Wavescales

Simulations of Cortical Slow Waves and Transition toward Awake States

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for the WaveScalES team (INFN, IDIBAPS, UNIMI, IBEC, ISS)

SP3-WP2: WaveScalES

Human Brain 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 ported from DPSNN prototyping engine to

nest::

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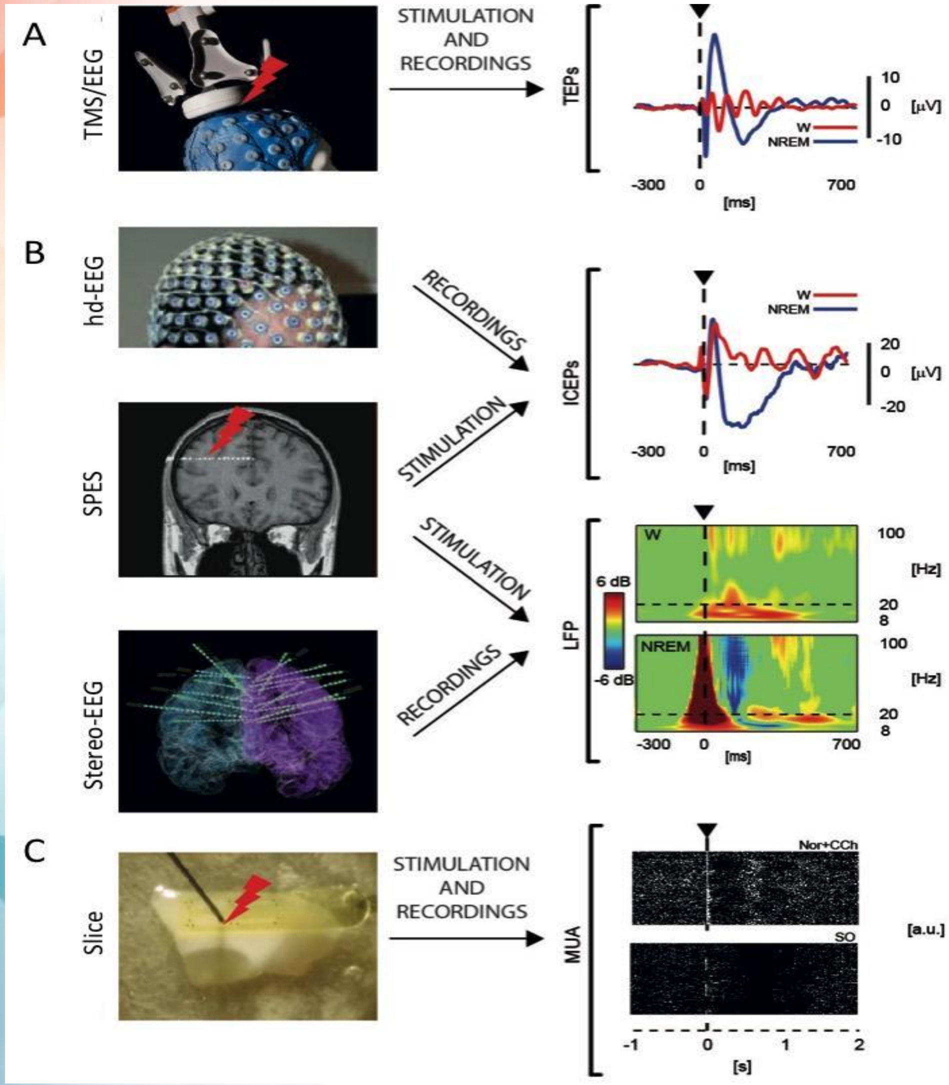
Pau Gorostiza

Maurizio Mattia

Pier Stanislao Paolucci

Experimental components



Perturb and measure at several spatio-temporal scales using multiple methodologies

