Human Brain Project

EBRAINS

Efforts on the integration and large-scale simulation of a whole-brain model led to the development of a collaborative framework for data-driven modeling

Carlos Enrique Gutierrez | Neural Computation Unit,
Okinawa Institute of Science and Technology

OIST

HBP Partnering Projects Meeting: Status quo & outlook

5-7 September 2022 | Nijmegen, The Netherlands

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Computational modeling of the Brain

Technical targets

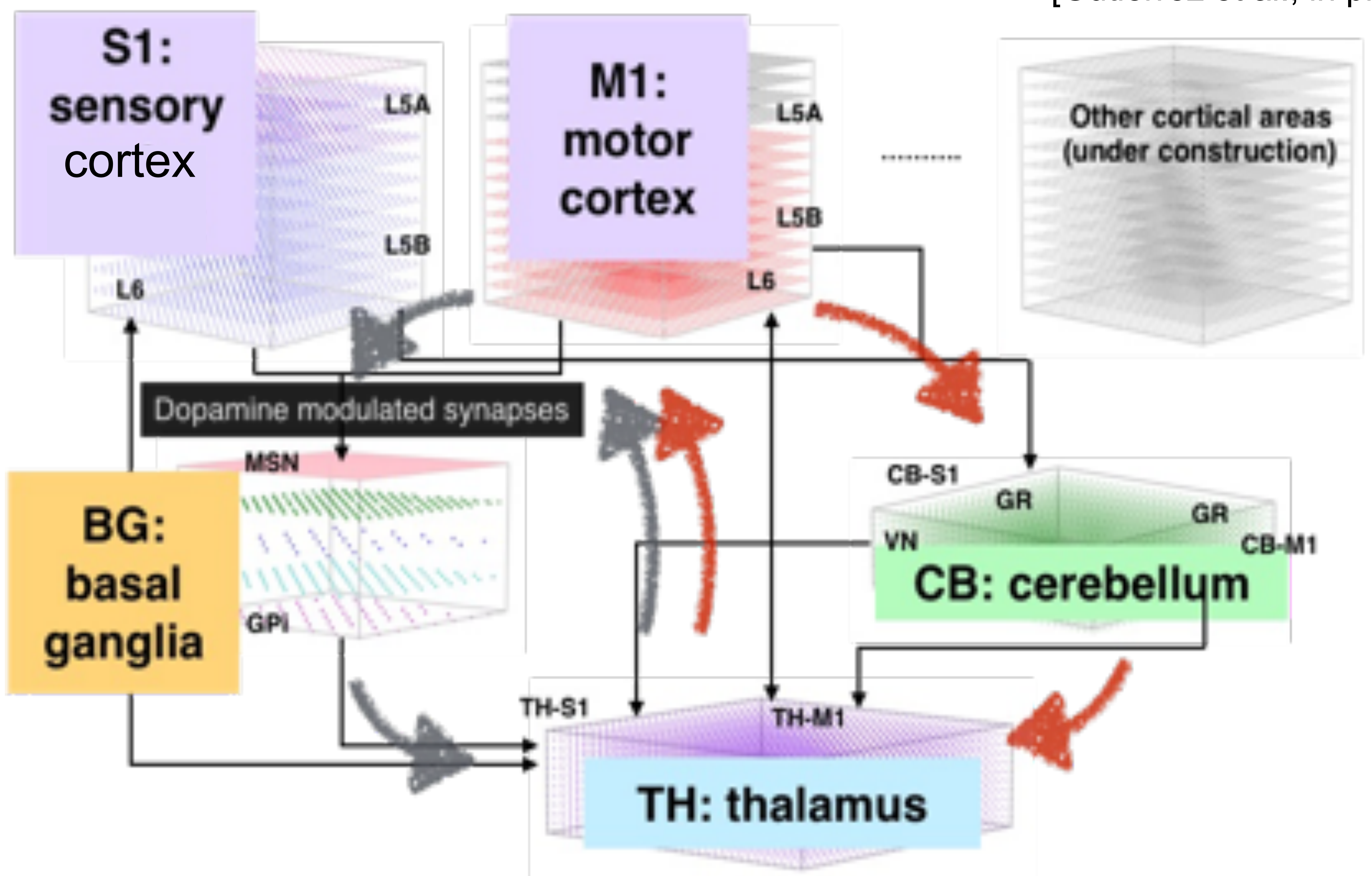
- Large scale simulation of neural models of different species on supercomputer.
- Improve simulation performance in terms of computational time, memory consumption, and processes communication.
- The ultimate goal is to simulate a real size human brain.

Scientific targets

- Investigate the dynamic nature of the whole-brain network realized by the interaction of multiple type of neurons [**Prof. Anne Graybiel: "Dynamics are critical"**].
- Understanding dynamics of cognitive and motor functions.
- Understanding neural dynamics of Mental Diseases.
- Integration with musculoskeletal models / robots.

A model of the Whole-brain

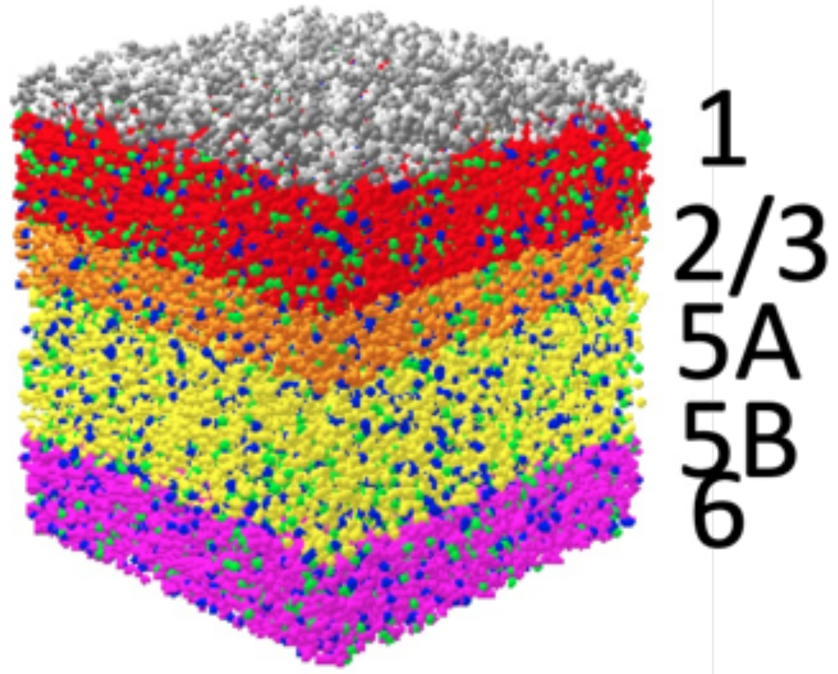
[Gutierrez et al., in preparation]



(only few population layers and inter-regional connections are displayed)

- Each region is modelled with **multiple layers using NEST**
- Several Integrate-and-Fire **neuron and synapse models**.
- Model is **biologically constrained** by electrophysiological, anatomical and morphological data.

Cerebral Cortex

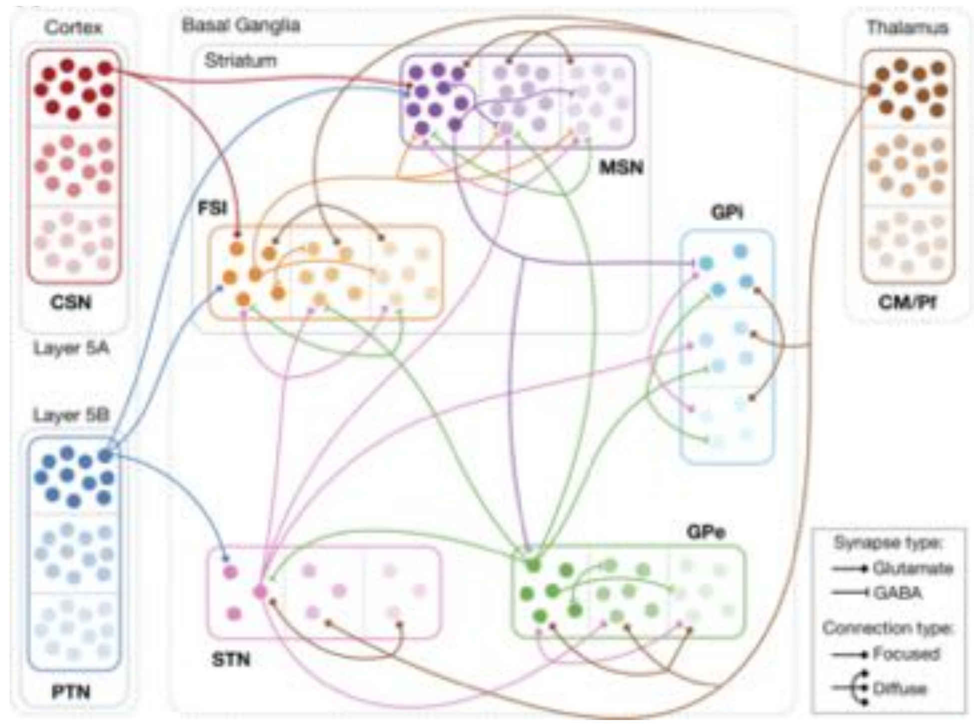


[Igarashi et al., 2019 Front. Neuroinformatics]

[Sun et al., 2019 JNNS 2019]

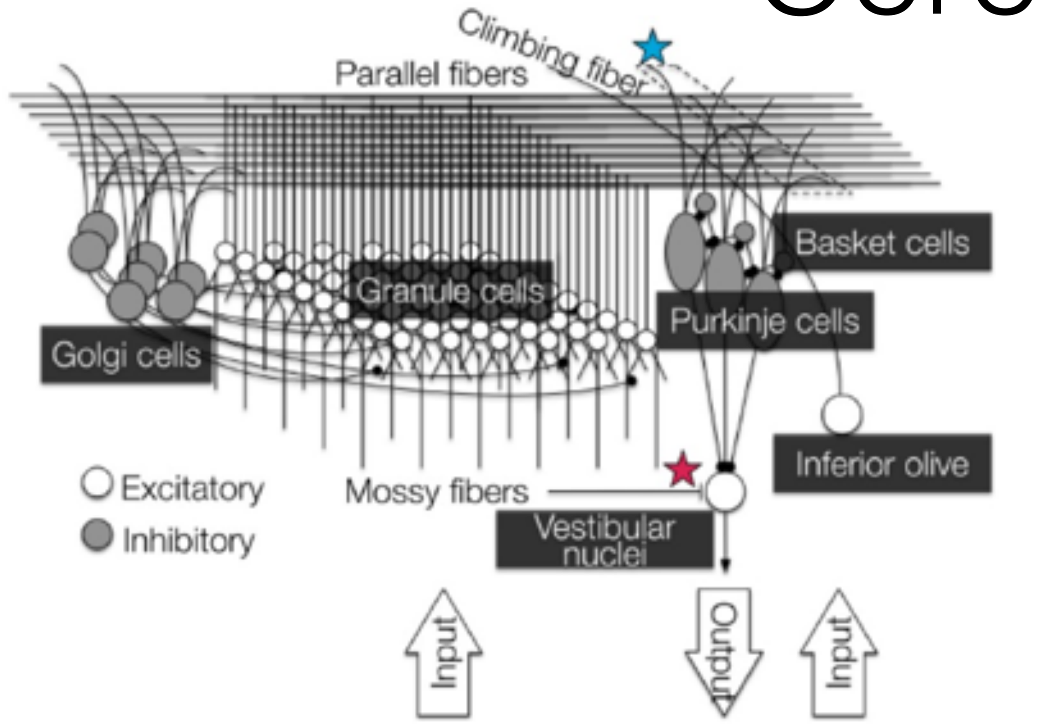
[Heidarinejad et al., 2019 JNNS 2019]

Basal Ganglia



[Girard et al., EJN 2020]

