variables and parameters. The model learns non-Markovian sequences by means of a structural Hebbian synaptic plasticity mechanism supplemented with a rate-based homeostatic control. In combination with nonlinear dendritic input integration and local inhibitory feedback, this type of plasticity leads to the dynamic self-organization of narrow sequence-specific feedforward subnetworks. These subnetworks provide the substrate for a faithful propagation of sparse, syn- chronous activity, and, thereby, for a robust, context-specific prediction of future sequence elements as well as for the autonomous replay of previously learned sequences. By strengthening the link to biology, our implementation facilitates the evaluation of the TM hypothesis based on experimentally accessible quantities. The continuous-time implementation of the TM algorithm permits, in particular, an investigation of the role of sequence timing for sequencelearning, prediction and replay. We demonstrate this aspect by studying the effect of the sequence speed on the sequence learning performance and on the speed of autonomous sequence replay.

Acknowledgements

This project was funded by the Helmholtz Association Initiative and Networking Fund (project number SO-092, Advanced Computing Architectures), and the European Union's Horizon 2020 Framework Programme for Research and Innovation under the Specific Grant Agreement No. 945539 (Human Brain Project SGA3) and No. 785907 (Human Brain Project SGA2).

References

1. Hawkins, J., Ahmad, S., & Dubinsky, D. (2011). Cortical learning algorithm and hierarchical temporal memory.*Numenta Whitepaper* , 1–68.

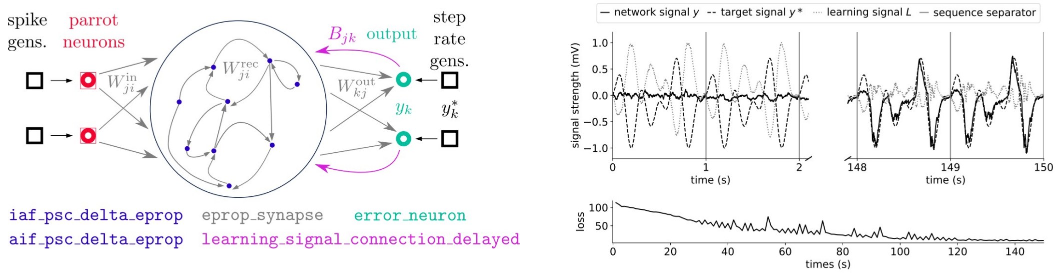
Event-driven implementation of eligibility propagation

Agnes Korcsak-Gorzo[1,2], Jonas Stapmanns[1,2], Sacha van Albada[1,3], David Dahmen[1], Markus Diesmann[1,4]

[1] Institute of Neuroscience and Medicine (INM-6) and Institute for Advanced Simulation (IAS-6) and JARA-InstituteBrain Structure-Function Relationships (INM-10), Jülich Research Centre, Jülich, Germany
[2] Department of Physics, Faculty 1, RWTH Aachen University, Aachen, Germany
[3] Institute of Zoology University of Cologne, Cologne, Germany
[4] Department of Psychiatry, Psychotherapy, and Psychosomatics, Medical School, RWTH Aachen University, Aachen,Germany

Email: a.korcsak-gorzo@fz-juelich.de

We port eligibility propagation (eprop) [1], a biologically plausible approximation of backpropagation through time for recurrent spiking neural networks, to NEST. Eprop is local in space and time and employs broadcast alignment, i.e., random feedback weights from output neurons to the recurrent network. In contrast to the original fully time-driven implementation in Tensorflow, we show here an implementation that is consistent with the event-driven update of synapses in NEST. Three factors enter this learning rule: the filtered presynaptic spike-trains, the postsynaptic membrane potential, and instructive learning signals emitted by the output neurons. Toaccumulate the factors until the weight update, we use the NEST archiving infrastructure [2]. As a proof of concept, we demonstrate efficient learning of a regression and a classification task in fully connected networks of a few hundred neurons. We currently study the learning behavior in sparsely connected, Brunel-type [3] networks and larger, more structured networks, like a cortical microcircuit [4].



