INFN in the Human Brain Project:

Investigate the physical mechanisms of cognition.

Human Brain Project

Simulation of cortical learning and cognitive functions, constrained by the analysis of experimental data about neural and synaptic activity.

From sleep (a state essential to learn) to wakefulness.
Toward brain-inspired artificial intelligence, fast learning from single events.

Also, key benchmark for next generations of computing architectures (ExaNest and EuroExa projects).
Longer-term: data analysis of physics experiments: automatic discriminination of novelty and outliers

Pier Stanislao PAOLUCCI

Coordinator of WaveScalES experiment in the Human Brain Project

Deputy Leader - System and Cognitive Neuroscience, HBP

On behalf of the APE Parallel/Distributed Computing Lab.

Computational Neuroscience: Scientific and Translational – a kingdom for physicists

Human Brain Project

Novel experimental techniques permit a quantitative multi-scale exploration of the Brain Architecture

Understanding the Brain, at different levels of abstraction.

Since ever, one of the greatest intellectual ambitions.

Theoretical models and Data constrained simulations

Europe, brain disorders and trauma cost: 798 billion € /year.

Increasing, due to population aging

Novel therapies.

Driver of next technological and social revolution: brain inspired artificial intelligence and robotics,

The Human Brain Project - Intro

- European fund. 500 MEuro, Oct 2013 – 2023
  - Consortium: 110 research institutes
- INFN Roma (APE lab) enters HBP in April 2016
  - Competitive call for new scientific proposals/partners (evaluation by external reviewers)
    - INFN leads the WaveScalES proposal, 4 proposals selected among 57 submitted
    - WaveScalES, about 1 MEuro/year, until 2023 (subject to yearly reviews)
    - Main current focuses of our group in HBP:
      - Study interplay between sleep and memories and transition between sleep and wakefulness, understand how to learn from few examples, large scale simulations of cortical activity
      - Key benchmark for next generation computing architectures (ExaNest and EuroExa European projects)

A personal view of brain architecture

- About 10^11 neurons each one directionally connected to about 10^4 other neurons through synapses. A total of about 10^15 synapses
- Learning of individual experiences. Each synapse is a coincidence detector of causality (and anti-causality) in time (at a few milliseconds time scale) between the presynaptic and post-synaptic neuron. Spike Timing Dependent Plasticity.
- Computing: each excitatory neuron expresses the degree of truth of a (complex) predicate about the current status of the world.
- Each neuron detects temporal cohincidence of top-down predictions and bottom-up observations expressed by other neurons.
- Inihibitory neurons select those neurons expressing more plausible truths
- Each neuron computes its predicate in its own local time frame and personal horizon of events, due to individual axo-synaptic transmission delays in the 2-50 ms range. Different time-scales, depending on the level of abstraction.
- The connectome: hierarchical, multi-scale probabilities of connection among neurons, capture best learning topologies through evolution.
- Capability of learning from single example, detection of novelty, classification of outliers in a scale-free world
- The human-brain: with few tens of Watt more than Exascale computation

APE group in HBP, current status

- *Nature Scientific Reports* (2019, in press). Sleep-like slow oscillations improve visual classification through synaptic homeostasis and memory association in a thalamo-cortical model. *C. Capone, E. Pastorelli, B. Golosio, P.S. Paolucci* (preprint arXiv:1810.10498)

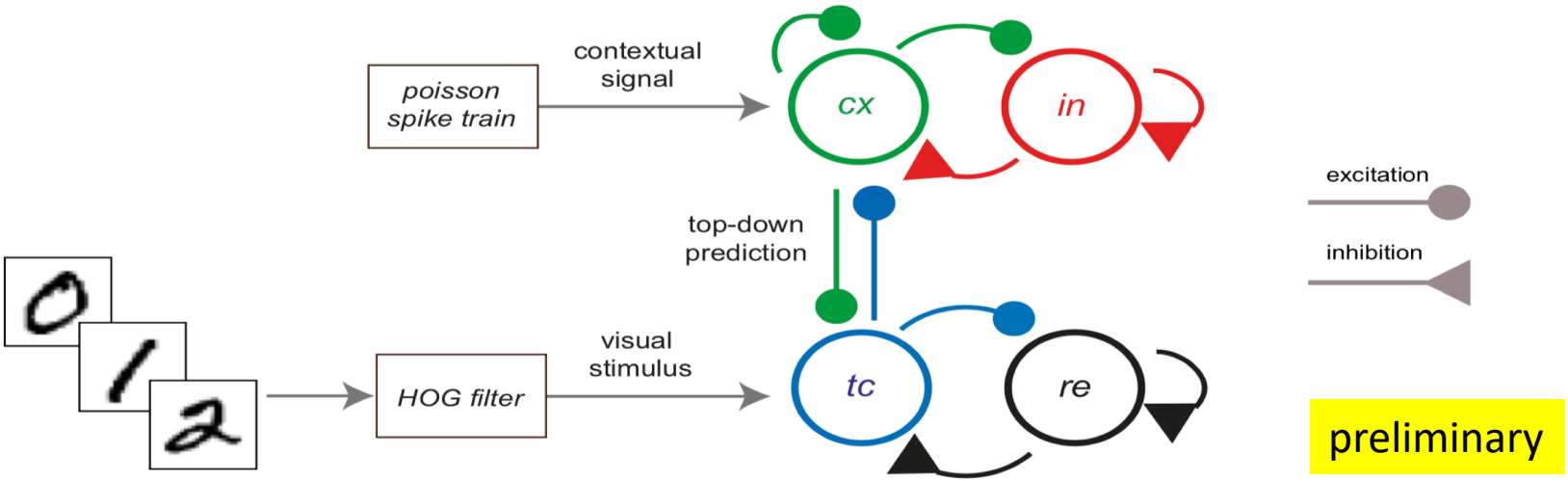
- Real-time cortical simulations: energy and interconnect scaling on distributed systems. *F. Simula, E. Pastorelli et al. PDP 2019, IEEE conf. Proc*. DOI: 10.1109/PDP.2019.00049