Cerebellum

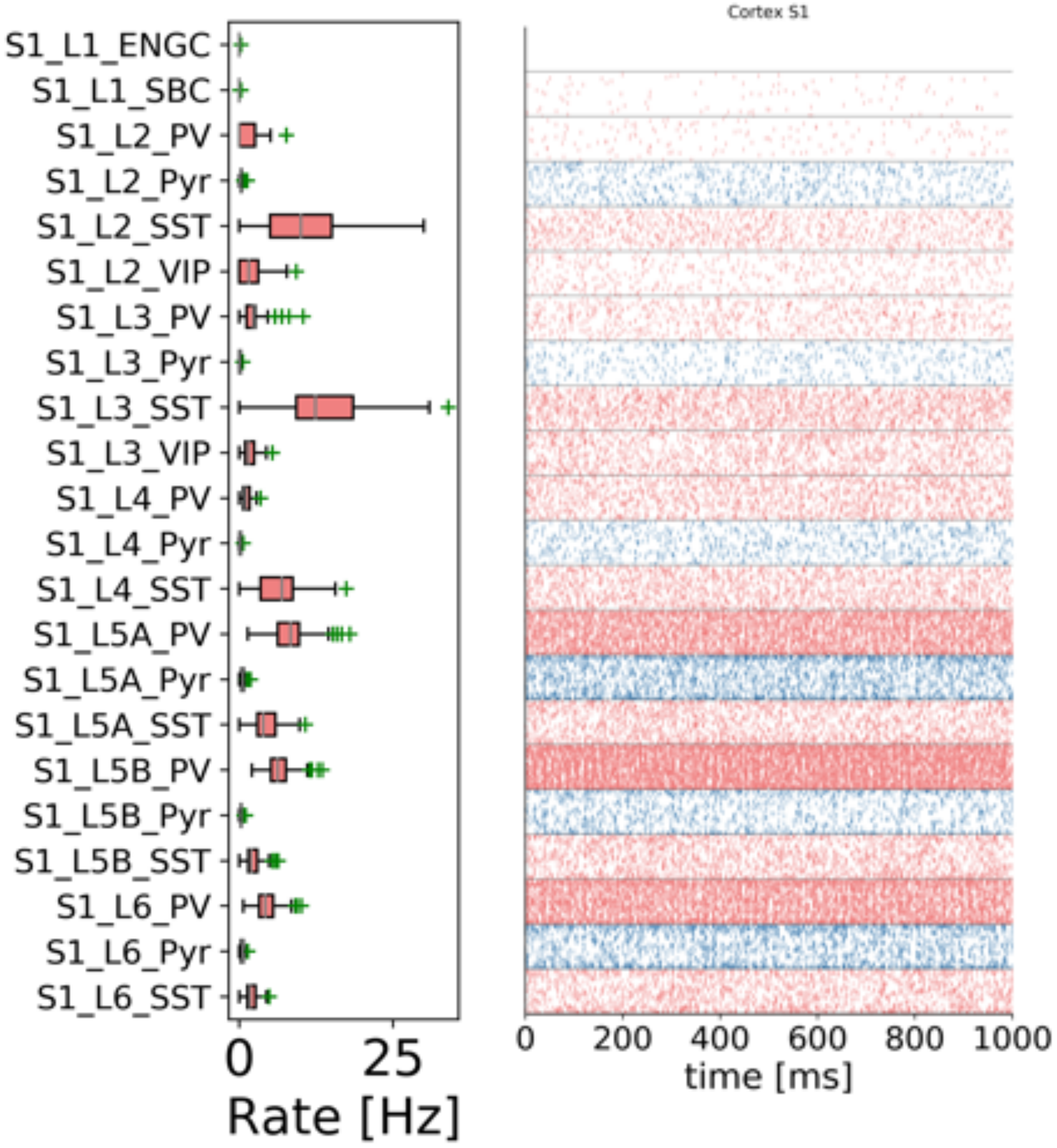


[Yamazaki and Nagao, PLoS ONE 2012]

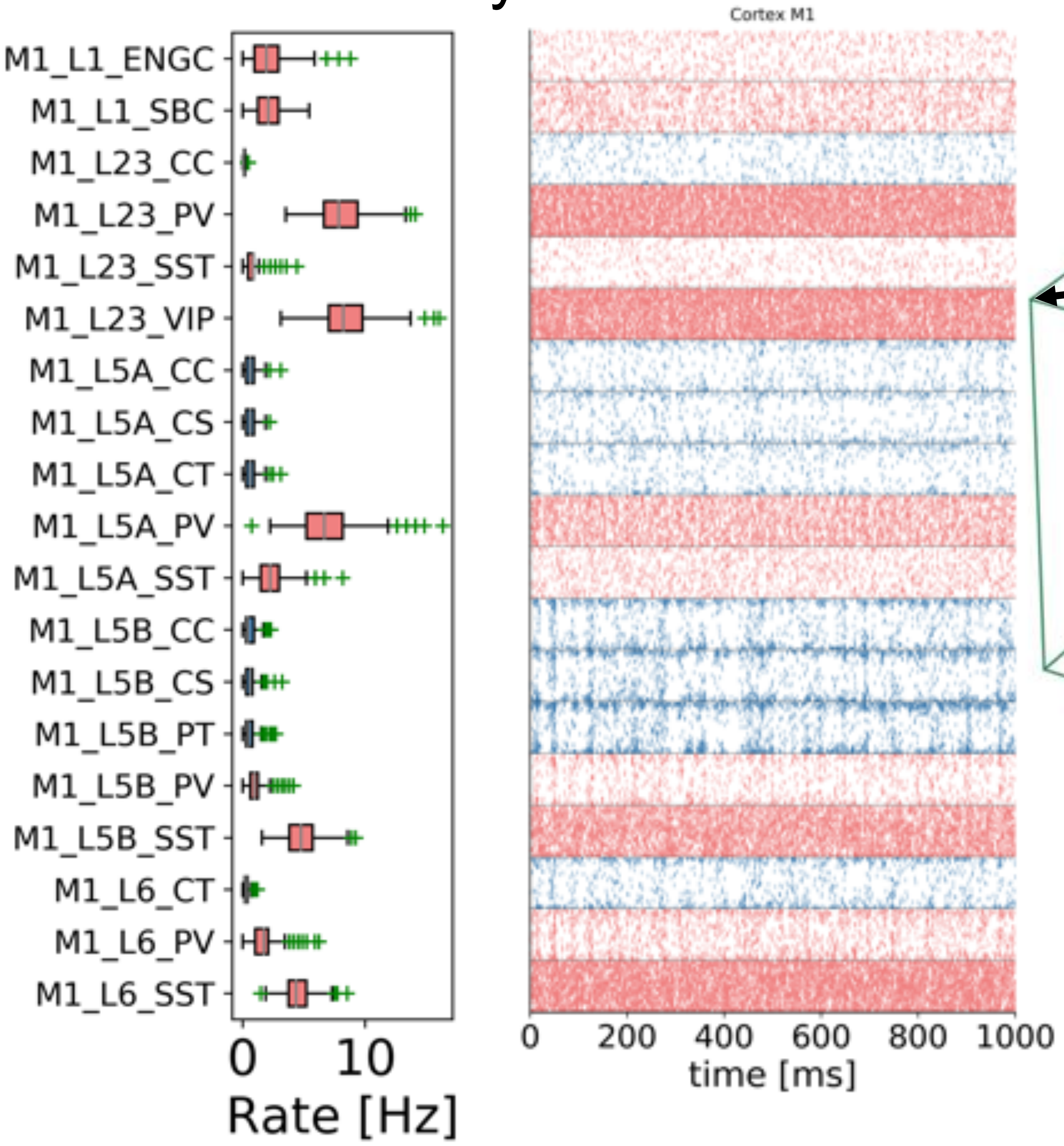
Cortical Areas - Resting State (1000 ms)

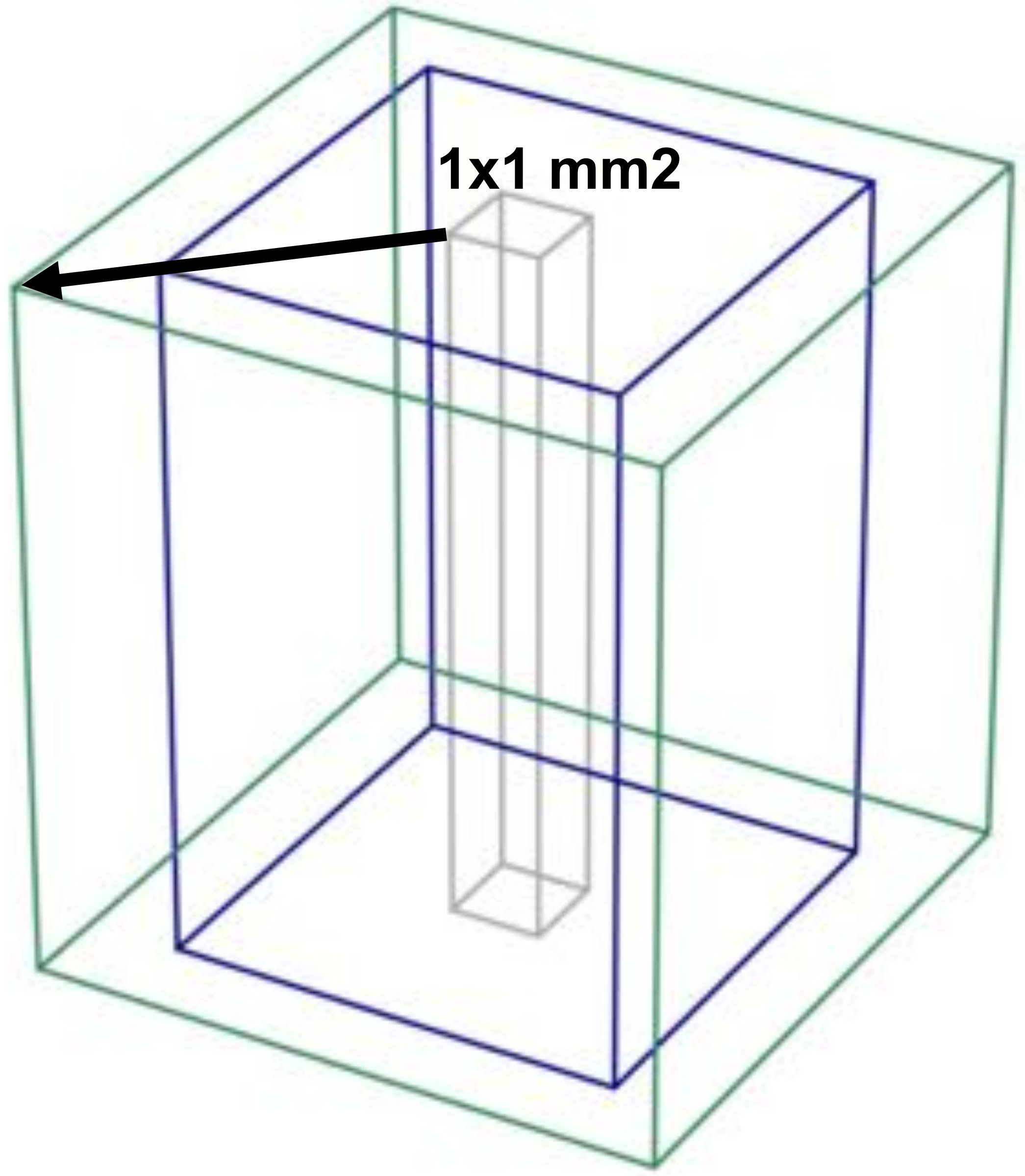
nest::

S1 - Primary Somatosensory Cortex



M1 - Primary Motor Cortex





scaling

EXABRAINPREP - Preparing brain models for exascale systems (NEST)

Target: to address scaling issues during network construction

Outputs:

- Whole-Brain model [Gutierrez, Sun, et al., in preparation] migration from NEST 2 to NEST 3 (PyNEST).
- Implementation of the new functions/commands in the model

