BRAIN Studies and Technologies for Artificial Intelligence and Neuroscience

INFN Sezioni di Roma, Roma2 e Cagliari

Analysis pipelines
data processing, data analysis

Brain models &
Simulations

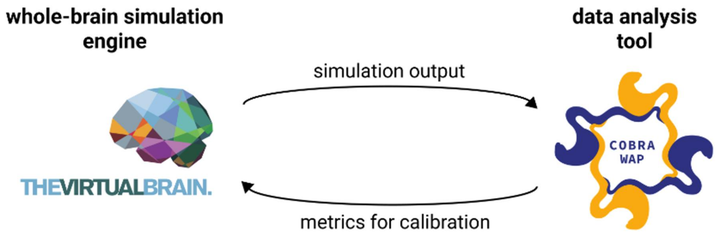
Understanding the Brain

Design of Brain-inspired **Computing Architectures for AI**

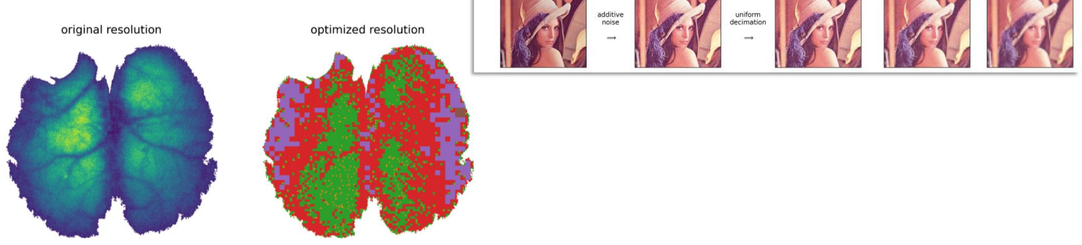
Brain states and Slow vawes

- **Cobrawap** [1,2], open-source software for brain wave analysis, provides generalized methods and algorithms to study and compare heterogeneous datasets and models

- **Tuning The Virtual Brain** [3]

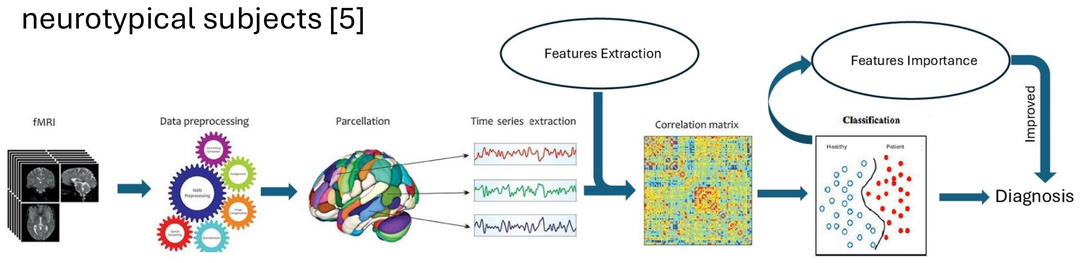


- **Hierarchical Optimal Sampling (HOS)** [4], method for dealing with high-resolution imaging data



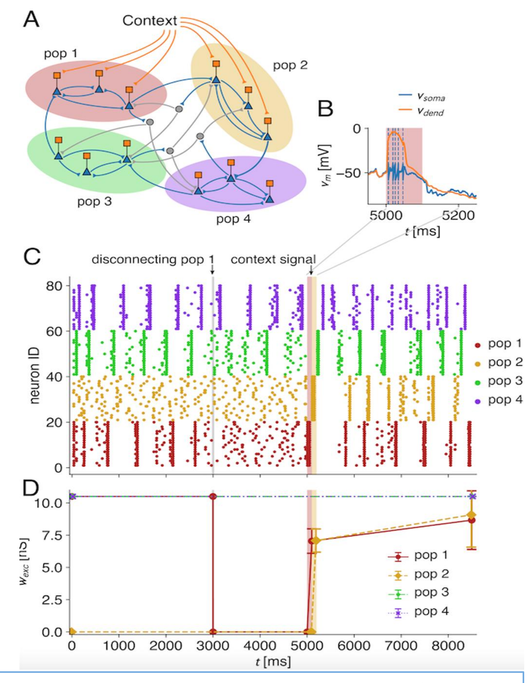
fMRI and AI for Diagnosis of Autism Spectrum Disorder

- **CPAC pipeline** uses brain atlases and AI models to classify ASD vs. neurotypical subjects [5]



