DPSNN

Large scale simulations of the cortical activity investigating slow waves, plasticity, sleep and memory consolidation

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P.S. Paolucci, et al., (2015) “Dynamic Many-process Applications on Many-tile Embedded Systems and HPC Clusters: the EURETILE programming environment and execution platforms”, Journal of Systems Architecture

P.S. Paolucci, et al.. (2013) “Distributed simulation of polychronous and plastic spiking neural networks: strong and weak scaling of a representative mini-application benchmark executed on a small-scale commodity cluster”, arXiv:1310.8478

P.S. Paolucci, et al., (2015) “Power, Energy and Speed of Embedded and Server Multi-Cores applied to Distributed Simulation of Spiking Neural Networks: ARM in NVIDIA Tegra vs Intel Xeon quad-cores”, arXiv: 1505.03015

E.Pastorelli, et al. (2015) “Impact of exponential long range and Gaussian short range lateral connectivity on the distributed simulation of neural networks including up to 30 billion synapses”, arXiv:1512.05264

E.Pastorelli, et al. (2015) “Scaling to 1024 software processes and hardware cores of the distributed simulation of a spiking neural network including up to 20G synapses”, arXiv:1511.09325

DPSNN

Distributed **P**lastic **S**piking **N**eural **N**etwork simulation engine

- Large-scale spiking simulations (up to hundreds of billions synapses) distributed over (up to tens of) thousands of MPI processes, including columnar, areal and inter-areal connectivity models.

- Computational objectives:
  - High-efficiency simulation of spontaneous and evoked slow-wave activity and sleep-wakefulness transition in single and multiple cortical areas (**WaveScalES – HBP** project)
  - Benchmarks for hardware-software co-design of brain inspired parallel/distributed architectures and high performance interconnect/communication networks (**Exanest** project)

WaveScalES research in HBP project

Towards a multi-scale perturbational atlas of the cerebral cortex. Linking the macro (TMS/EEG) to the microscale (cortical slices) through simultaneous recording of hd-EEG and Stereo-EEG responses to intracortical stimulation

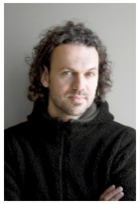
Photostimulation and photoinhibition of slow-wave activity by light-regulated ligands of neuronal receptors

Multiscale theory/model of cortical dynamics of slow-waves. Matching theory and simulations with experiments

Parallel simulations with DPSNN simulation engine

Maria Victoria Sanchez-Vives

Marcello Massimini



Pau Gorostiza

Maurizio Mattia

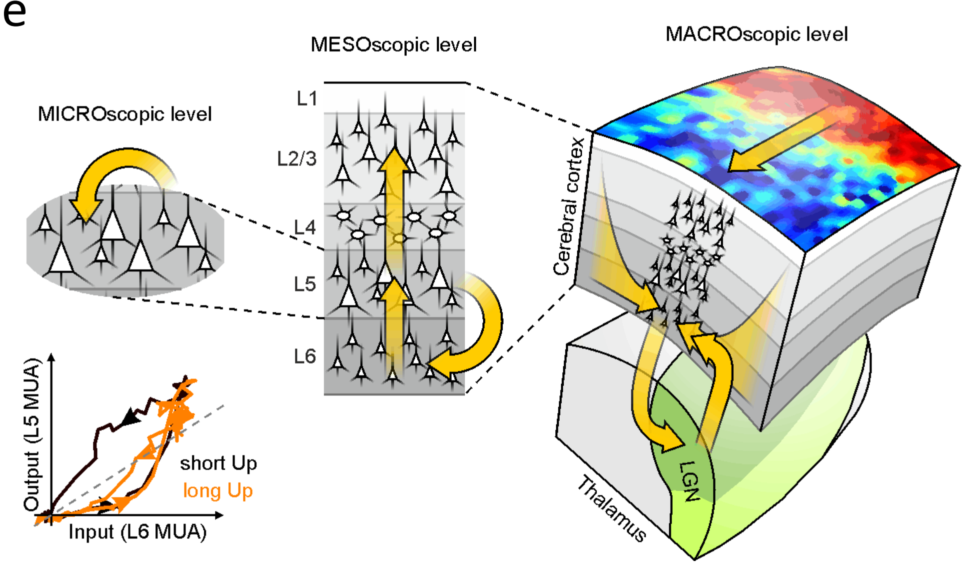
Pier Stanislao Paolucci

The WaveScalES tasks

Human Brain Project

Understand multiscale brain exploiting Slow-Wave Activity (SWA). Five Tasks:

1. Slow-wave activity changes during sleep/anesthesia (ISS)
2. Slow-wave and complexity: from the micro-scale to the bedside (UniMi)
3. Slow-wave activity in murine transgenic models of neurological disease (IDIBAPS)
4. Modulation of slow-wave activity with opto-pharmacology (IBEC)
5. Slow wave simulation platforms (INFN)

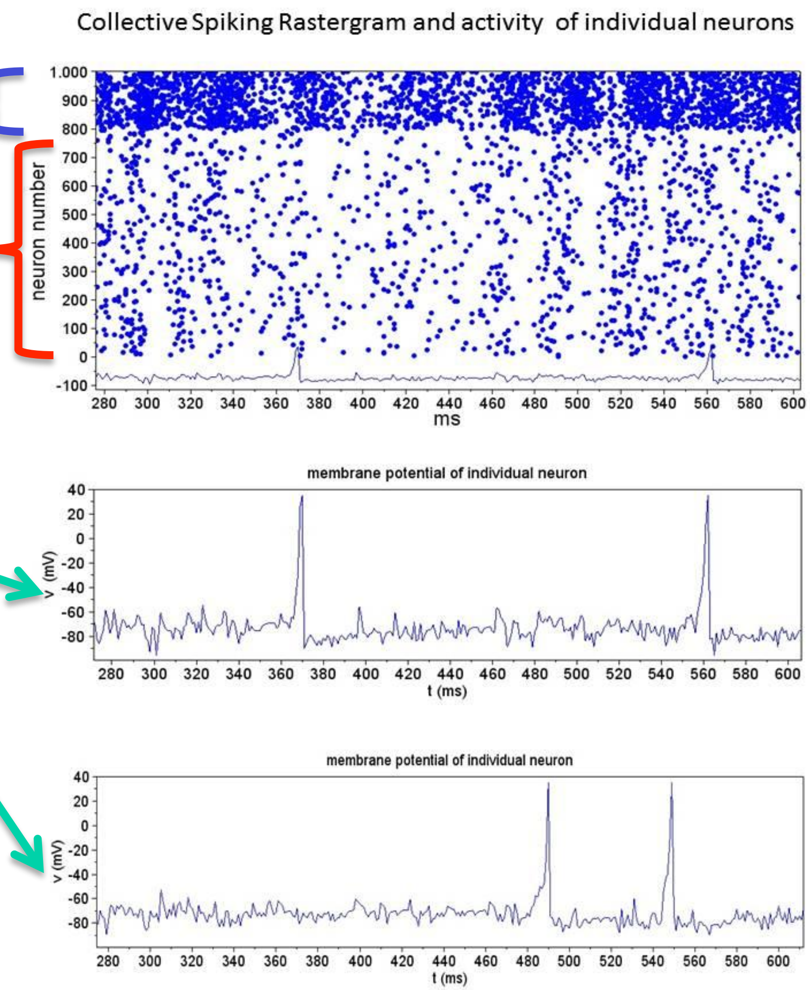


The DPSNN simulator

- **Distributed**: designed for execution on distributed/parallel computing systems:
  - ~ 3 elapsed sec/Hz to simulate one second of activity in Awake state of ~1 cm^2 of rat cortical tissue with reduced network complexity (15 times less synapses per neuron, compared to biology): 17.6G syn and 12M neu on a 64 server cluster (Galileo - Intel Haswell 2xIntel Xeon 2630 v3@2.4GHz, 8 cores each)
- **Spiking Neural Net**: present implementation:
  - Cortical Field: a bi-dimensional grid of Cortical Modules with local and first, second, third … neighboring modules connections
  - Cortical Modules composed of point neurons. Implemented models:
    - Izhikevich neuron
    - Leaky-Integrate-and-Fire neuron with spike frequency adaptation
- **Plastic**: synaptic long term potentiation/depression based on relative timing of synaptic activation and post-synaptic neural spiking (STDP)
- **Polychronous**: prospective investigation of the computational properties created by hierarchies of individual synaptic delays