- Representation of populations as compact GIDCollections

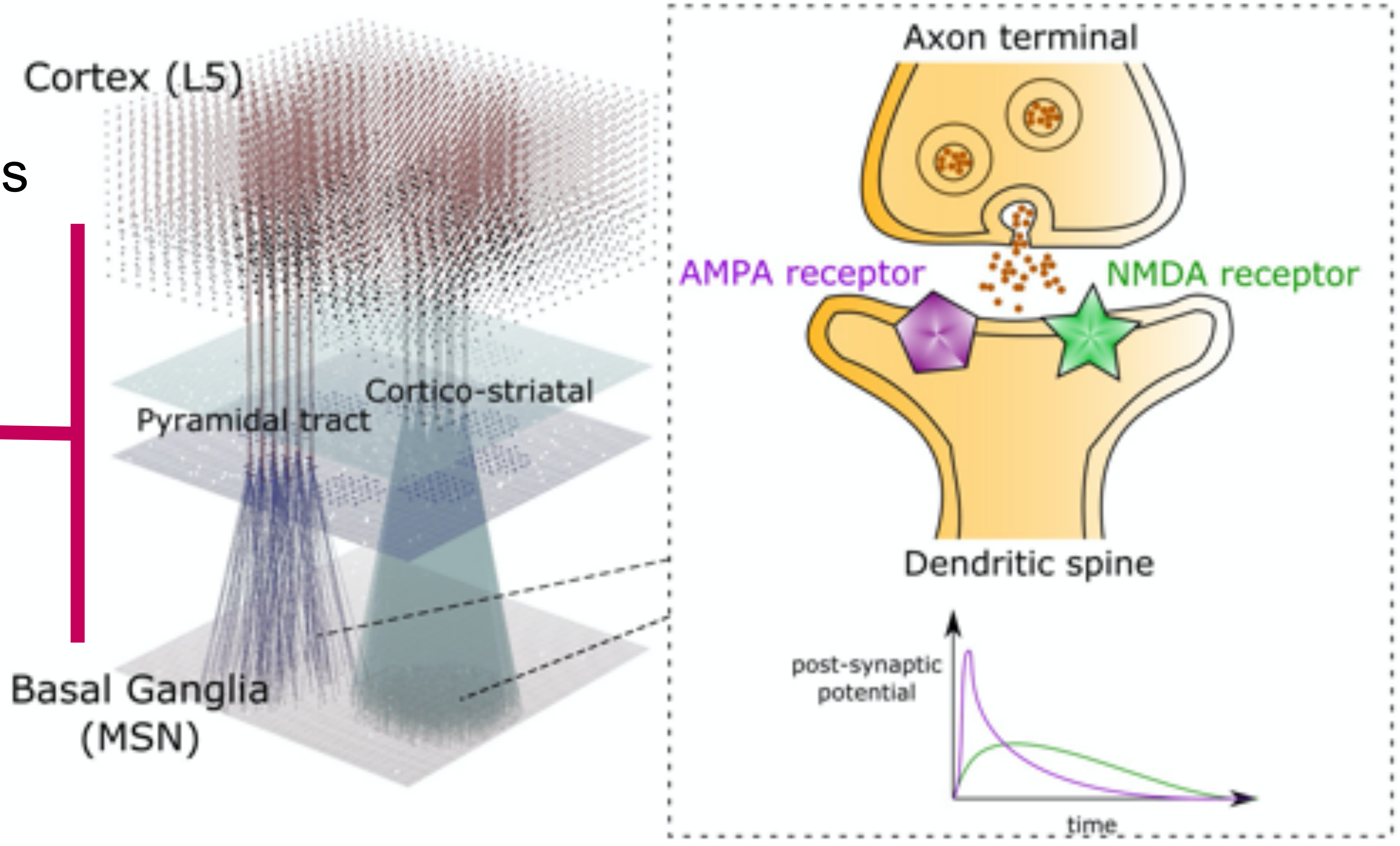
Neuronal populations are not full lists of neuron IDs anymore, that eliminates memory bloat.

- CollocatedSynapses()

It is now possible to create connections with several synapses simultaneously.

- Aggregated Connection Rules and BuildNetwork()

Aggregating `Connect()` reduces significantly the call and parallelization overhead during network construction, by using the same connection rules across pairs of populations.



Compiler Flags Evaluation for NEST 3 (PyNEST)@Fugaku supercomputer

[https://www.r-ccs.riken.jp/en/fugaku/about/]

Compilers
C : Fujitsu mpifcc
C++ : Fujitsu mpiFCC

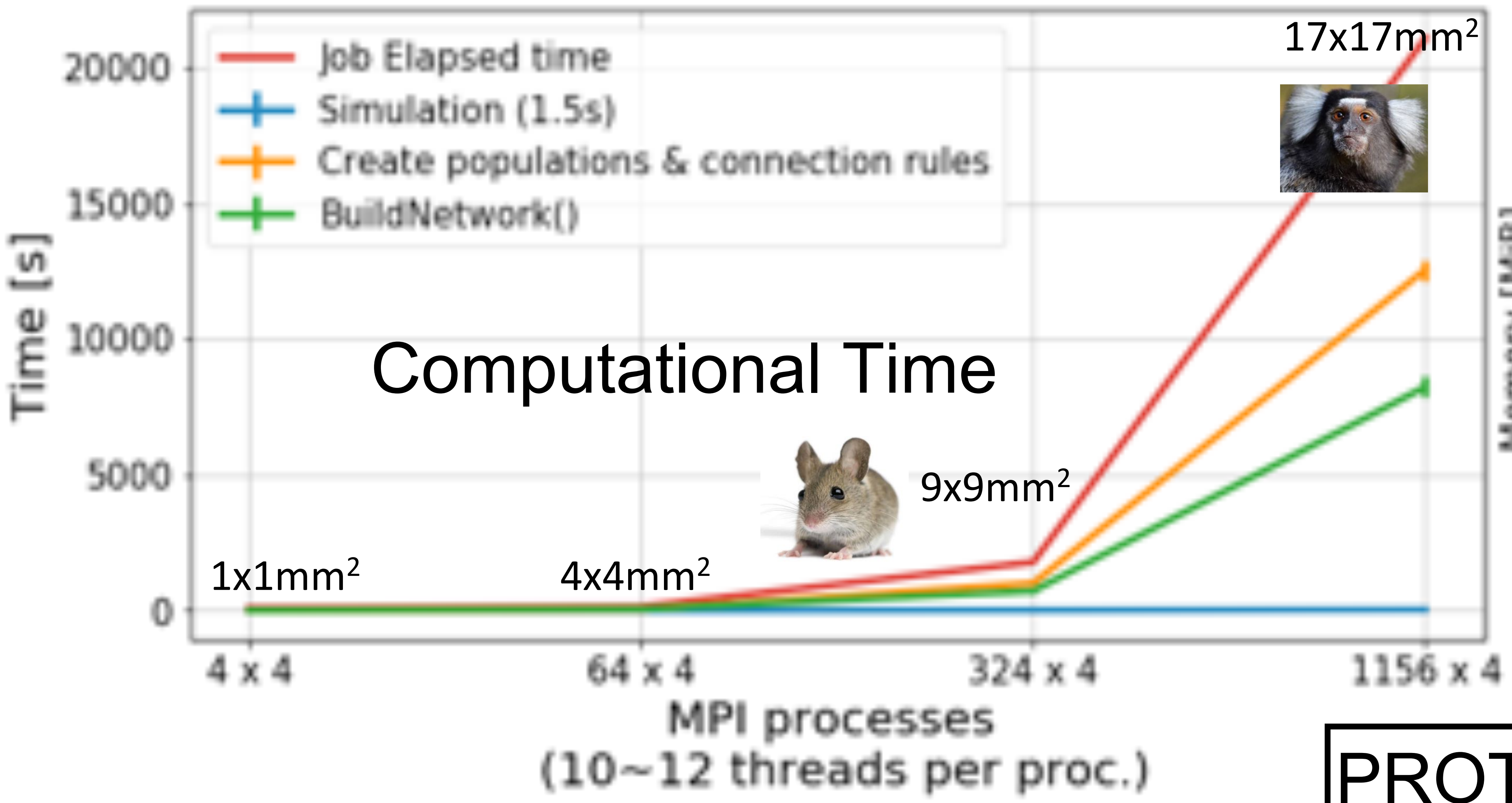
Network Model
Brunel Network (Random balanced populations)
2 MPI processes running at an interactive job

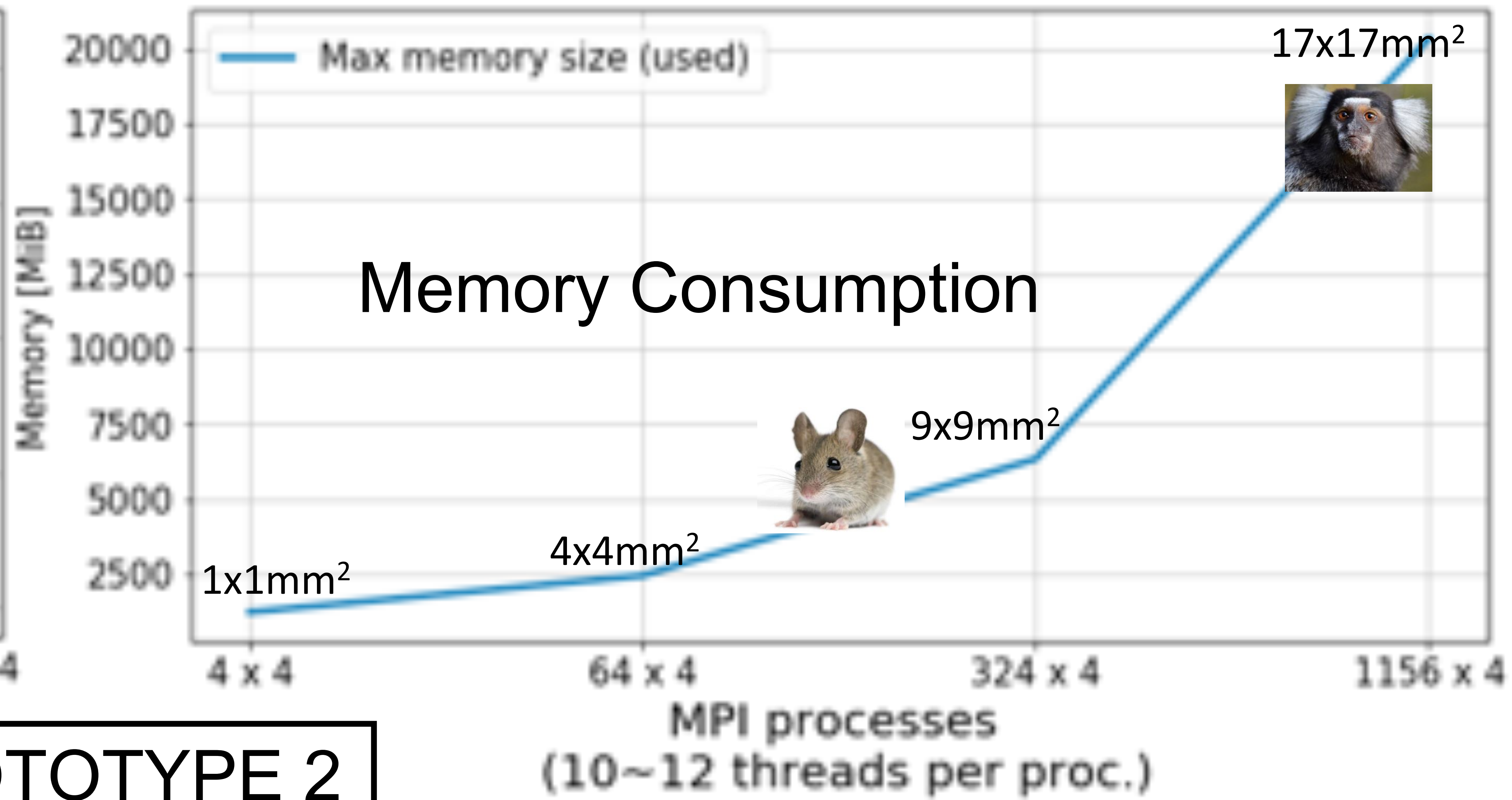
	C compiler flags : -fPIC -Kfast -Kparallel -x1 -fopenmp C++ compiler flags : -std=c++11 -fPIC -Kfast -Kparallel -x1 -fopenmp	C compiler flags : -fPIC -x1 -Kparallel -Kopenmp -openmp C++ compiler flags : -std=c++11 -fPIC -x1 -Kparallel -Kopenmp -openmp	C compiler flags : -fPIC -Kfast -x1 -Kparallel -Kopenmp -openmp C++ compiler flags : -std=c++11 -fPIC -Kfast -x1 -Kparallel -Kopenmp -openmp	C compiler flags : -fPIC -Kfast -x1 -fopenmp C++ compiler flags : -std=c++11 -fPIC -Kfast -x1 -fopenmp	C compiler flags : -Kfast,parallel -fPIC -fopenmp C++ compiler flags : -std=c++11 -Kfast,parallel -fPIC -fopenmp	C compiler flags : -fPIC -fopenmp C++ compiler flags : -std=c++11 -fPIC -fopenmp
Building Time (s) per process	44.20	48.04	42.36	42.44	17.17	163.52
Simulation Time (s) per process	85.73	111.30	85.74	85.59	51.73	446.93