Acknowledgements

The authors gratefully acknowledge the computing time granted through JARA on the supercomputer JURECA [5] at Forschungszentrum Jülich, funding from the European Union's Horizon 2020 Framework Programme for Research and Innovation under grant agreement number 945539 (Human Brain Project SGA3) and funding from the Helmholtz Association Initiative and Networking Fund under project number SO-092 (Advanced Computing Architectures). We thank Jakob Jordan and Alexander van Meegen for an early implementation and Franz Scherr for helpful discussions.

References

1. Bellec et al. (2020). *Nature communications*, *11*(1), 1-15. https://doi.org/10.1038/s41467-020-17236-y
2. Stapmanns et al. (2020). *arXiv preprint arXiv:2009.08667*. https://arxiv.org/abs/2009.08667
3. Brunel (2000). *Journal of computational neuroscience*, *8*(3), 183-208. https://doi.org/10.1023/A:1008925309027
4. Potjans & Diesmann (2014). *Cerebral cortex*, *24*(3), 785-806. https://doi.org/10.1093/cercor/bhs358
5. Jülich Supercomputing Centre. (2018). JURECA: Modular supercomputer at Jülich Supercomputing Centre. Journalof large-scale research facilities, 4, A132. https://doi.org/10.17815/jlsrf-4-121-1

Activity simulations in random networks subject to neurodegradation

Sylvain Casteilla[1], Samuel Bottani[1]

[1] Laboratoire Matières et Systèmes Complexes UMR CNRS 7057, Université de Paris

Email: samuel.bottani@u-paris.fr

In Neuroscience, in vitro cultures of neurons play a particular role; they provide systems where neurons can be reproducibly stimulated, with controlled parameters. These setups make it possible, by reducing the complexity of the system, to investigate the properties of a neuronal network and how computation may occur in these structures. In our case, we study the activity of a neuronal network in culture under the attack of a neurodegenerative process which progressively destroys links or nodes.

Theoretical deductions from experiments and simulations show complex spiking avalanches and large scale activity bursts [1]. Additionally, the activity of the network can exhibit phase transitions from an asynchronous state to one displaying synchronous bursting, which is connected to the topological features of the network.

We simulate using NEST the evolution of the activity in random networks of adaptative integrate and fire neurons while the network is progressively degraded. We considered two different strategies to perform the simulations over attacked networks.

In the first approach, a new simulation is restarted for each network modification. In the second strategy, the NEST disconnect function is used to modify the network while the simulation of activity is running. Additionally, modifications of the network are made with different strategies as: a uniform random removal of the neurons, a selective targeted removal depending on their out- or in-degree, or a specific targeting of nodes identified among initiators of synchronous bursting states.

We monitor different properties for the same topological neuronal network modified with these two approaches, and observe that the post transitory state of the network dynamics is only topology-dependent.

Acknowledgements

We would like to thank Tanguy Fardet, and Stephane Metens for their helpful discussions.

References

1. Tanguy Fardet, Mathieu Ballandras, Samuel Bottani, Stéphane Métens and Pascal Monceau (2018), **Understanding the Generation of Network Bursts by Adaptive Oscillatory Neurons** *Front. Neurosci.* doi: 10.3389/fnins.2018.00041

NEST for Associative Memory with Winner Take All Nets

Christian Huyck[1], Alberto Vergani[2]

[1] Middlesex University, London, UK
[2] Aix-Marseille University, Marseille, France

Email: c.hyuck@mdx.ac.uk

Using NEST [1] and PyNN [2], an extensible mechanism for representing continuously valued concepts in a network of spiking neurons was developed. This implemented a continuously valued cell assembly, which had persistent firing to represent short term memory. This mechanism was embedded in an associative memory [3] associating discrete beverage (coffee and coke) and temperature (hot, cold and warm) concepts with continuously valued temperatures. Two inputs (e.g. hot and coffee) retrieved the associated concept (e.g. 82º-87º). Continuously valued concepts were represented by Winner Take All Networks. In this case, two dimensional bump attractors with local connectivity were used, but the mechanism should translate to higher dimensional attractors. The associative memory context led to an issue of a wide range of values being activated, leading to problems with attractor dynamics and multiple streams of values firing instead of a single stream. An exploration of the attractor dynamics of the system supported the development of a mechanism to resolve the problem; extra topology was added to resolve this problem via merging streams then overcoming the streams repelling each other. A compensatory Hebbian learning rule is also applied to learn the associations. This led to results that converge in psychologically realistic time; the system is thus a simple neurocognitive model. Standard NEST synapse and neuron models are used; Hebbian learning is done between epochs using python, though it can be done as a user defined NEST synapse model, or indeed, as the system uses PyNN, in SpiNNaker. The system can readily be integrated with the NEAL component architecture to develop more sophisticated agents.