- Slow Waves Analysis Pipeline for extracting the Features of the Bi-Modality from the Cerebral Cortex of Anesthetized Mice. *G. De Bonis et al,* (2019, under review, preprint arXiv: 1902.08599)

- Gaussian and exponential lateral connectivity on distributed spiking neural network simulations. *P.S. Paolucci et al.* PDP 2018, IEEE Conf Proc. DOI: 10.1109/PDP2018.2018.00110

Fast learning from few examples, in a brain inspired thalamo-cortical spiking model

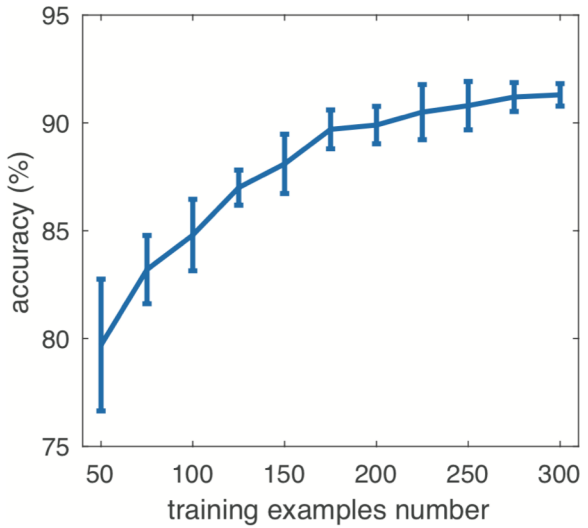
Human Brain Project



Neural Network trained to classify handwritten characters (MNIST dataset). The learning is incremental.