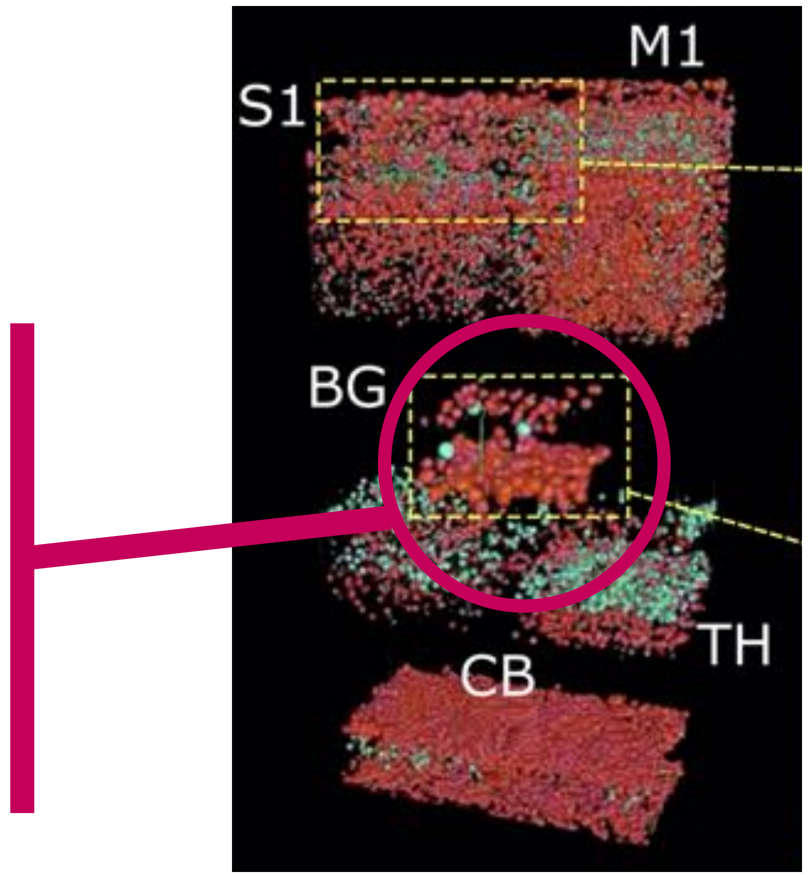
Scaling tests @FUGAKU supercomputer

富岳

PROTOTYPE 1



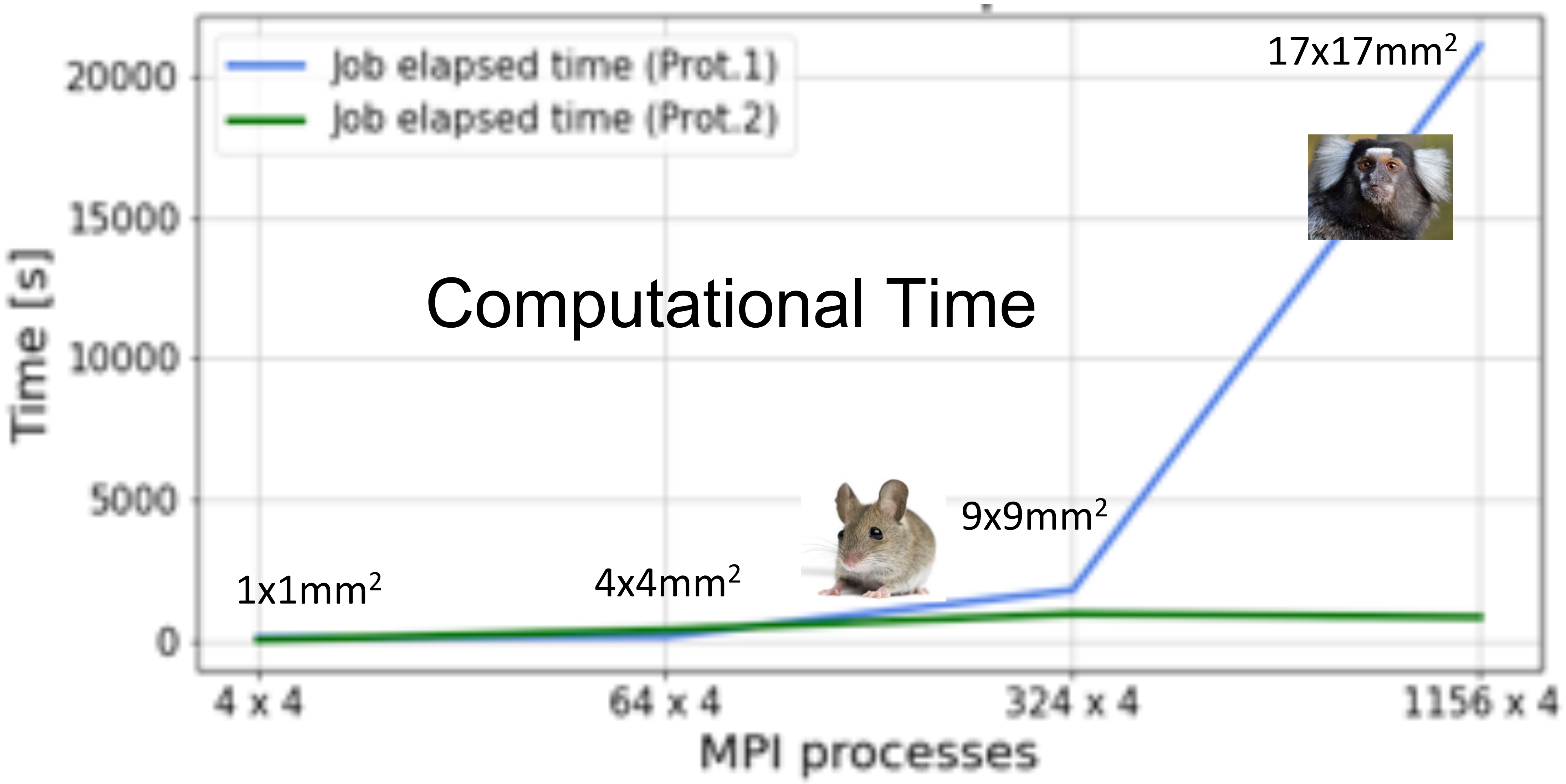


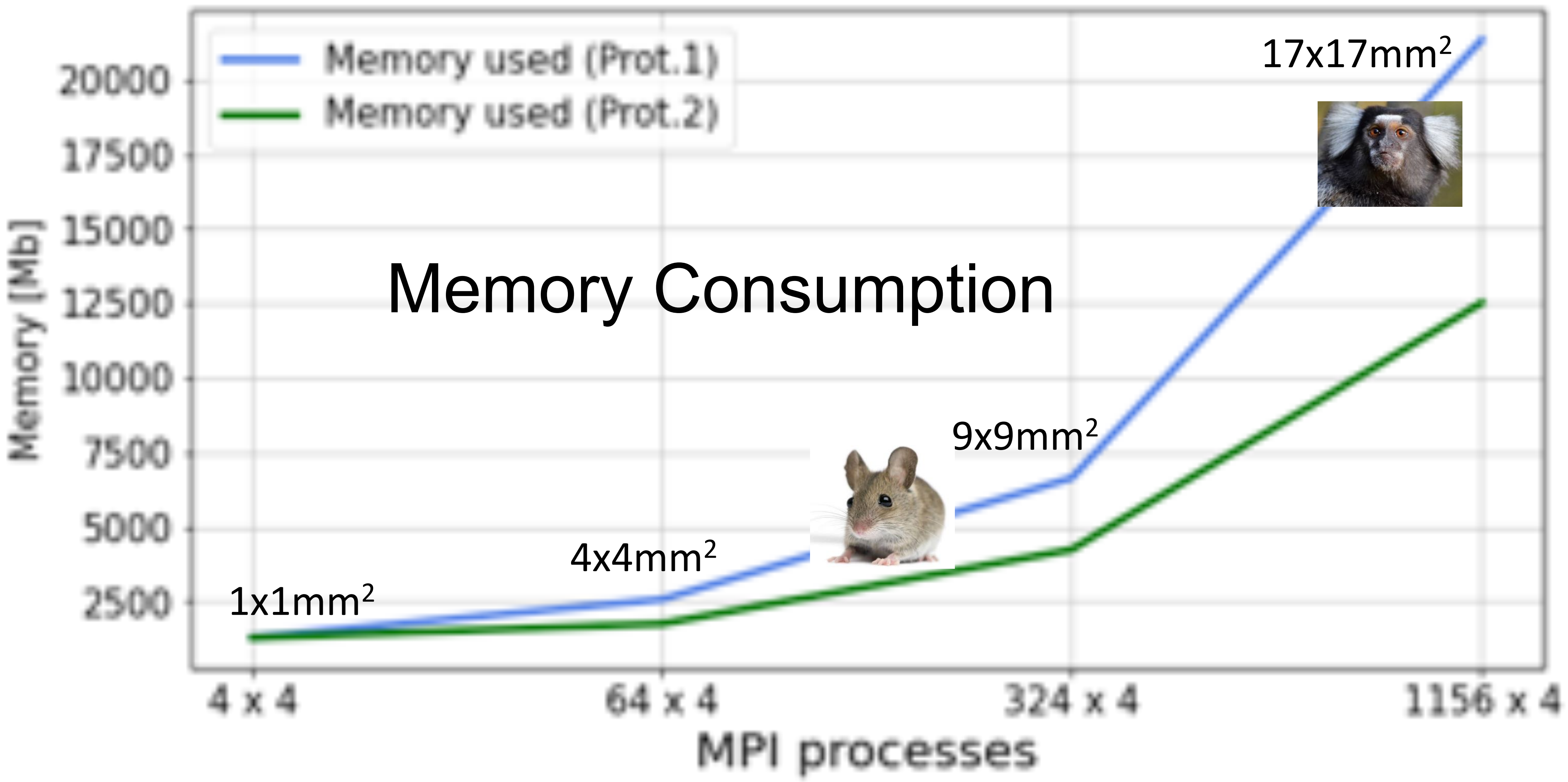


Basal Ganglia

Network Size	Number of neurons
1x1mm^2	47K
4x4mm^2	751K
9x9mm^2	3805K
17x17mm^2	13576K