Acknowledgements

This work has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 720270 (the Human Brain Project) and the UK EPSRC grants EP/D059720 and EP/P00542X/1.

References

1. M. Gewaltig and M. Diesmann (2007), **NEST (Neural Simulation Tool)**, *Scholarpedia,*
2. A. Davidson, D. Bruderle, J. Eppler, E. Muller, D. Pecevski, L. Perrinet and P. Yqer (2008), **PyNN: a common interface for neuronal network simulators**, *Frontiers in neuroinformatics,*.
3. C. Huyck and A. Vergani, **Hot coffee: associative memory with bump attractor cell assemblies of spiking neurons**, *Journal of Computational Neuroscience.*

Towards a systematic understanding of deep-sleep-like activity effects on the network working points during learning cycles

Chiara De Luca[3,4], Cristiano Capone[4], Bruno Golosio[1,2], Elena Pastorelli[4], Giovanni Stegel[5],Gianmarco Tiddia[1,2], Giulia De Bonis[4], Pier Stanislao Paolucci[4]

[1]Dipartimento di Fisica, Università di Cagliari, Italy
[2]Istituto Nazionale di Fisica Nucleare (INFN), Sezione di Cagliari, Italy
[3]Ph.D. Program in Behavioural Neuroscience, "Sapienza" University of Rome
[4]Istituto Nazionale di Fisica Nucleare (INFN), Sezione di Roma, Italy
[5] Dipartimento di Chimica e Farmacia, Università di Sassari, Italy

Email: Chiara.DeLuca@roma1.infn.it

The brain exhibits capabilities of fast incremental learning from a few noisy examples, as well as the ability to associate similar memories in autonomously-created categories, and to combine contextual hints with sensory perceptions. Together with sleep, these mechanisms are thought to be key components of many high-level cognitive functions. Sleep is known to be essential for awake performance, but the mechanisms underlying its cognitive functions are still to be clarified: here we aim to investigate the effect of deep-sleep-like activity over internal memory representation and its energetic and entropic effects.

At last year NEST 2020 Conference, we demonstrated how to exploit the combination of context and perception in a new thalamo-cortical model (ThaCo) based on a soft winner-take-all circuit of excitatory and inhibitory spiking neurons [1][2]: this model is capable of undergoing multiple wake-sleep cycles during incremental learning, it adapts its pre-sleep, deep-sleep and post- sleep firing rates in a manner that is similar to the experimental measures of [3], and it demonstrates the beneficial cognitive role played by such adaptations. During the last year, we investigated the effect of a deep-sleep like activity on the network working point exploring the transition from awake classification phases towards deep-sleep like phases, and vice versa. We show that during sleeping, the total input current to the cortical neurons decreases due to the sleep-induced homeostatic effect. Sleep-like activity, on the other hand, affects the network status during the following awake classification phase: the effect of STDP during sleep is a general reduction and homogenization of input current distribution. We also show an association effect between the internal representation of similar memories. Finally, aiming at a more systematic description of the effects of deep-sleep-like activity, some of us defined a simplified rate-based thalamo-cortical model relying on minimal assumptions. In this model, sleep formally implements a "density based clustering" in the thalamo-cortical connections. Also, a set of entropic and energetic measures are introduced to quantify the effects of sleep. These measures are applicable to experimental data. These results are also reproducible in a more biological spiking network model.

Acknowledgements

This work has been supported by the European Union Horizon 2020 Research and Innovation program under the FET Flagship Human Brain Project (grant agreement SGA3 n. 945539) and by the INFN APE Parallel/Distributed Computing laboratory.