IDIBAPS
Institut D'Investigacions Biomèdiques August Pi i Sunyer

UNIVERSITÀ DEGLI STUDI DI MILANO

Novel photostimulation and photoinibition tools based on small molecules

IBEC
Institute for Bioengineering of Catalonia

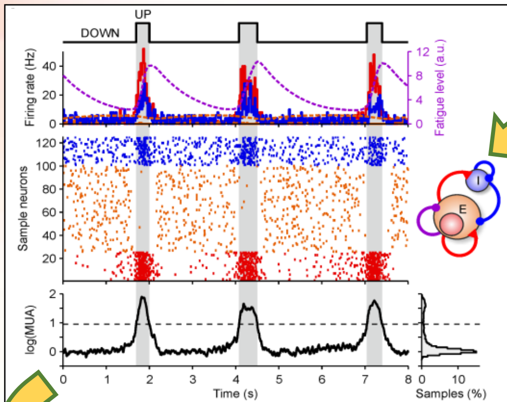
Theoretical component

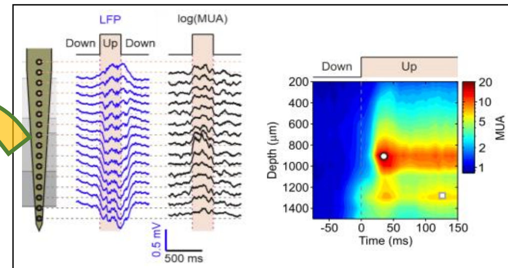
Human Brain Project

Theory and simulations

Experiments

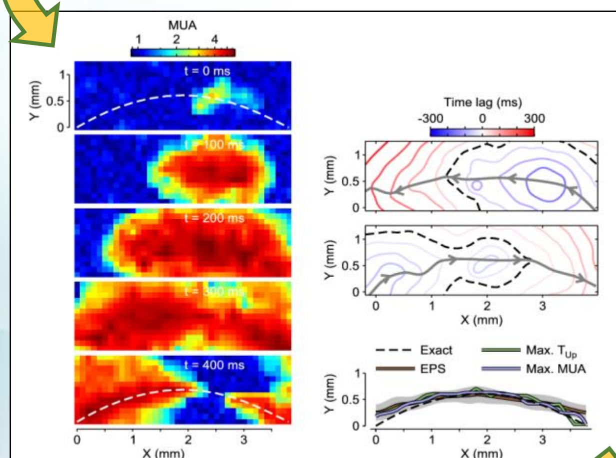
Micro-Mesoscale

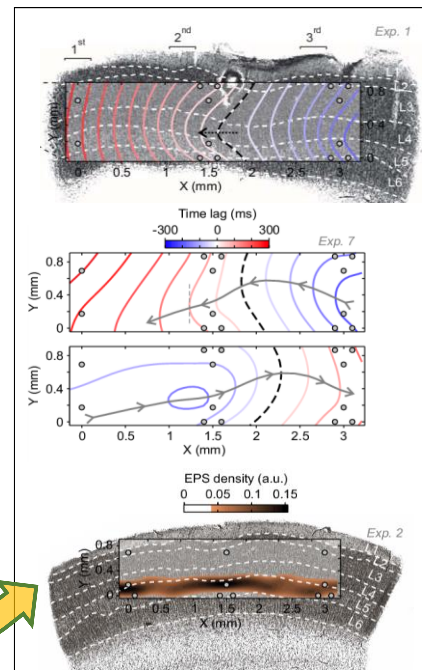




Matching theory and models with experiments

Meso-Macroscale





ISTITUTO SVPERIORE DI SANITÀ

INFN - Istituto Nazionale di Fisica Nucleare

Human Brain Project

- The National Institute for Nuclear Physics is the Italian research agency dedicated to the study of the fundamental constituents of matter and of the laws that govern them
- INFN states itself as a "community of researchers that invent and develop innovative technologies, contributing to the most accurate measurements, posing the ground to discover the fundamental laws of universe"
- INFN contributes to the researches of about 5,000 scientist and to several state-of-the-art international laboratories (e.g. CERN, VIRGO, CNAO, …)
- Strong interest in applications to health, technological transfer, understanding the physics of complex systems and the computational capabilities of brain-inspired architectures

The Ape Parallel/Distributed Computing lab. of INFN

- Italian pioneer in design and development of parallel / distributed computing systems / solutions for grand challenges in numerical simulations, created in 1984 by Nicola Cabibbo and Giorgio Parisi
- Applications: theoretical physics (LQCD, LBE), engineering (e.g. weather forecast, synthetic aperture radar processing, oil and gas, digital signal processing)
- Custom numerical processors and interconnection networks: APE (1984-1988), APE100 (1989-1994), APEmille (1995-2000), APEnext (2001-2006), SHAPES (2006-2009), EURETILE (2010-2014), EXANEST (2015-…), APEnet (2006-…)

Custom processor of APE100 (1992)

APE100 Tower, 512 processors / Tower, 3D interc.