PROTOTYPE 2



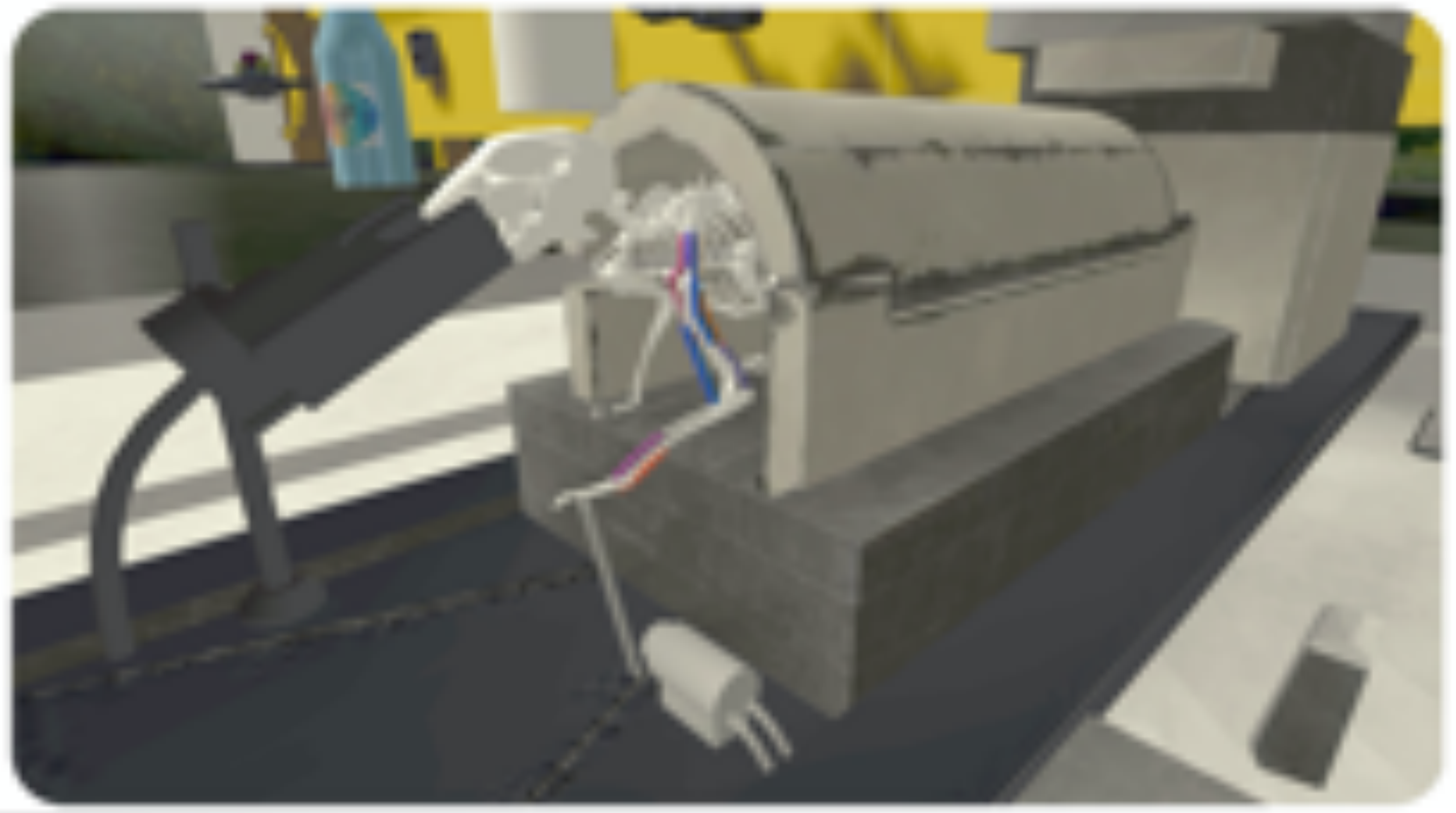


Next steps

Model scaling to marmoset, macaque and human brain sizes, while improving model fitting and evaluating dynamics against experimental data.

ROBOBRAIN (NRP)

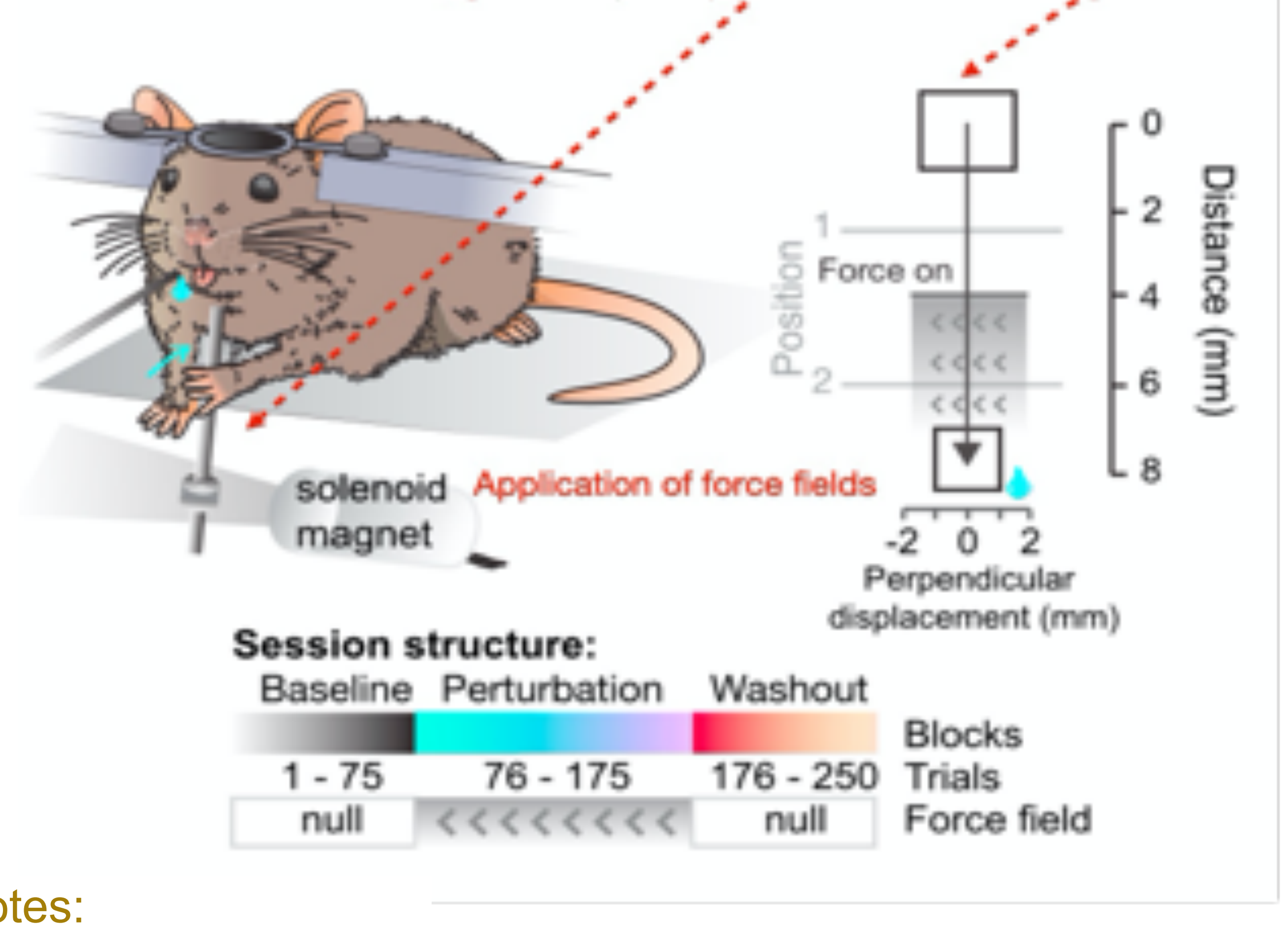
Target: **Whole-brain spiking neural network and rodent musculo-skeletal models integration for behavioral experimentation in the Neurorobotics Platform**



Body Model contains a mouse skeleton and a forelimb with 8 muscles

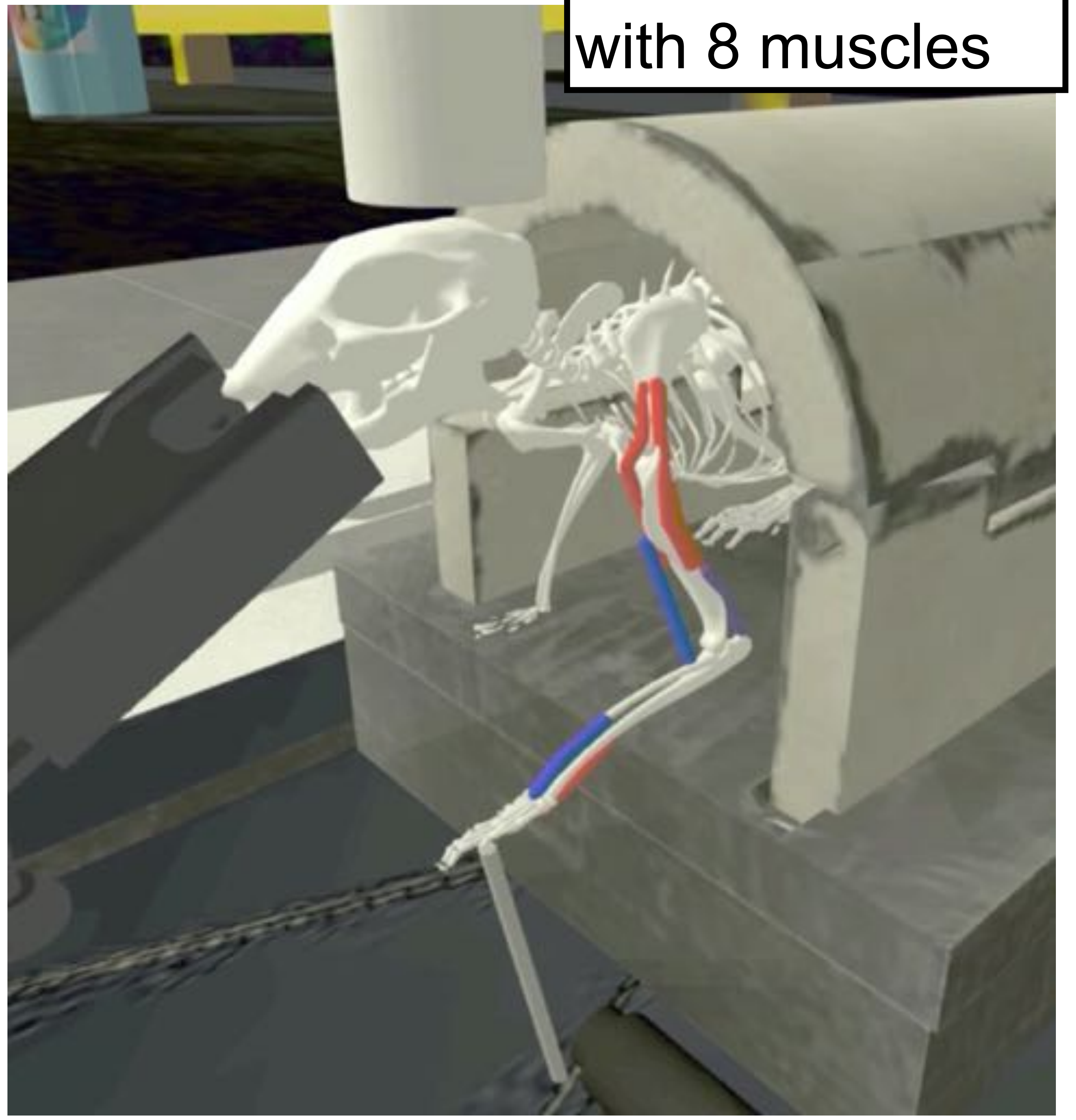
Physical setup

*Mouse forelimb manipulating a Joystick with 2-degree of freedom.
*Based on M. Mathis et al., 2017 (Somatosensory Cortex Plays an Essential Role in Forelimb Motor Adaptation in Mice)



Notes:
- Track the paw position and joystick position
- Task performed in the dark (or light conditions)
- Setting spatial thresholds to activate lateral force (based on joystick position)
- Joystick with 2-degree of freedom (xy plane).

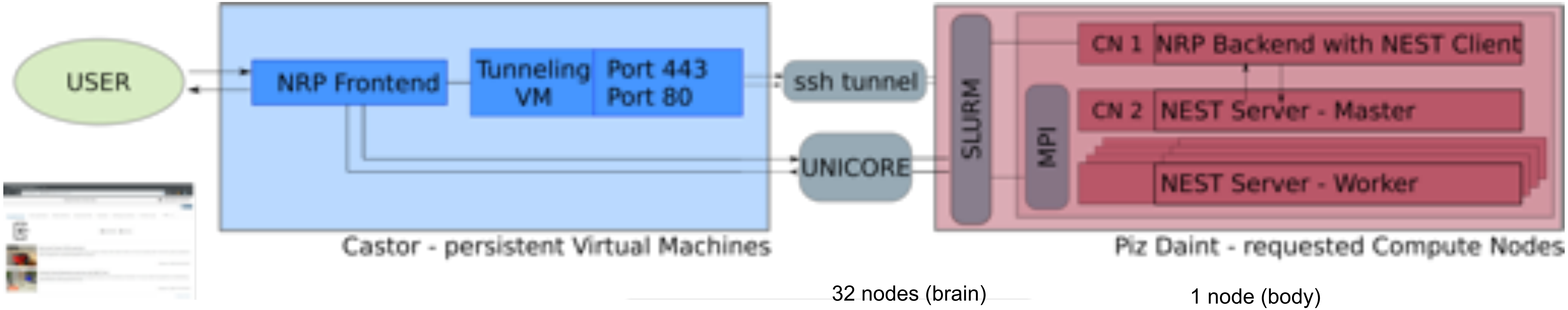
[M. Mathis et al., 2017]