Small scale example of neural net simulation

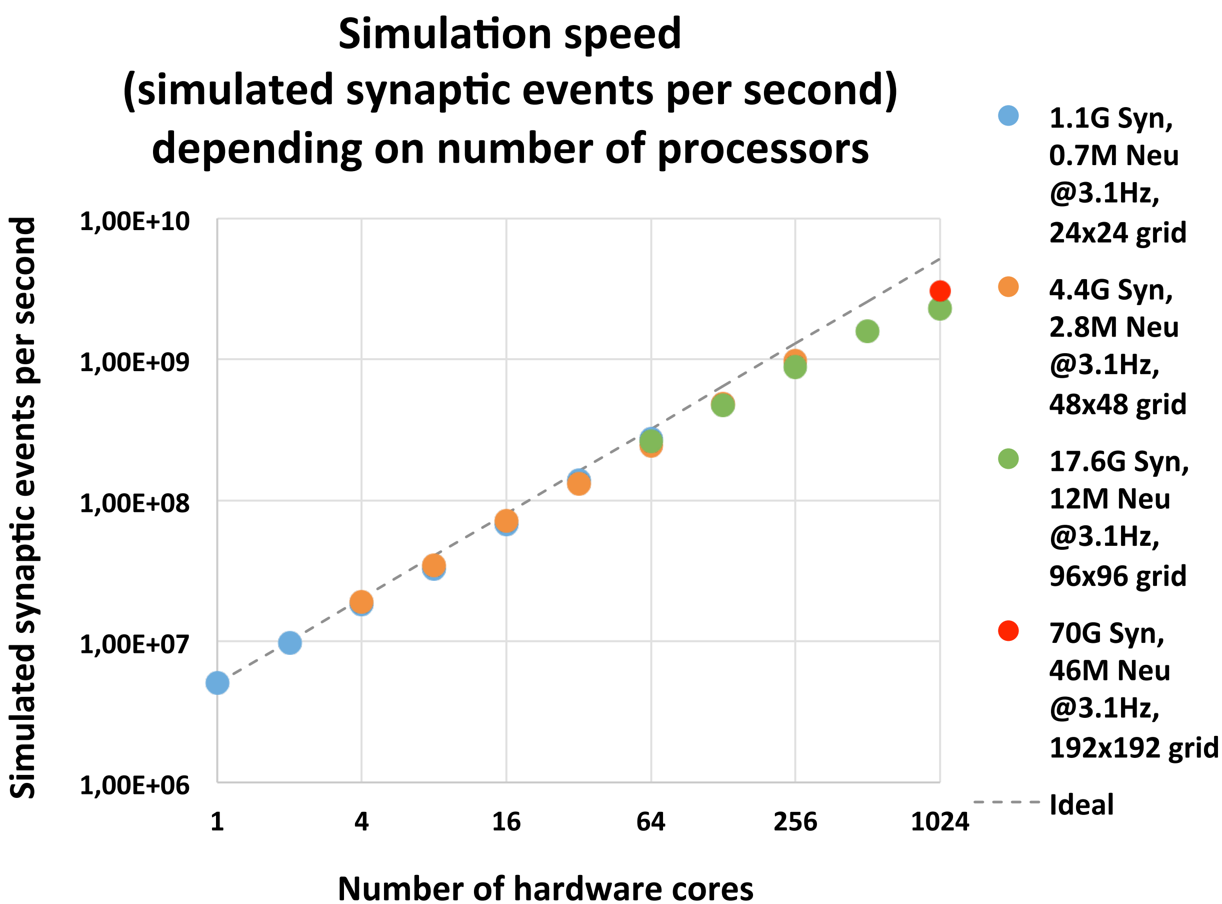
- 200 inhibitory neurons
- 800 excitatory neurons
- Time resolution: 1ms (horizontal axis)
- Each dot in the rastergram represents an individual spike
- The evolution of the membrane potential of individual neurons is simulated
- The evolution of individual synaptic strength is computed (not shown in the picture)
- individual synaptic delays are taken into account
- Individual connections and neural types can be programmed



Simulation Cost

- Processing cost
  - Proportional to the number of synapses (M) in the system and to the average firing rate (ν) of the network
    - Measures normalized to **synaptic events** = M * ν
  - Mainly ascribable to:
    - Searching ordered lists
    - Random numbers extraction
    - Sorting data structures
    - Few tens of FLOPs per synaptic event (in the simplest model)
- Communication cost
  - Widely variable with the network parameters and with the mapping on the MPI processes
    - From negligible values up to ~30-40% of the total execution time