[1] github.com/NeuralEnsemble/cobrawap; cobrawap.readthedocs.io
[2] Gutzen et al (2025) Cobrawap v0.2.1, doi: 10.5281/zenodo.15005123
[3] Gaglioti et al (2025), arXiv:2509.12873 **[q-bio.NC]**
[4] Lupo et al (2025), in preparation
[5] Mainas et al (2024), doi: 10.3390/app14177632

Small-scale models

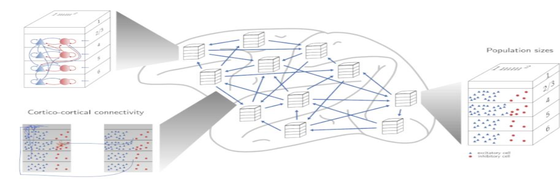


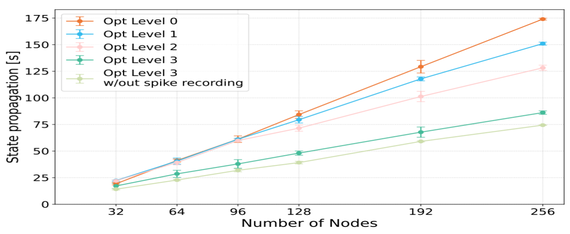
- **Bio-inspired multi-compartment neuron model** [6]
  - ✓ integrates somatic (perceptual) and apical (contextual) inputs
  - ✓ simulates different brain states (e.g. sleep cycle)
  - ✓ improves learning features in plastic networks capable of **incremental learning**

→ Integration into large-scale AI systems through high-level transfer functions

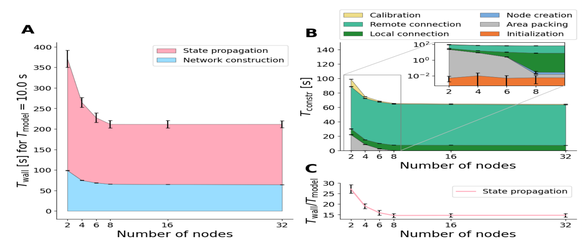
Large-scale models

- **Multi-area model of the macaque cortex** (multi-GPU, ~$4x10^6$ neurons, ~$24x10^9$ synapses) simulated using NEST GPU on CINECA Leonardo booster [7]





Scalable Construction of Spiking Neuronal Networks using up to **thousands of GPUs**

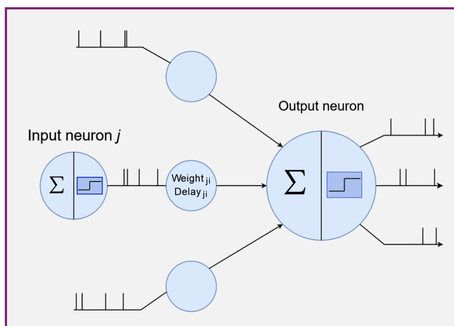


[6] Pastorelli et al (2025), doi: 10.3389/fncom.2025.1566196
[7] Tiddia et al (2022), doi: 10.3389/fninf.2022.883333

AIGOR

Neuromorphic computer architecture specialized for **energy efficiency, real-time processing, incremental learning**

- Targeting primarily **dataflow-intensive applications in physics (Spiking Neural Networks, edge AI)**

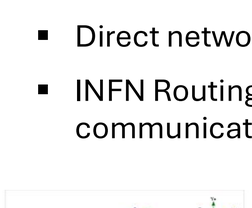


<u>Spiking Neural Networks (SNNs)</u>:
Artificial neural networks that communicate through "spikes" or pulses, similar to biological neurons

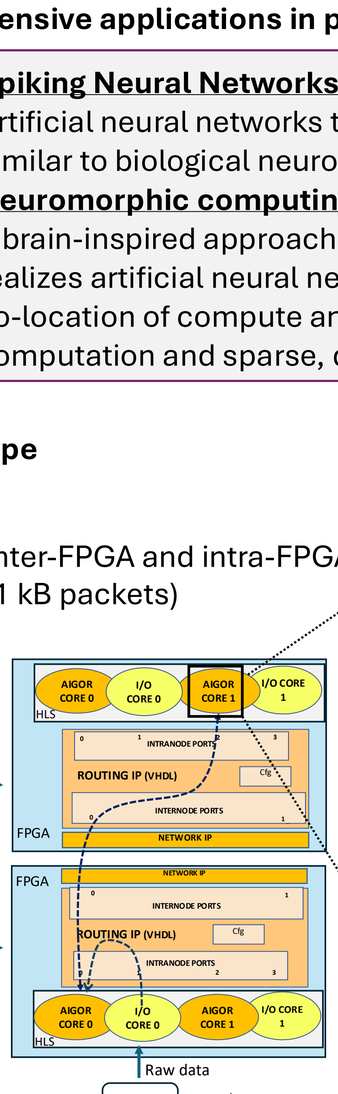
<u>Neuromorphic computing</u>
A brain-inspired approach to hardware and algorithm design that efficiently realizes artificial neural networks, thanks to a highly parallel architecture, co-location of compute and memory units, asynchronous event-based computation and sparse, distributed information encoding through spikes