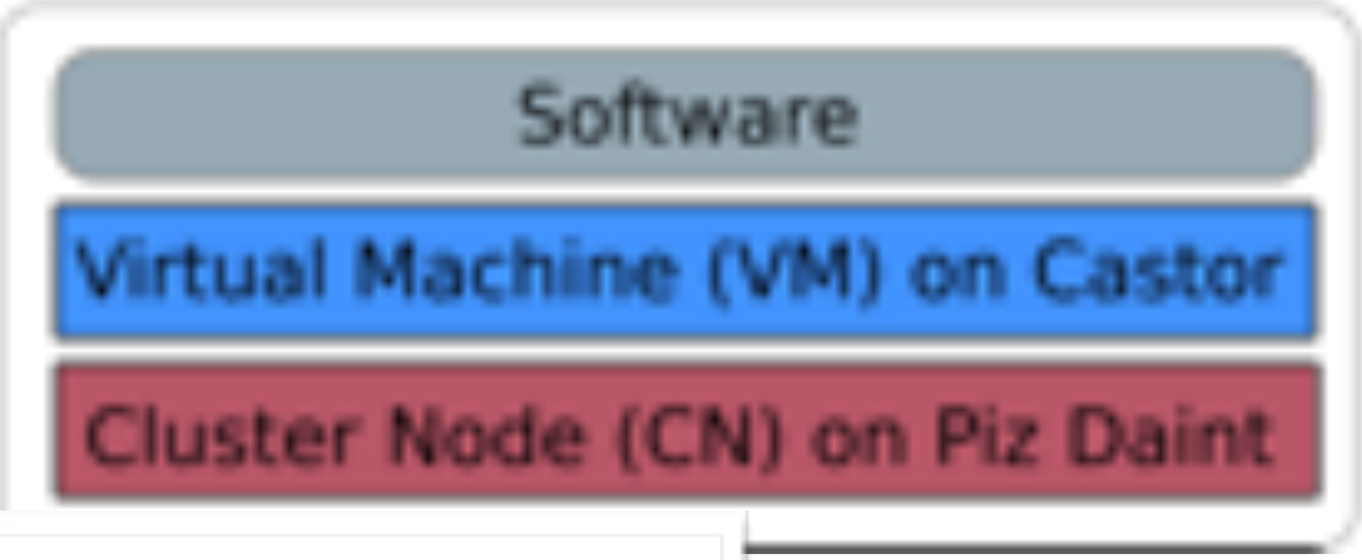
[Neurorobotics Platform, HBP]

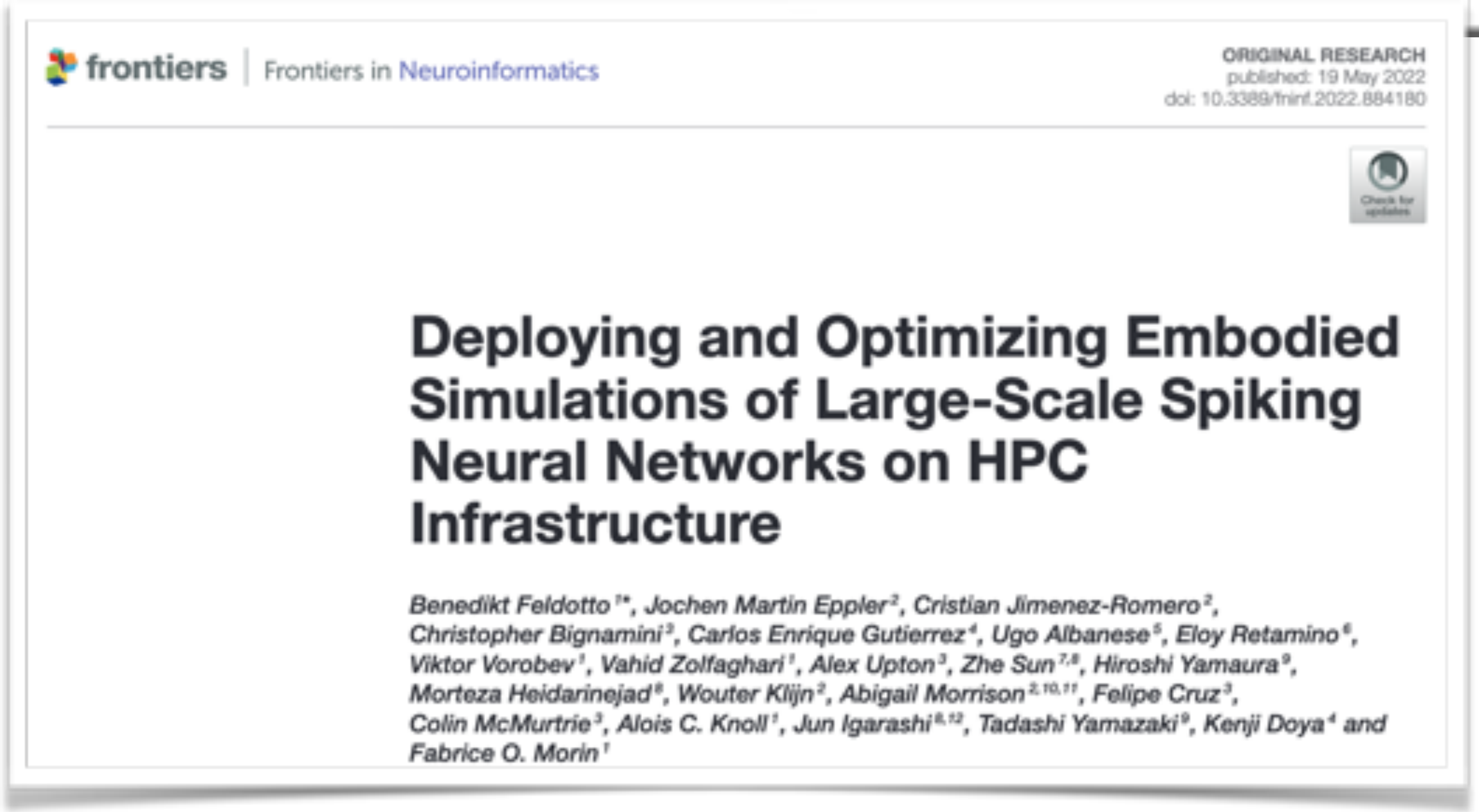
ROBOBRAIN (NRP)

Deployed Architecture



Graphical Interface





frontiers | Frontiers in Neuroinformatics
ORIGINAL RESEARCH
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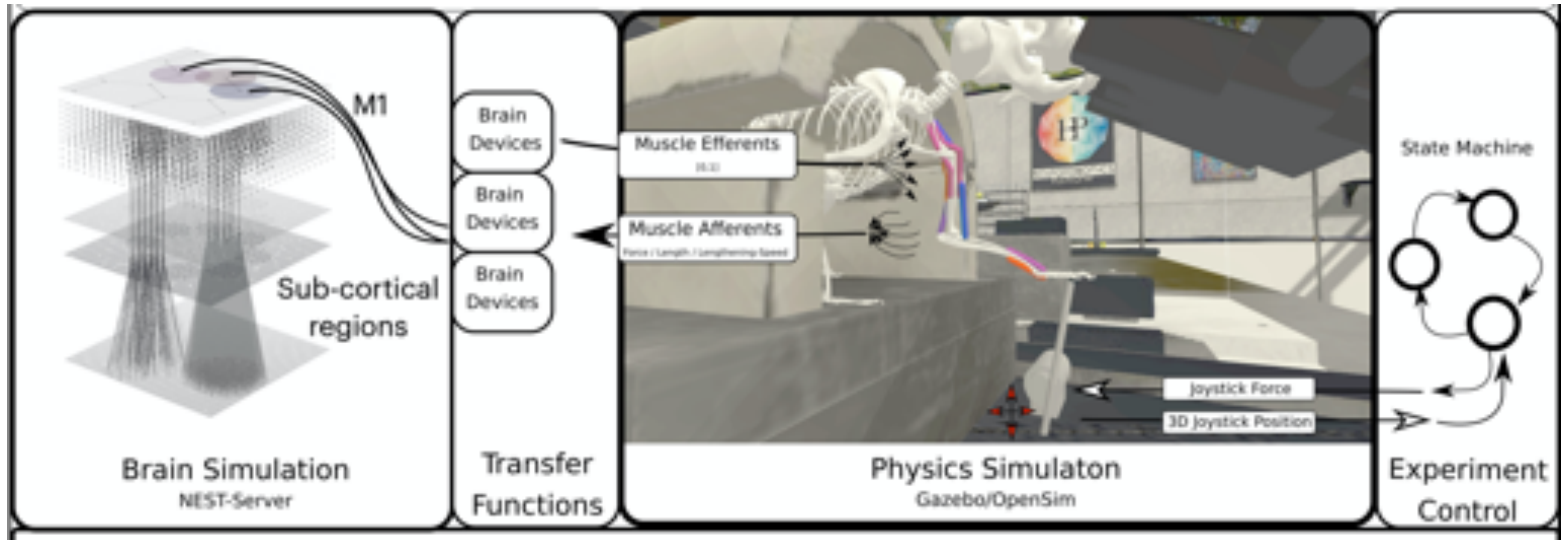
Deploying and Optimizing Embodied Simulations of Large-Scale Spiking Neural Networks on HPC Infrastructure

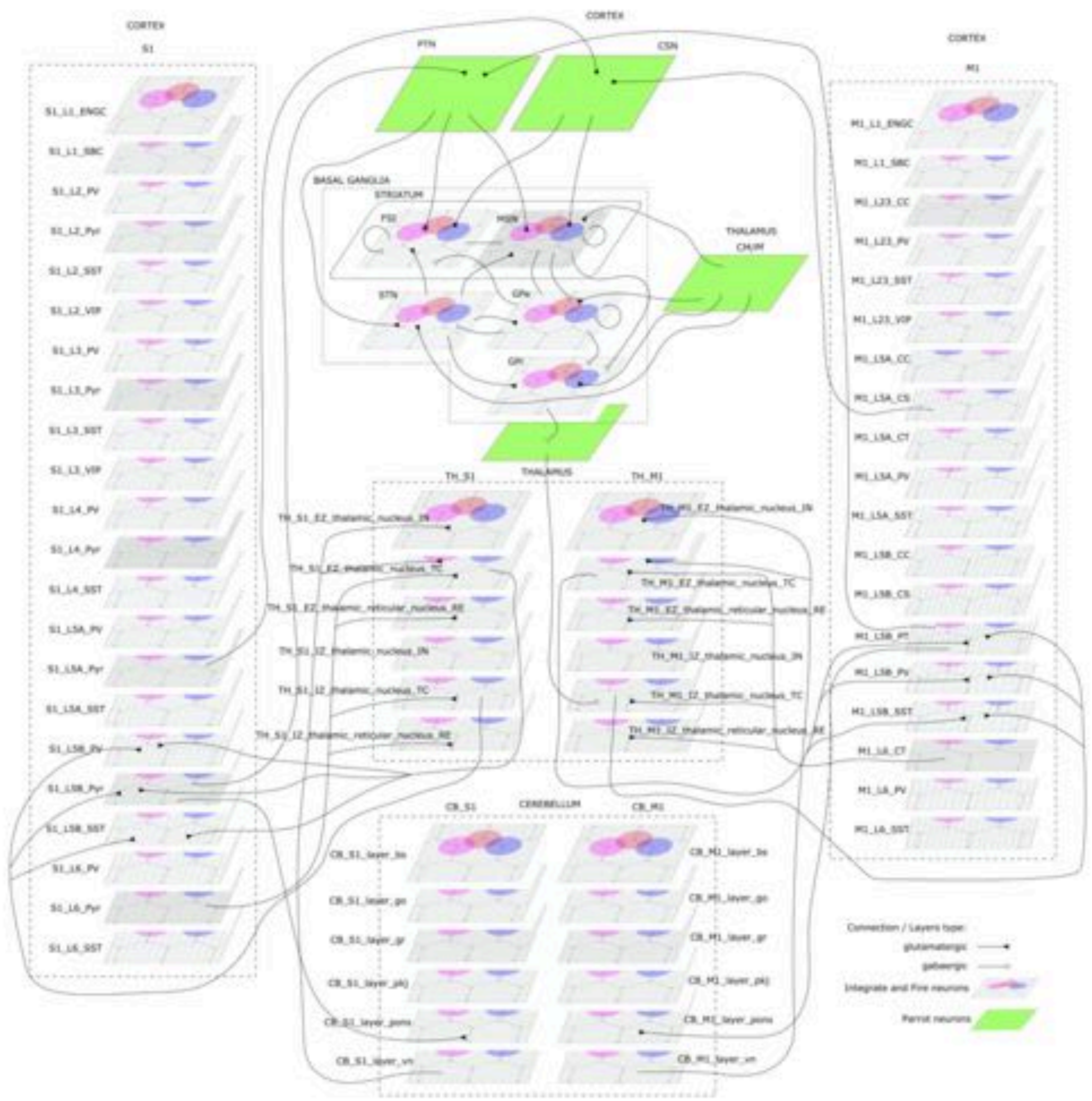
Benedikt Feldotto[1], Jochen Martin Eppler[2], Cristian Jimenez-Romero[3], Christopher Bignamini[3], Carlos Enrique Gutierrez[4], Ugo Albanese[5], Eloy Retamino[6], Viktor Vorobev[1], Vahid Zolfaghari[1], Alex Upton[3], Zhe Sun[7,8], Hiroshi Yamaura[9], Morteza Heidarinejad[9], Wouter Klijn[2], Abigail Morrison[2,10,11], Felipe Cruz[3], Colin McMurtrie[3], Alois C. Knoll[1], Jun Igarashi[8,12], Tadashi Yamazaki[9], Kenji Doya[4] and Fabrice O. Morin[1]*