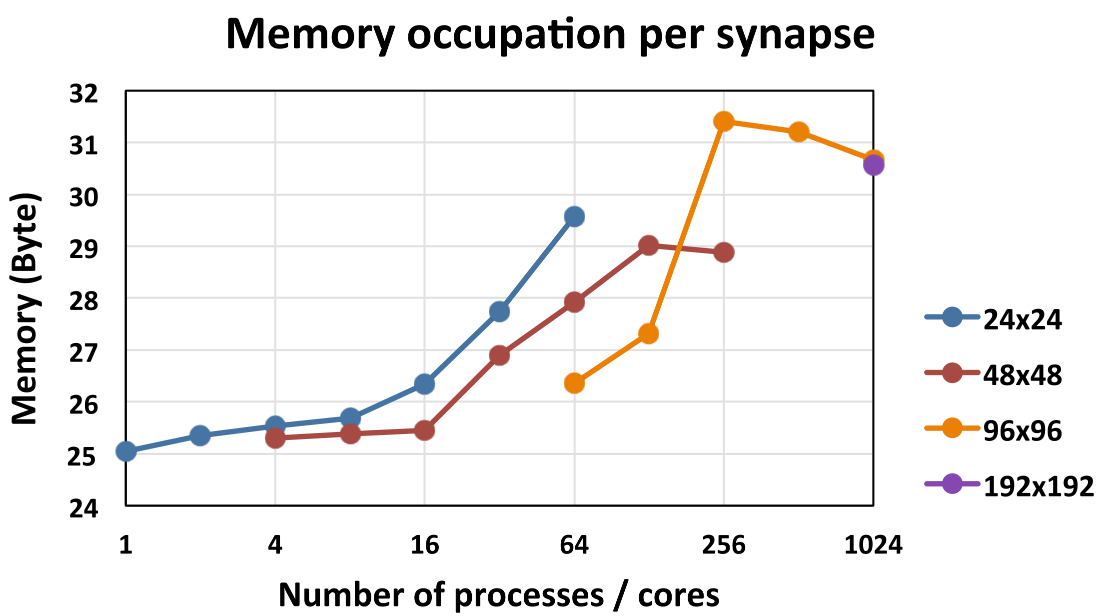
Strong Scaling of DPSNN
up to 1024 cores and 70G synapses



Efficient simulation of tens of billions of synapses, projected by grids of columns of point spiking neurons, distributed on thousands of hardware cores and software processes.

Paolucci, Pastorelli et al.
In preparation

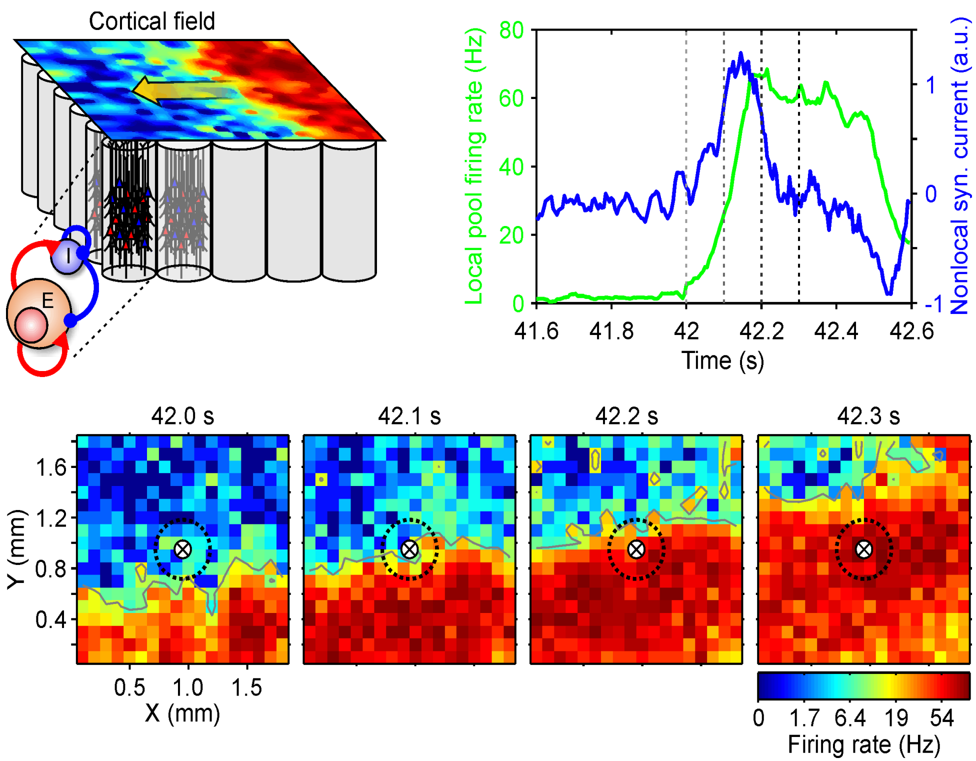
Memory occupation



- Proportional to the number of synapses in the network
- Growing with the number of MPI processes
- Less than **32 Byte** per synapse in the explored range
- Improvements for memory occupancy reduction already identified