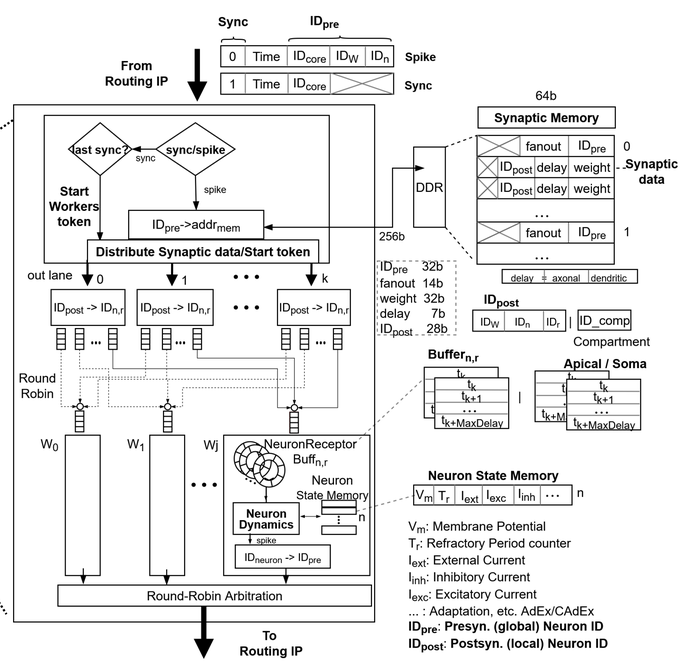
Multi-FPGA architecture prototype

- Direct network. 3D Torus
- INFN Routing IP for low-latency inter-FPGA and intra-FPGA communication (< 1 us for up to 1 kB packets)



AMD Versal Premium VPK180



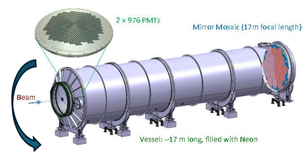


- **Modular, scalable, reconfigurable** architecture prototype with multiple levels of parallelism

- **Adaptable neuron dynamics module** supports biologically realistic neuron models, multiple receptors (e.g. multi-compartment neuron)

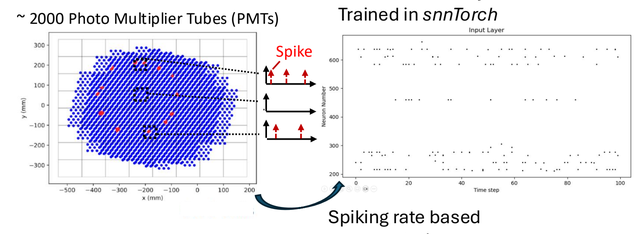
- **High Level Synthesis (HLS)-based Workflow**

- **Test-case:** NA62 RICH rings



Input layer 784 neurons
Hidden layer 1000
Output layer 4 (Rings 0,1,2, 2+)
10000 samples (7000 train, 2000 test)
Test Set Accuracy: ~ 80%
Trained in *snnTorch*

~ 2000 Photo Multiplier Tubes (PMTs)



Spiking rate based representation

- **FPGA Occupancy** single AIGOR-Core (ON VPK180)

Single Aigor-Core	LUT	FlipFlop	DSP	BRAM	Synaptic Mem requires
512 N (4 W, 128 n x W)	75.5k **2.25%**	30.6k **0.45%**	0 **0.00%**	16 **0.32%**	4 Mb
2048 N (32 W, 64 n x W)	764.0k **22.7%**	197.3k **2.93%**	2 **0.01%**	96 **1.94%**	84 Mb
2048 N (16 W, 128 n x W)	708.5k **21.1%**	106.9k **1.59%**	34 **0.24%**	64 **1.30%**	84 Mb

N: tot. neurons, W: workers
n x W: neurons per worker

VPK-180 Total PL mem 994 Mb

Contacts:
APE Lab website: https://apegate.roma1.infn.it
Presenter contact: pierpaolo.perticaroli@roma1.infn.it