32 nodes (brain) | 1 node (body)

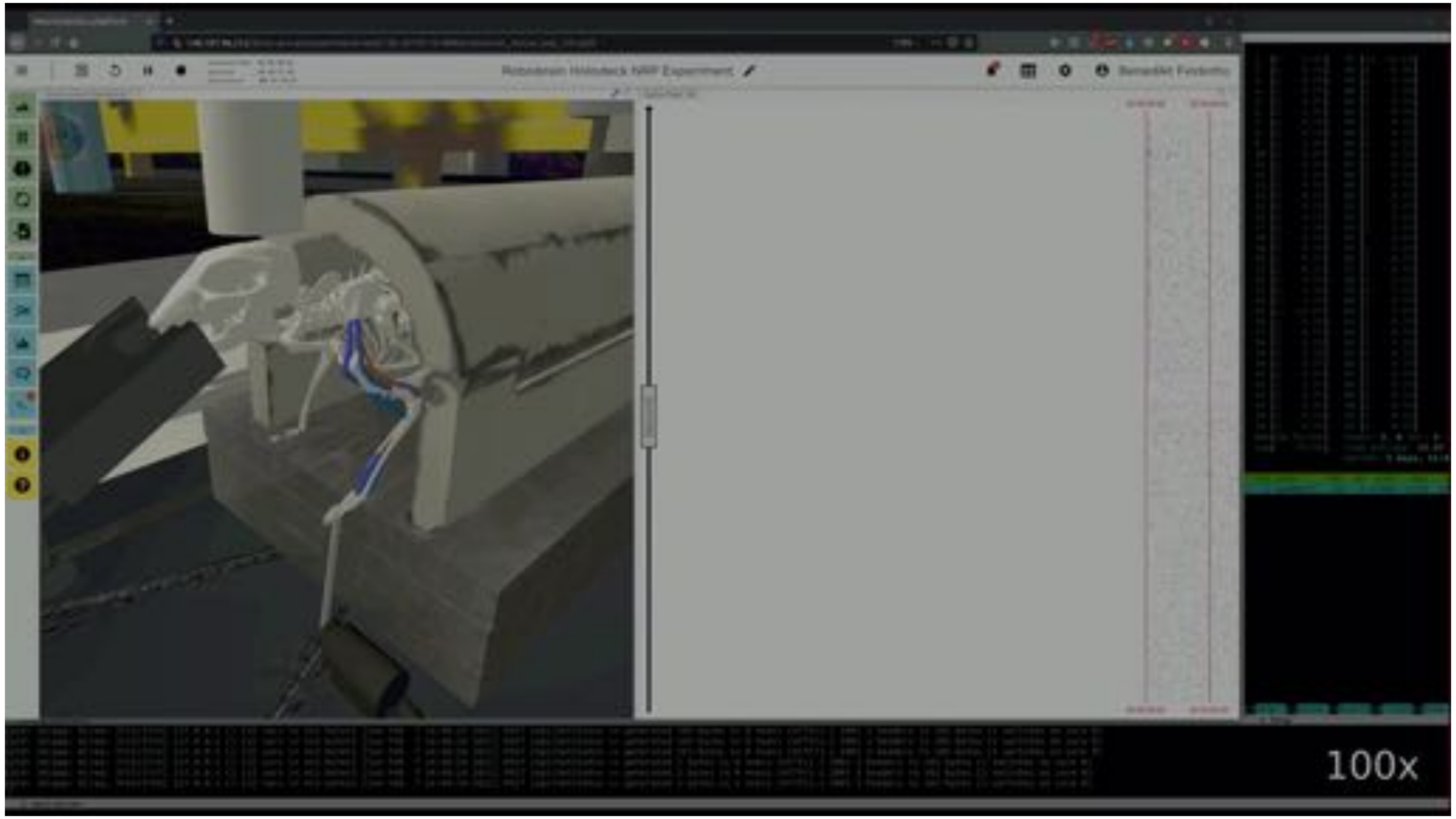


Proof-of-concept simulation @HBP infrastructure

- We connected WB model to a musculoskeletal model in the NRP
- Whole-Brain model correspond to NEST 3 version (PyNEST), with ~1M neurons ~1.5B synapses
- The motor cortex was stimulated, and the brain-body connection allowed forelimb movement



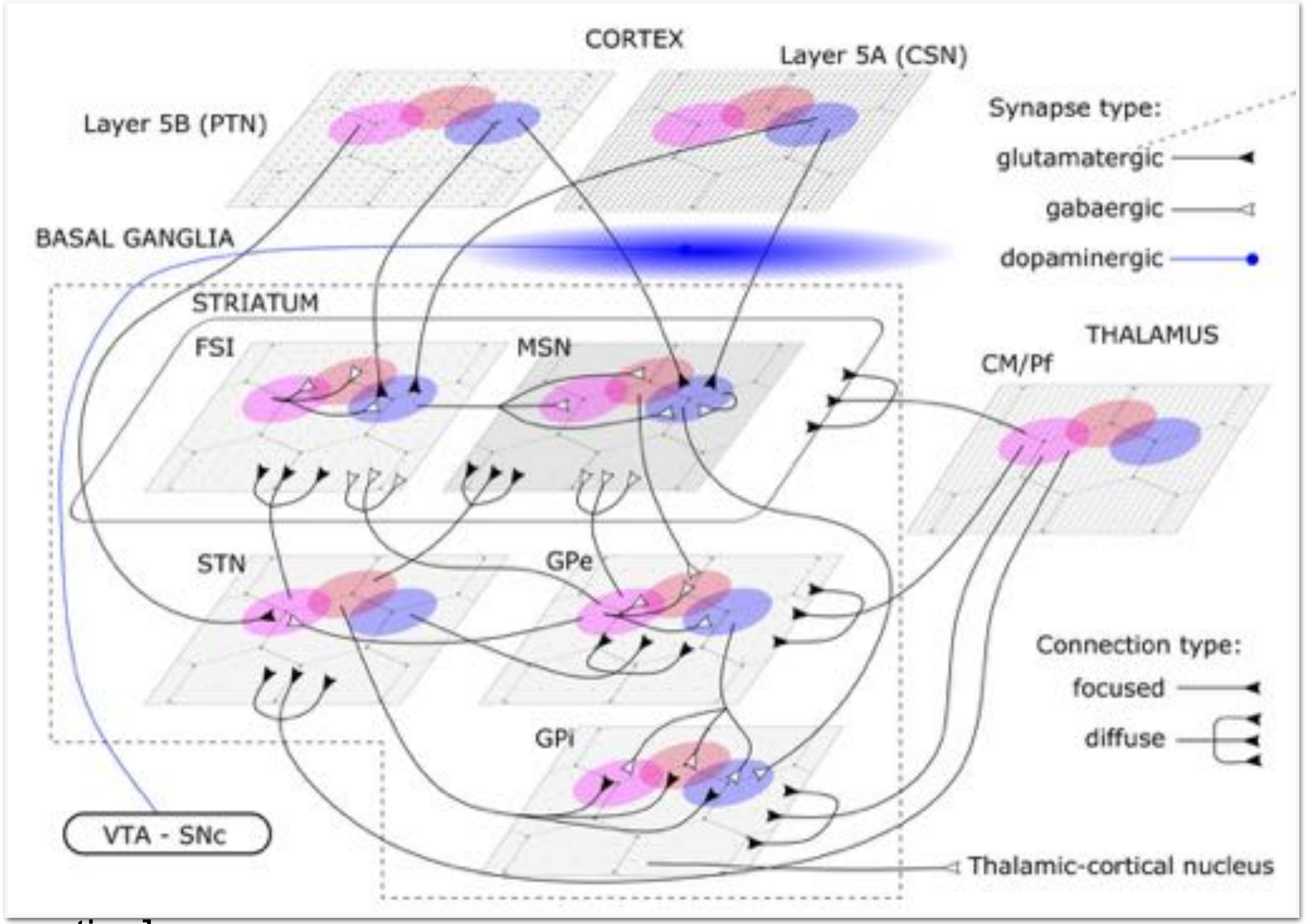
[Gutierrez, Sun, et al., in preparation]

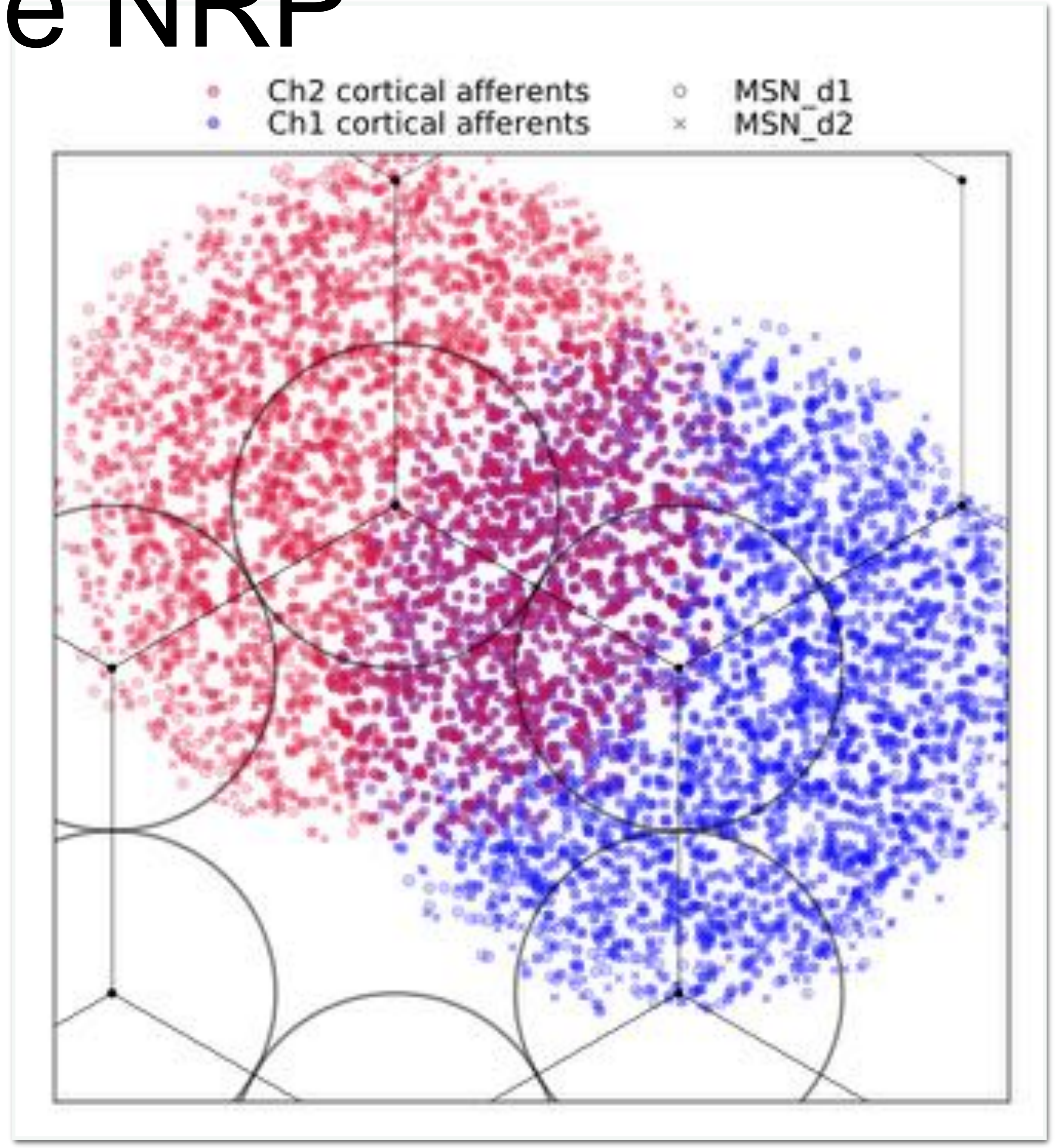


[Feldotto B. et al., 2022]