References

1. Golosio et al., *arXiv:2003.11859. Accepted in PLOS Computational Biology*
2. Capone et al (2019), *Scientific Reports* 9:8990.
3. Watson et al. (2016), *Neuron*.

Workshop: Modeling and simulation of synaptic plasticity using NESTML and NEST Simulator

Charl Linssen[1,2], Pooja Babu[1], Jochen M. Eppler[1], Abigail Morrison[1-3]

[1]Simulation Lab Neuroscience, Jülich Supercomputer Centre, Institute for Advanced Simulation, Jülich-Aachen Research Alliance, Forschungszentrum Jülich GmbH

[2]Institute for Neuroscience and Medicine INM-6 / INM-10, Jülich-Aachen Research Alliance, Institute for Advanced Simulation IAS-6, Forschungszentrum Jülich GmbH

[3]Department of Computer Science 3 - Software Engineering, RWTH Aachen University, Aachen, Germany

Email: c.linssen@fz-juelich.de

Spike-timing dependent plasticity (STDP) is a ubiquitous and diverse phenomenon in neural networks. We will review some of the empirical observations on STDP before looking at two mathematical formalisations in more detail, namely STDP with all-to-all and nearest-neighbour spike pairing, and the triplet STDP rule from [1]. These mathematical models are then expressed in the NESTML modelling language [2], and instantiated in a simple network which is simulated in NEST. We analyse how the parameters of the plasticity rule influence the evolution of synaptic strength during simulation.

All of the model definition, simulation and subsequent analysis will be controlled from a Jupyter (Python) notebook. Code will be provided for all models, and we invite interactive experimentation during and after the tutorial. Next to running NESTML on a local computer, participants will also have the opportunity to log into virtual machines courtesy of HBP/EBRAINS. These can be accessed worldwide in the browser, without any prior set-up or installation required.

References

1. Pfister JP, Gerstner W (2006). *The Journal of Neuroscience 26(38)*:9673-9682.
2. NESTML https://nestml.readthedocs.org/

Spiking model of the head direction cell system for orientation estimation

Rachael Stentiford[1], Tom Knowles[1], Martin Pearson[1]

[1] Bristol Robotics Laboratory, Bristol, UK

Email: rachael.stentiford@brl.ac.uk

In mammals, navigation and spatial learning rely on building an internal representation of the environment using both idiothetic (self-motion) cues and allothetic (external) cues, such as vestibular [1] and visual landmark [2] information. Heading is represented by Head Direction cells which are active when the animals head faces a preferred direction.

Visual landmarks have been shown to control the head direction signal in cue rotation studies [2], with longer experience of cues resulting in stronger rotations indicating confidence in a cues association with a heading is important for overriding the idiothetic estimation, which is liable to become less accurate overtime.

Head direction has been previously modelled as a ring attractor with gaussian connectivity between HD cells [3], and as an excitatory population connected to two inhibitory populations that drive activity around the ring (representing the reciprocal connections between two brain regions know to generate the head direction signal) [4].

We propose a spike-based ring attractor model, build using the NEST simulator, composed of an excitatory population and inhibitory population, with two additional rings providing angular velocity (idiothetic) input, and additional cells for associating landmark information with HD cells to correct for drift in the estimation.

The aim of this work is to understand how uncertainty in the animals heading is represented in the brain and explore how allothetic cues can be used to correct drift in a model of the head direction system primarily driven by idiothetic cues.

Acknowledgements

This work is funded by the Human Brain Project.

References

1. Yoder RM, Taube JS. (2014) **The vestibular contribution to the head direction signal and navigation.** *Front Integr Neurosci*.;8:32. doi: 10.3389/fnint.2014.00032. PMID: 24795578; PMCID: PMC4001061.
2. Yoder RM, Peck JR, Taube JS. (2015) **Visual landmark information gains control of the head direction signal at thelateral mammillary nuclei**. *J Neurosci*.;35(4):1354-67. doi: 10.1523/JNEUROSCI.1418-14.2015.
3. McNaughton BL, Battaglia FP, Jensen O, Moser EI, Moser MB.(2006) **Path integration and the neural basis of the'cognitive map'**. *Nat Rev Neurosci*.;7(8):663-78. doi: 10.1038/nrn1932. PMID: 16858394.
4. Boucheny C, Brunel N, Arleo A. (2015) **A continuous attractor network model without recurrent excitation: maintenance and integration in the head direction cell system.** *J Comput Neurosci*.;18(2):205-27. doi: 10.1007/s10827-005-6559-y.