Paolucci, Pastorelli et al.
In preparation

Example of simulation with DPSNN

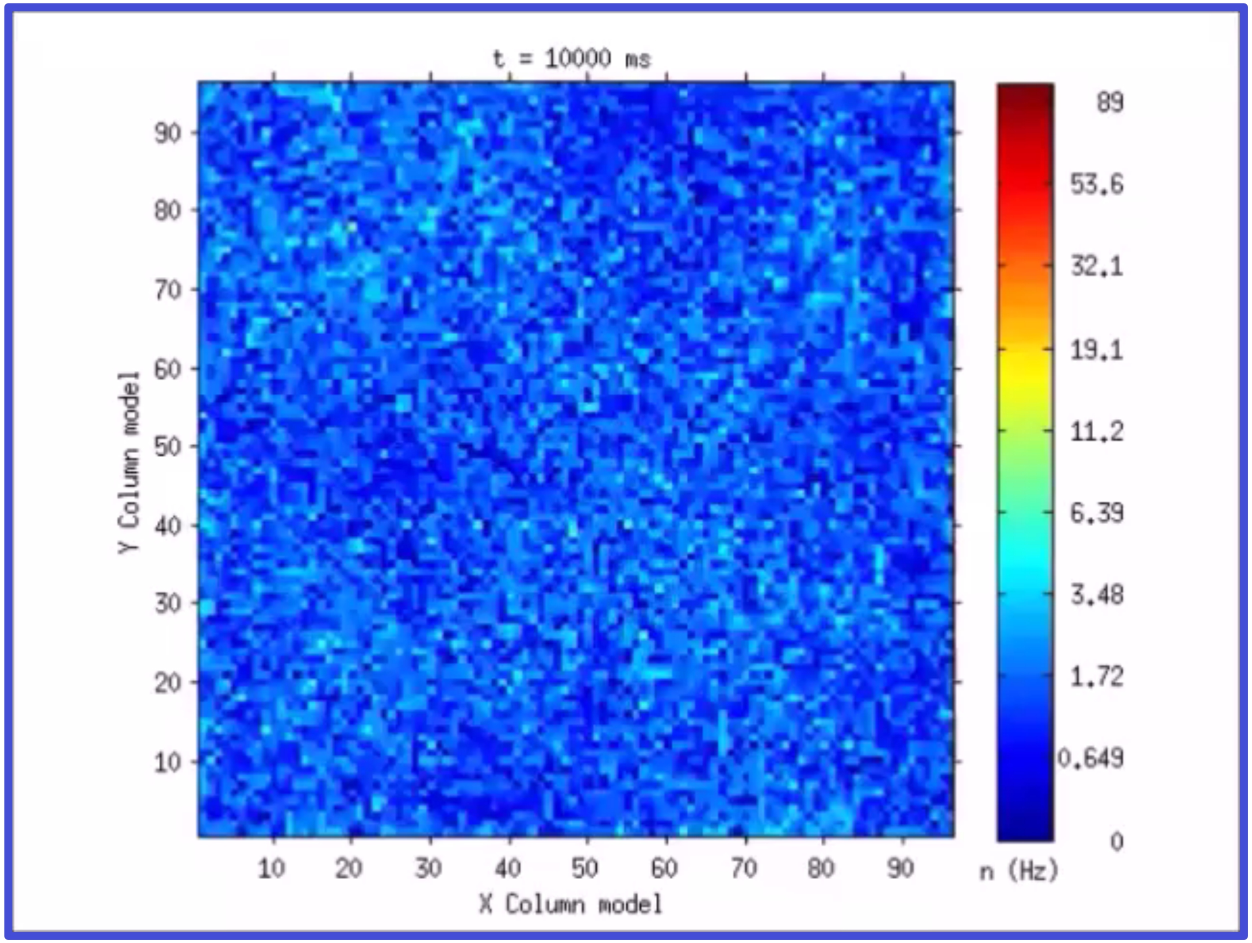


Simulation of a large field of cortical columns (pixels of the bottom snapshots), each composed of 2500 excitatory and inhibitory leaky IF neurons. Top, firing rate of the central column (green) of the cortical field and the net synaptic input it receives from neighbouring columns (blue): local vs global contribution. Simulations performed within CORTICONIC project (ISS/INFN) with a total of 10^6 cells and 10^9 synapses.

Theoretical model: equations and parameters from Mattia, Del Giudice, Capone (ISS)

Cortical Slow Waves Simulation

Slow Wave Simulation on DPSNN: 96x96 cortical columns, 1250 neurons per column, ~1500 equivalent synapses per neuron, for a total of 11.5M neurons and 17.5G synapses.



Theoretical model: equations and parameters from Mattia, Del Giudice, Capone (ISS)