after 10 examples per digit, 85% classification accuracy

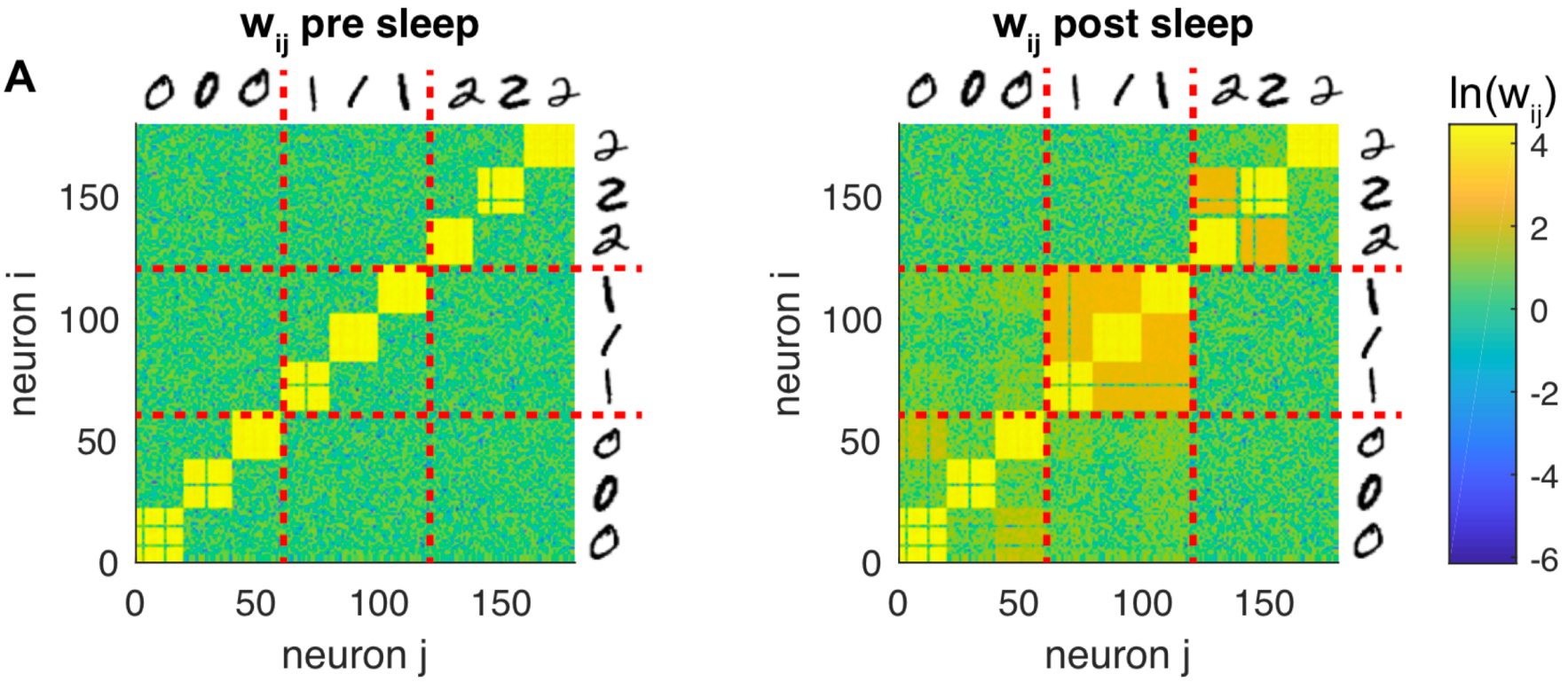
…preliminary results of improved architectures with even faster learning and reachin higher accuracies



Sleep induced association of individual examples in classes of digits improves classification during wakefulness