Conditions for wave trains in spiking neural networks

Johanna Senk[1,2,*], Karolína Korvasová[1,2], Jannis Schuecker[1], Espen Hagen[1,3], Tom Tetzlaff[1], MarkusDiesmann[1,4,5], Moritz Helias[1,4]

[1] Institute of Neuroscience and Medicine (INM-6), Institute for Advanced Simulation (IAS-6), and JARA-InstituteBrain Structure-Function Relationships (INM-10), Jülich Research Centre, Jülich, Germany
[2] RWTH Aachen University, Aachen, Germany
[3] Department of Physics, Faculty of Mathematics and Natural Sciences, University of Oslo, Oslo, Norway
[4] Department of Physics, Faculty 1, RWTH Aachen University, Aachen, Germany
[5] Department of Psychiatry, Psychotherapy, and Psychosomatics, Medical Faculty, RWTH Aachen University, Aachen,Germany

Email: j.senk@fz-juelich.de

Spatiotemporal patterns such as traveling waves are frequently observed in recordings of neural activity. Previous studies have investigated the existence and uniqueness of different types of wavesor bumps of activity using neural-field models [1], phenomenological coarse-grained descriptionsof neural-network dynamics. But it remains unclear how these insights can be transferred to more biologically realistic networks of spiking neurons, where individual neurons fire irregularly.
Here, we employ mean-field theory [2] to reduce a microscopic model of leaky integrate-and-fire (LIF) neurons with distance-dependent connectivity to an effective neural-field model [3,4]. The dynamics in this neural-field model depends on the mean and the variance in the synaptic input,both determining the amplitude and the temporal structure of the resulting effective coupling kernel.For the neural-field model we employ linear stability analysis to derive conditions for the existence of spatial and temporal oscillations and wave trains, that is, temporally and spatially periodic traveling waves. Compatible with the architecture of cortical neural networks, wave trains emergein two-population networks of excitatory and inhibitory neurons as a combination of delay-induced temporal oscillations and spatial oscillations due to distance-dependent connectivity profiles. We demonstrate quantitative agreement between predictions of the analytically tractable neural-field model, implemented in the toolbox LIF Meanfield Tools [5], and direct NEST simulations of both: networks of nonlinear rate-based units and networks of LIF neurons.

Acknowledgements

This project has received funding from Helmholtz portfolio theme SMHB, HGF Grant VH-NG- 1028, EU Grant 720270 (HBP), EU Grant 785907 (HBP), German Research Foundation (DFG; grant DI 1721/3-1 [KFO219-TP9]), ERS seed funds MSCALE and G:(DE-82)ZUK2-SF-CLS002
(partly financed by Hans Herrmann Voss Stiftung) of the RWTH Aachen University, and ResearchCouncil of Norway (Grant 250128/COBRA).

References

1. Coombes S (2005) **Waves, bumps, and patterns in neural field theories.** *Biol Cybern.* 93:91-108. doi: 10.1007/s00422-005-0574-y
2. Brunel N and Hakim V (1999) **Fast global oscillations in networks of integrate-and-fire neurons with low firingrates.** *Neural Comput.* 11(7):1621-1671. doi: 10.1162/089976699300016179.
3. Senk J, et al. (2020) **Conditions for wave trains in spiking neural networks.** *Phys Rev Research.* 2, 023174.doi: 10.1103/PhysRevResearch.2.023174
4. Senk J, et al. (2020) **Wave trains.** *Zenodo.* doi: 10.5281/zenodo.3661379
5. **LIF Meanfield Tools** [https://github.com/INM-6/lif_meanfield_tools]

Dynamics of multiple interacting excitatory and inhibitory populations with delays