Rack of 16 APE100 boards

8 processor APE100 board

High-resolution Fast Cortical Simulations Parallelized on Thousands of Processors

Human Brain Project

WaveScalES models of cortical slow-waves and awakening: single and multiple area, tens of billions of synapses, projected by grids of layered columns, point spiking neurons, distributed on thousands of hardware cores, STDP and LTP/LTD

Cooperation between SP3 and SP7 (exchange of requisites, specific developments, reciprocal support) to port WaveScalES models from DPSNN ⟷ nest:: → research community

SP3 – WP2 DPSNN sim. engine (INFN/ISS):

- fast, scalable, no user-interface, model specific optimizations
- hardware/software co-design tool and application benchmark

SP7 – NEST Platform:

- configurable, user friendly, large user community, multiple execution platforms, multiple models, scalable

The APE parallel comp. lab. of Italian INFN (Istituto Nazionale di Fisica Nucleare

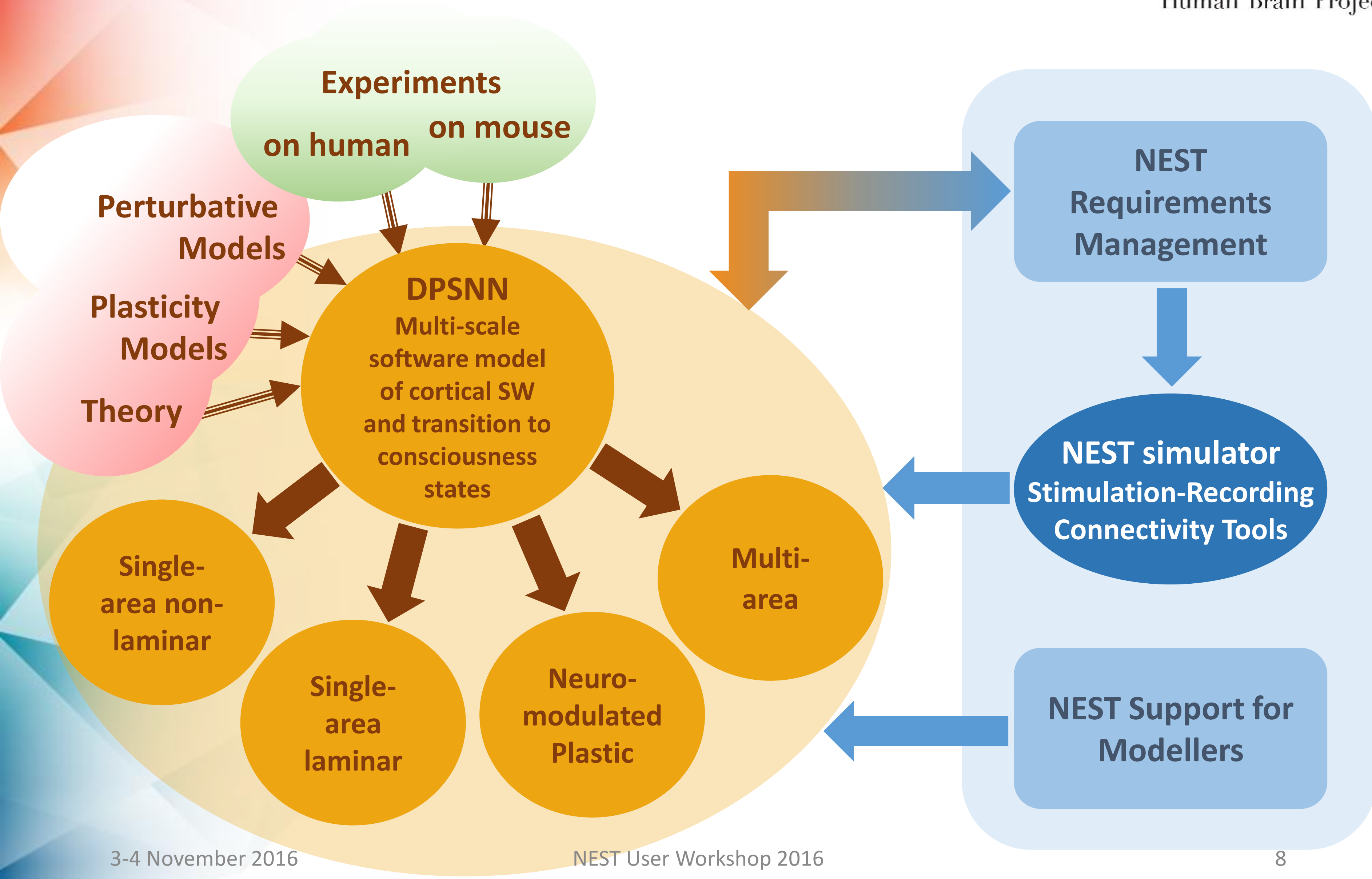
INFN

APE

In cooperation with

Istituto Superiore di Sanità

Collaboration with NEST



Simulation models for cortical SW and transition to AW states

- **Single-area non-laminar model**

  Two-dimensional grid of cortical modules of point-like neurons (LIF model variant with spike frequency adaptation / Izhikevich model) interconnected with probability laws depending on distance and source-target population kinds

- **Single-area laminar model**

  Two-dimensional grid of cortical modules with laminar structure, accounting for the different properties of the cortical layers (neural dynamics, connections, synaptic weights, etc.)