Human Brain Project

Nature Scientific Reports (2019, in press). Preprint arXiv:1810.10498

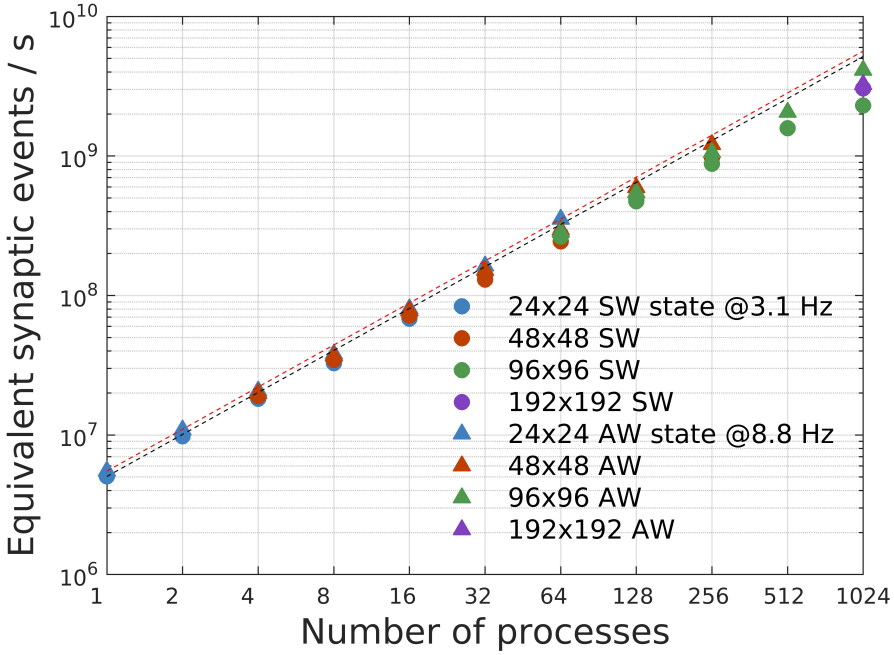


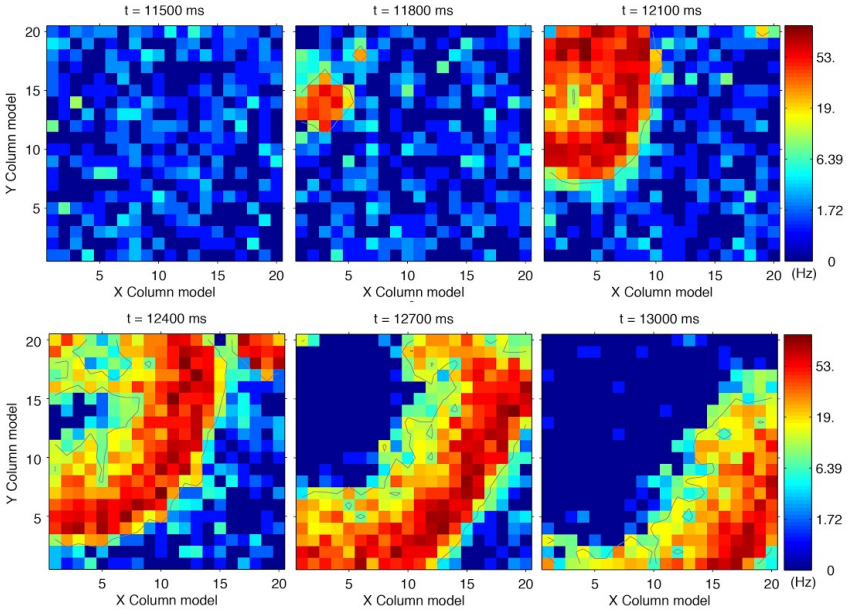
Thalamo-cortical spiking neural model, with STDP synaptic plasticity, awake learning of handwritten characters, … then put to sleep… then awakened again

Large scale simulations of deep-sleep-like cortical slow waves and wakefulness like asynchronous regime

Human Brain Project

Real-time cortical simulations: energy and interconnect scaling on distributed systems.
F. Simula, E. Pastorelli et al. PDP 2019, IEEE conf. Proc. DOI: 10.1109/PDP.2019.00049





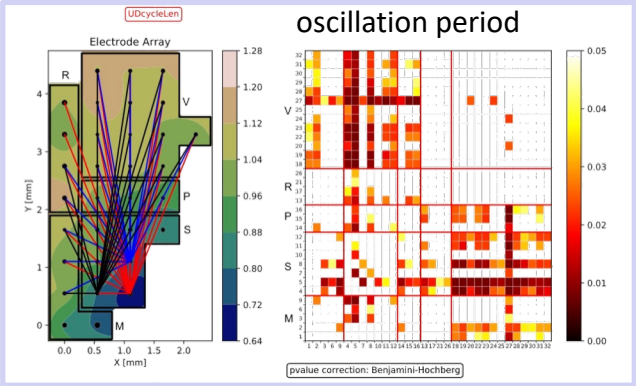
- Billions synapses
- large grid of cortical modules
- long range interconnections
- high remote/local syn. ratio

- Cortical area at biological resolution
- thousands of syn/neuron
- efficient scaling
- joule/syn update metrics

SWAP (Slow Waves Analysis Pipeline)

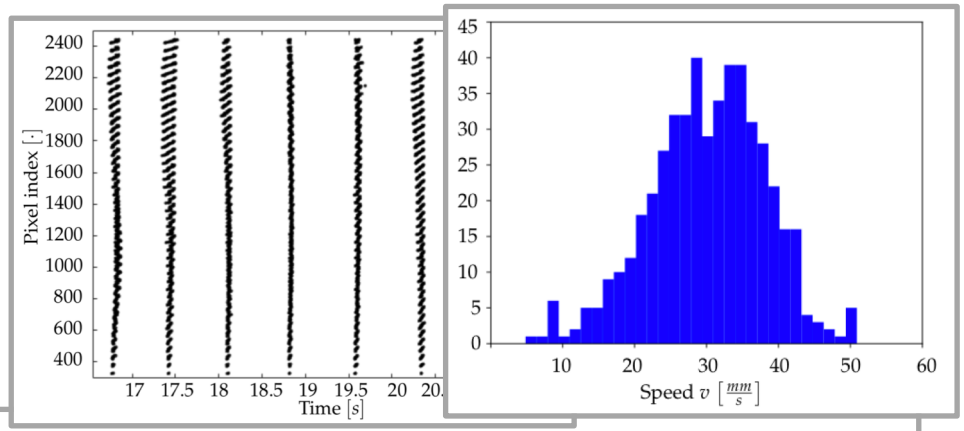
data from the cerebral cortex of anesthetised mice

(2019, submitted). Preprint, arXiv:1902.08599



Slow Oscillations (SOAP)

(2019, submitted). Preprint, arXiv:11811.11687



ElePhySWAP
electro-physiological data

CaImanSWAP
Calcium Imaging data

trigger times
(raster plot)

Waves collection

different
experimental setups

common
analysis framework
benchmark obervables
validation tools

Reduction of systematics

inference of models

bio-inspired data-driven simulations

Summary

Simulation of cortical learning and cognitive functions, constrained by analysis of experimental data about neural and synaptic activity.

From sleep (a state essential to learn) to wakefulness.

Simulation of spiking activity of neurons and synaptic plasticity

Key benchmark for next generations of computing architectures.

Toward brain-inspired artificial intelligence, fast learning from single events. Longer-term: data analysis of physics experiments: automatic discriminination of novelty and outliers