Christopher M. Kim[1], Ulrich Egert[1,2], Arvind Kumar[1,3]

[1] Bernstein Center Freiburg, 79104 Freiburg, Germany
[2] Biomicrotechnology, IMTEK—Department of Microsystems Engineering, University of Freiburg, 79110 Freiburg,Germany
[3] Department of Computational Science and Technology, School for Electrical Engineering and Computer Science,KTH Royal Institute of Technology, Lindstedtsvägen 3, 11428 Stockholm, Sweden

Email: chrismkkim@gmail.com

A network consisting of excitatory and inhibitory (EI) neurons is a canonical model for understandinglocal cortical network activity. In this study, we extended the local circuit model and investigated how its dynamical landscape can be enriched when it interacts with another excitatory (E) populationwith long transmission delays. Through analysis of a rate model and numerical simulations of a corresponding network of spiking neurons, we studied the transition from stationary to oscillatory states by analyzing the Hopf bifurcation structure in terms of two network parameters: (1) transmission delay between the EI subnetwork and the E population and (2) inhibitory couplings thatinduced oscillatory activity in the EI subnetwork. We found that the critical coupling strength can strongly modulate as a function of transmission delay, and consequently the stationary state can be interwoven intricately with the oscillatory state. Such a dynamical landscape gave rise to an isolatedstationary state surrounded by multiple oscillatory states that generated different frequency modes, and cross-frequency coupling developed naturally at the bifurcation points. We identified the network motifs with short- and long- range inhibitory connections that underlie the emergence of oscillatory states with multiple frequencies. Thus, we provided a mechanistic explanation of how the transmission delay to and from the additional E population altered the dynamical landscape. In summary, our results demonstrated the potential role of long-range connections in shaping the network activity of local cortical circuits.

Acknowledgements

This work was supported by the BrainLinks-BrainTools Cluster of Excellence funded by the GermanResearch Foundation (DFG EXC 1086), the German Federal Ministry of Education and Research (FKZ 01GQ0830), and the INTER- REG IV Rhin superieur program and European Funds for Regional Development through the project TIGER A31 and the Swedish Research Council (2018- 03118).

References

1. I. Vlachos, T. Deniz, A. Aertsen, and A. Kumar (2016), *PLoS Comput. Biol.* **12**, e1004720 .
2. N. Brunel (2000), *J. Comput. Neurosci*. **8**, 183.
3. E. Ledoux and N. Brunel,(2011) *Front. Comput. Neurosci*. **5**, 25 .

Compartmental models with user-defined trans-membrane currents through NESTML

Krzysztof Blaszczyk[1], Pooja Babu[2], Charl Linssen[2], Abigail Morrison[1,2,3], Willem A.M. Wybo[3]

[1] Department of Computer Science 3 - Software Engineering, RWTH Aachen University, Aachen, Germany
[2] Simulation & Data Lab Neuroscience, Jülich Supercomputing Centre, Institute for Advanced Simulation, JARA,Forschungszentrum Jülich, Germany
[3] Institute of Neuroscience and Medicine (INM-6) & Institute for Advanced Simulation (IAS-6) & JARA-InstituteBrain Structure-Function Relationship (JBI-1 / INM-10), Research Centre Jülich, Jülich, Germany

Email: w.wybo@fz-juelich.de

Neurons in the brain are characterized by their elaborate dendritic trees and varied distributions of trans-membrane currents [1]. In previous work, we extended NEST with the capability to simulate compartmental models [2]. While the dendritic layout could be defined at runtime, ion channel and synaptic receptor dynamics could not be customized. Here, we address this shortcoming by leveraging NESTML: trans-membrane currents can be written intuitively as equations, which are combined with the previously implemented integrator for compartmental dynamics and compiled.

All trans-membrane currents in a given neuron model are written down in a single NESTML file, either as ion channels or as receptor currents. The compartmental layout is defined at run-time, while optionally specifying the ion channel parameters declared in NESTML. Finally, synaptic receptors are added, again while optionally specifying receptor parameters.