- **Neuromodulated Plasticity model**

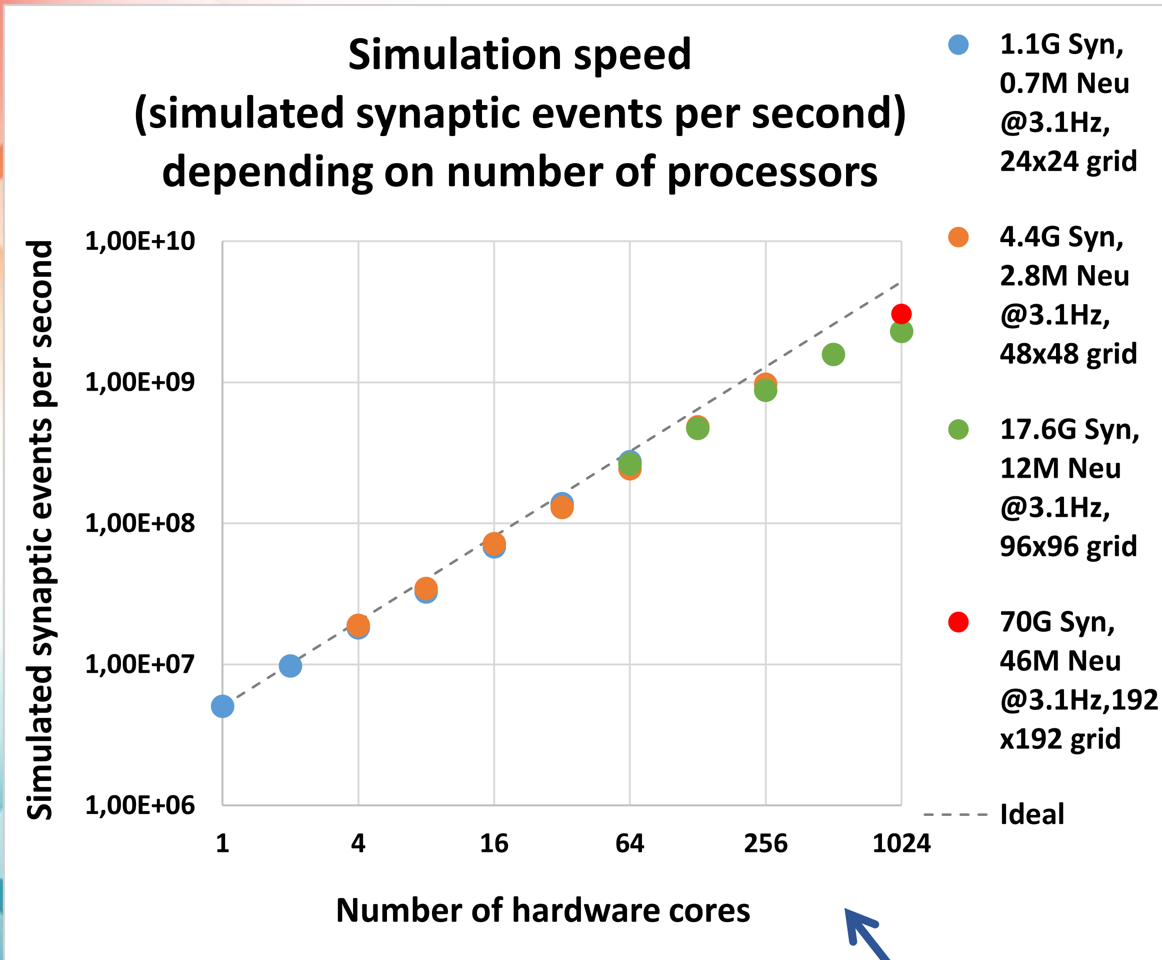
  Model incorporating neuromodulated STDP, LTP/LTD, to investigate the role of deep sleep in memory consolidation and synaptic homeostasis

- **Multi-area model**

  Single cortical areas connected using low-complexity (effective/resting states) connectivity matrixes

Large Scale Parallel Simulation

Human Brain Project



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.