In contrast to other compartmental simulators [3], we have chosen a low-level interface for the compartmental models in NEST, where the parameters of individual compartments are exposed. Thus, users can easily define few-compartment models with abstract dendritic subunits. Additionally, NEAT (Neural Analysis Toolkit) provides a high-level interface to export both detailed and simplified dendritic models [5] to NEST. With these additions, NEST becomes an attractive tool for the simulation of micro-, meso- and massive-scale networks of neurons with dendritic trees.

Acknowledgements

Supported by the Helmholtz Portfolio theme Supercomputing and Modeling for the Human Brain, the Excellence Strategy of the Federal Government and the Länder [G:(DE-82)EXS-PF-JARA- SDS005, G:(DE-82)EXS-SF-neuroIC002] and the European Union's Horizon 2020 Framework Programme for Research and Innovation under Specific Grant Agreement Nos. 720270, 785907 and945539 (Human Brain Project SGA1-3).

References

1. P. Poirazi and A. Papoutsi (2020), **Illuminating dendritic function with computational models**, *Nat. Rev. Neurosci.*,.
2. W. A. M. Wybo, J. Jordan, M. Petrovici, and W. Senn,(2020) **Dendrites in NEST**, *NEST Conf. Proc.*
3. M. L. Hines and N. T. Carnevale (2001), **NEURON: A Tool for Neuroscientists**, *Neurosci.*, vol. 7, no. 2, pp. 123–135.
4. W. A. M. Wybo, J. Jordan, B. Ellenberger, U. M. Mengual, T. Nevian, and W. Senn, (2021) **Data-driven reduction ofdendritic morphologies with preserved dendro-somatic responses** *Elife*, vol. 10, pp. 1–26,

Combining NEST Simulator and Python Modules in Parallel HPC Implementation

Petia Koprinkova-Hristova[1], Simona Nedelcheva[1], Sofiya Ivanovska[1], Mariya Durchova[1]

[1] Institute of Information and Communication Technologies, Bulgarian Academy of Sciences, Sofia, Bulgaria

Email: pkoprinkova@yahoo.com

During our work on implementation of a hierarchical spike timing model of dynamic visual information processing and decision making via reinforcement learning [1] we have encountered a problem to conduct complete simulation combining an open source Python module [2] of retinal ganglion cells with NEST module for the rest of modelled brain structures. It appeared that the bottleneck in overall simulation was the retinal ganglion cell layer that took much more computational time than the rest of the model so we have implemented it in parallel simulation using mpi4py [3] that shortened computational time more than 17 times even on a 8 cores desktop computer. However,joint simulation of both Python and NEST modules still remained a challenging task. That is why inour recent work [4] we have implemented a joint parallel simulation of both modules via spawning the Python module and consecutive running the NEST module. We have tested our parallel implementation of a piece of our model from [1] consisting of a layer of retinal ganglion cells in Python and a layer of LGN cells in NEST version 2.18 [5] on the HPC facility of our institute - the supercomputer Avitohol. Simulations of the developed module on different number of nodes and varying number of parallel processes were investigated and compared with respect to their time consumption.

Acknowledgements

This work was partially supported by the Bulgarian Science Fund under the project No DN02/3/2016"Modelling of voluntary saccadic eye movements during decision making". We also acknowledge the provided access to the e-infrastructure of the NCHDC - part of the Bulgarian National Roadmapon RIs, with the financial support by the Grant No DO1 – 387/18:12:2020.

References

1. Koprinkova-Hristova P., Bocheva N. (2020) **Brain-Inspired Spike Timing Model of Dynamic Visual Information Perception and Decision Making with STDP and Reinforcement Learning**. *Lecture Notes inComputer Science* 12566: 421-435. doi: 10.1007/978-3-030-64580-9_35
2. Opensource Brain [http://www.opensourcebrain.org/projects/111]
3. Nedelcheva, S., Georgieva, K., Koprinkova-Hristova, P. (2020) **Parallel Implementation of the Model of RetinaGanglion Cells Layer**. *2020 IEEE INISTA*, doi: 10.1109/INISTA49547.2020.9194616
4. Nedelcheva, S., Ivanovska, S., Durchova, M. Koprinkova-Hristova, P. (2021) **HPC Parallel ImplementationCombining NEST Simulator and Python Modules**. *Cluster Computing* (under review)
5. Jordan, J. et al. (2019) **NEST 2.18.0**. *Zenodo* doi: 10.5281/zenodo.2605422

Sub realtime simulation of a full density microcircuit model on a single compute node

Anno Kurth[1,2], Justin Finnerty[1], Dennis Terhorst[1], Jari Pronold[1,2], Johanna Senk[1], Markus Diesmann[1,3,4]

[1] Institute of Neuroscience and Medicine (INM-6) and Institute for Advanced Simulation (IAS-6) and JARA-InstituteBrain Structure-Function Relationships (INM-10), Jülich Research Centre, Jülich, Germany
[2] RWTH Aachen University, Aachen, Germany
[3] Department of Psychiatry, Psychotherapy and Psychosomatics, School of Medicine, RWTH Aachen University,Aachen, Germany
[4] Department of Physics, Faculty 1, RWTH Aachen University, Aachen, Germany

Email: a.kurth@fz-juelich.de

The cortical microcircuit is a building block of the mammalian brain. In a model of the network below a 1 mm2 patch of cortical surface [1] the spatial structure is replaced by cell-type specific random connectivity. Each layer is represented by an excitatory and an inhibitory population of integrate-and- fire model neurons. The network model is a benchmark for neuromorphic systems [2, 3, 4].
This contribution shows performance data for the microcircuit model on two AMD EPYC Rome 128 core compute nodes coupled by a direct Infiniband interconnect and running NEST 2.14 [5] (with fix 726f9b04bbd47c). On a single node we observe sub realtime performance, on two the simulation is 1.7 times faster than realtime. Our study of the aged 4g kernel serves as a reference for present optimizations, exposes bottlenecks, and guides the design of future computing systems.
For the single node the energy per synaptic event is 0.26 µJ, and for the fastest configuration using two nodes 0.39 µJ. These values are in the same order of magnitude as the lowest reported so far. The findings confirm a non-trivial relationship [2] between the resources in use and the energy required.
At the poster we demonstrate how power measurements with a contemporary PDU can be aligned with benchmark timers to obtain a reliable time course of power consumption.

Acknowledgements

Partially supported by EU Horizon 2020 945539 (HBP SGA3) and Helmholtz IVF SO-092 (ACA).

References

1. Potjans TC & Diesmann M (2014) **The cell-type specific cortical microcircuit: relating structure and activity ina full-scale spiking network model**. *Cerebral Cortex* 24:785–806. doi: 10.1093/cercor/bhs358
2. van Albada SJ, et al. (2018) **Performance comparison of the digital neuromorphic hardware SpiNNaker andthe neural network simulation software NEST for a full-scale cortical microcircuit model**. *Front Neurosci 12:291*. doi: 10.3389/fnins.2018.00291
3. Knight JC & Nowotny T (2018) **GPUs outperform current HPC and neuromorphic solutions in terms of speedand energy when simulating a highly-connected cortical model**. *Front Neurosci* 12:941. doi: 10.3389/fnins.2018.00941
4. Rhodes O, et al. (2019) **Real-time cortical simulation on neuromorphic hardware**. *Phil Trans R Soc A* 378:20190160. doi: 10.1098/rsta.2019.0160
5. Peyser A, et al. (2017) **NEST 2.14** *Zenodo*. doi: 10.5281/zenodo.882971

NEST Conference 2021

Organization committee

NEST Conference 2021 was organized by Hans Ekkehard Plesser, Dennis Terhorst, Anne Elfgen, Johanna Senk, Abigail Morrison, Markus Diesmann, Steffen Graber and Jonas Oberste-Frielinghaus.

The organization can be contacted before, during and after the conference at:

conference@nest-initiative.org

Thank you to all speakers and participants for being part of NEST Conference 2021!

The NEST Initiative is a non-profit member-based organization incorporated in Ecublens, VD, Switzerland, on 4 October 2012. Any natural (i.e., you as an individual) or legal (e.g., your company or university) person sharing and supporting the goals of the NEST Initiative can become a member of the Initiative.

Read more about membership types and benefits at:

https://nest-initiative.org/membership