Study of hardware and software technologies for neural simulations

INFN

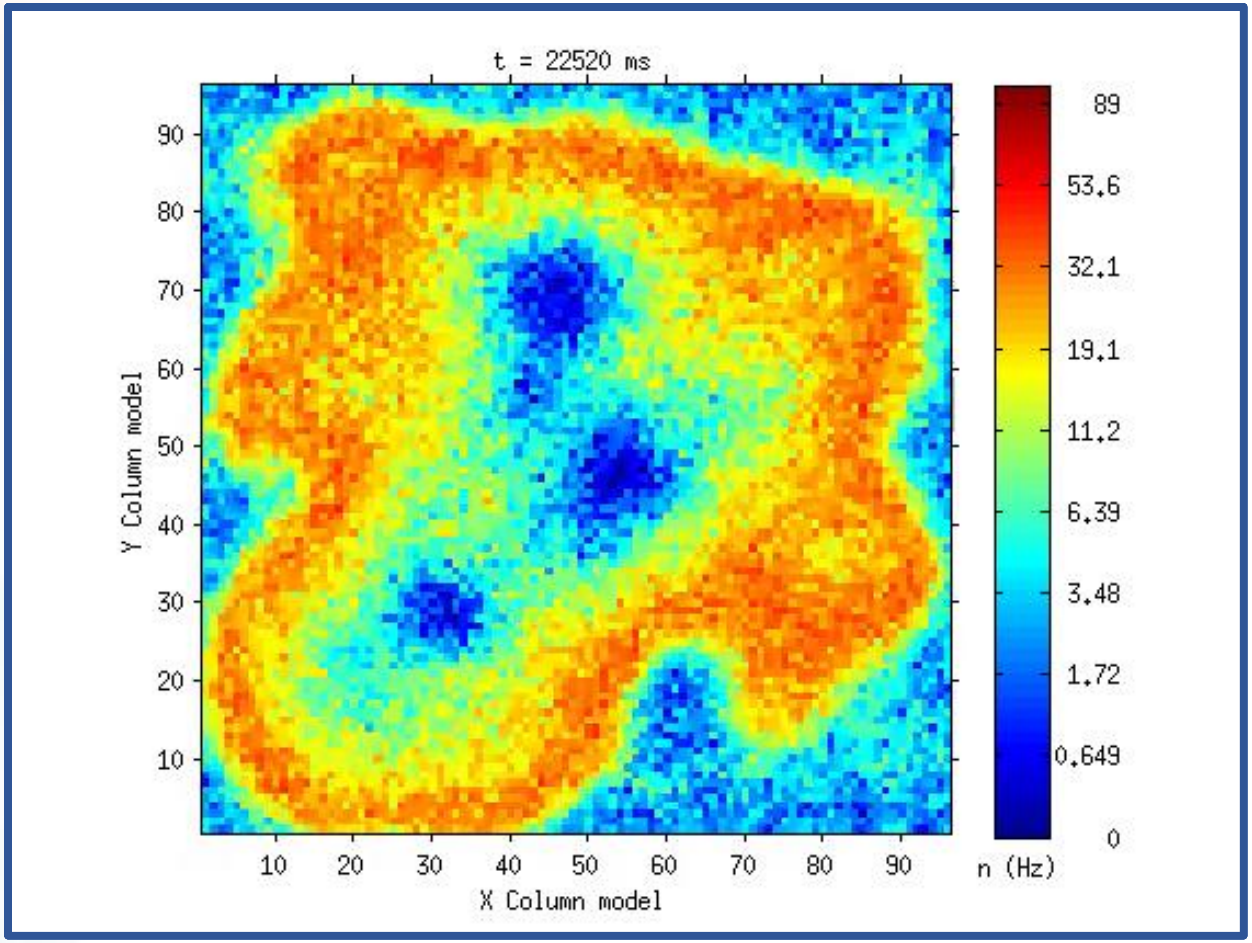
On proprietary DPSNN (Distributed Plastic Spiking Net Simulator) to be ported to

nest::

HBP research infrastructure

Cortical Slow Waves Simulations

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.



First implementation in NEST (on-going activity)

Single-area non-laminar model

- ✓ Grid of cortical modules described with NEST topology
- ✓ Neuron model: a variant of LIF model with spike frequency adaptation modeled with NESTML
- ✓ Layered structure for the description of excitatory and inhibitory populations
- ✓ Poissonian noise with a gradient from peripheral to internal columns

What next

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Single-area non-laminar model

- Inter-columnar connectivity with Gaussian distribution
- Specific distribution for:
  - Synaptic weights
  - Assonal delays
- Observables
  - Spike detectors
  - Rate extractions

Thank you!

Aknowledgments

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