Next steps

Implementation of reinforcement learning (basal ganglia, large scale model) and experimentation in the NRP





[Gutierrez et al., in preparation]

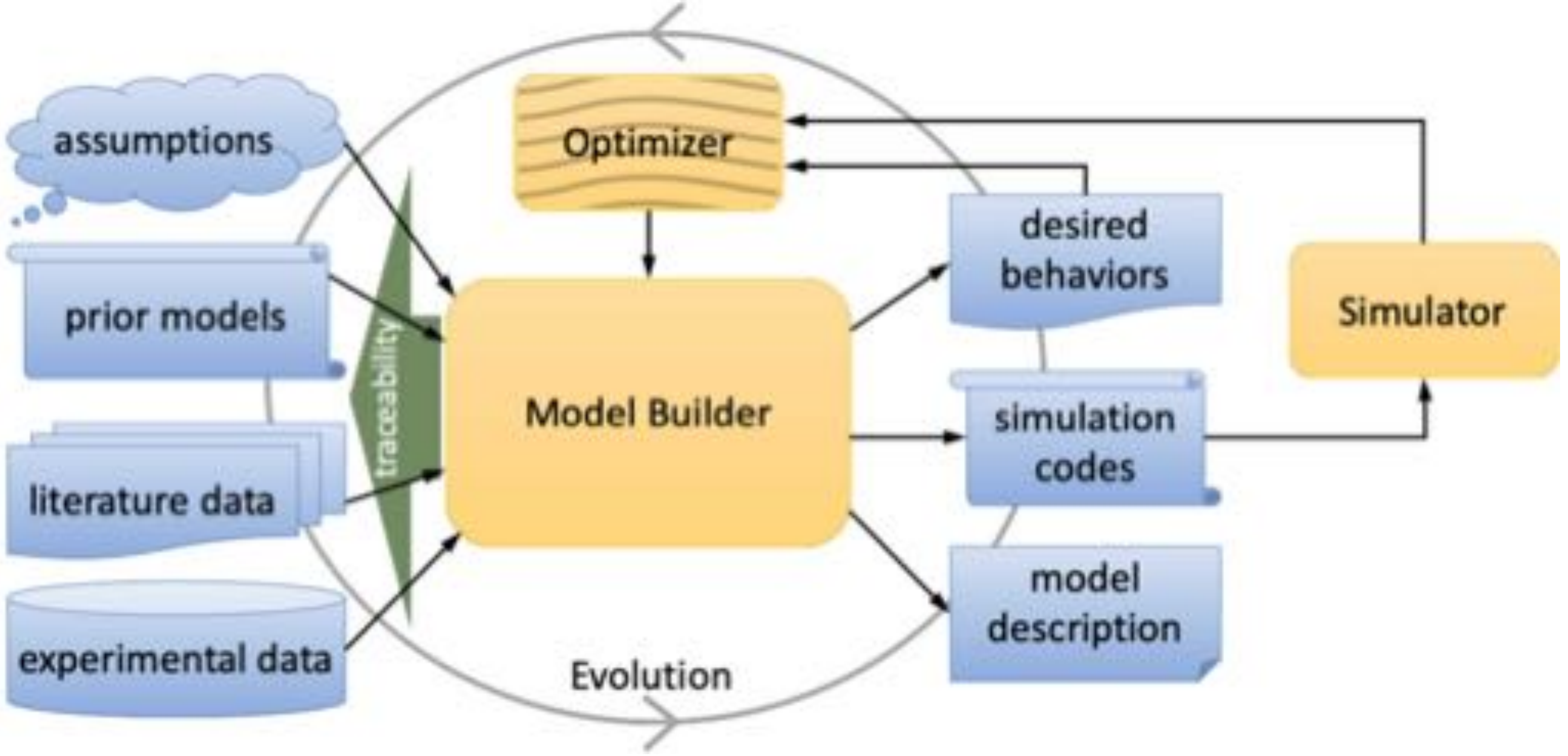
SNNBuilder: A Spiking Neural Network Builder for Systematic Data-to-Model Workflow

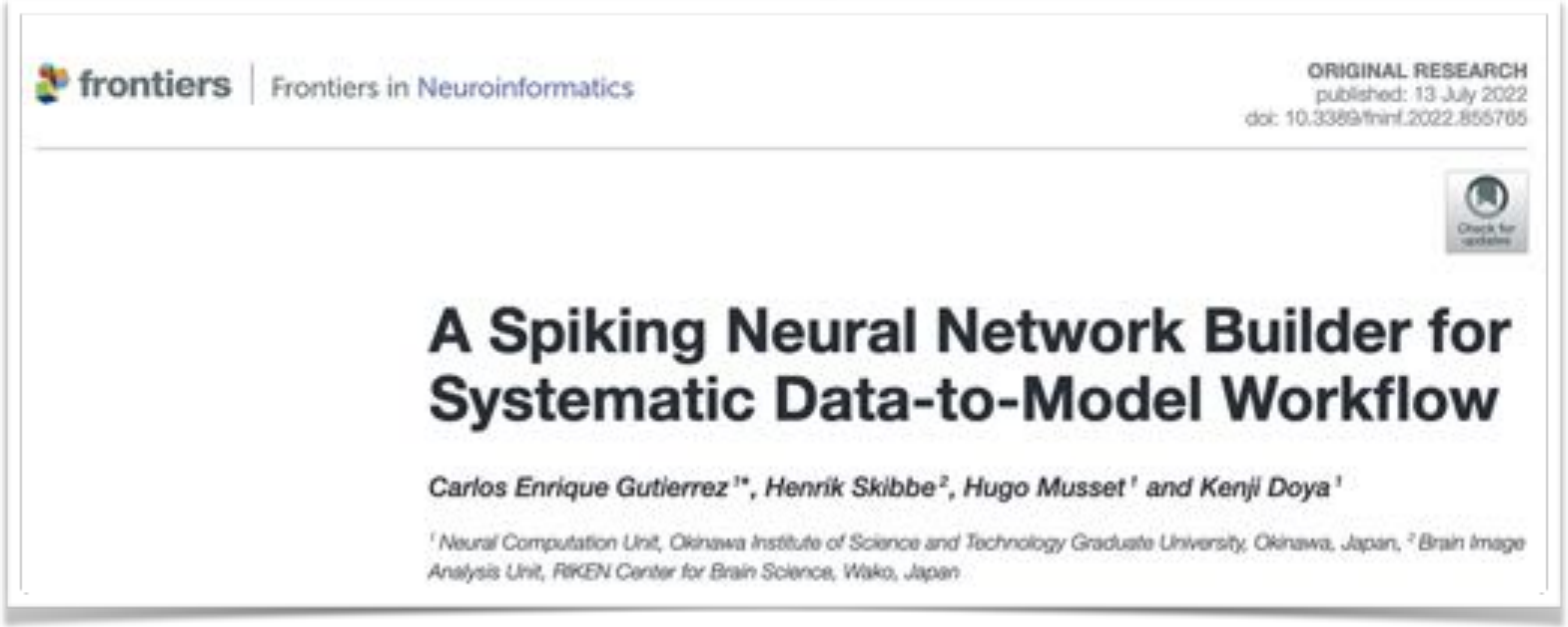
Goal:

- Improve the impact of computational models in neuroscience, by building with transparency and data-driven validation (**no more black boxes**).
- Build **collaboratively**, by integrating multiple data sources and multi-user access.

SNNBuilder

Conceptualization





frontiers | Frontiers in Neuroinformatics

ORIGINAL RESEARCH
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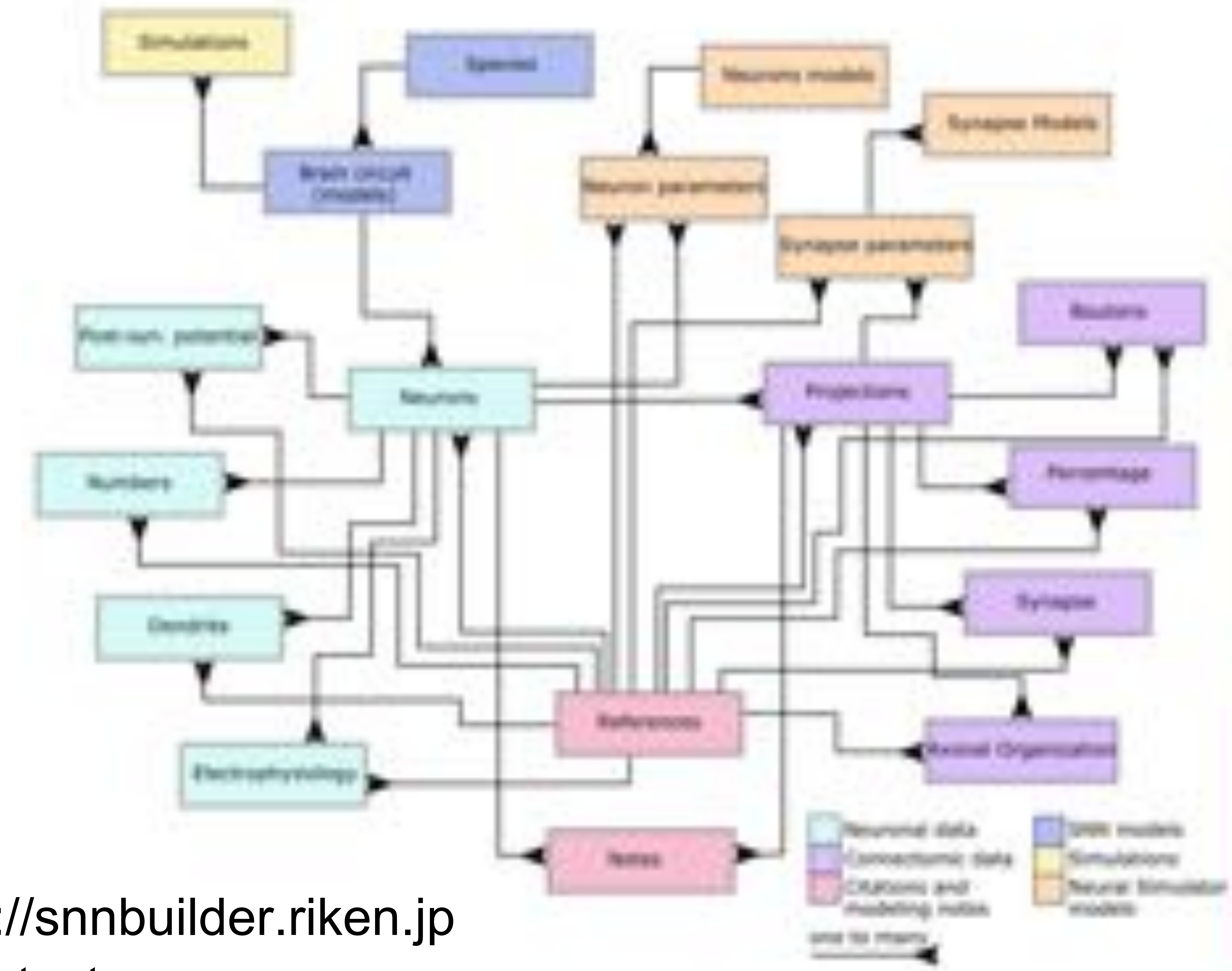
Check for updates

A Spiking Neural Network Builder for Systematic Data-to-Model Workflow

Carlos Enrique Gutierrez [1], Henrik Skibbe [2], Hugo Musset [1] and Kenji Doya [1]*

[1] Neural Computation Unit, Okinawa Institute of Science and Technology Graduate University, Okinawa, Japan, [2] Brain Image Analysis Unit, RIKEN Center for Brain Science, Wako, Japan

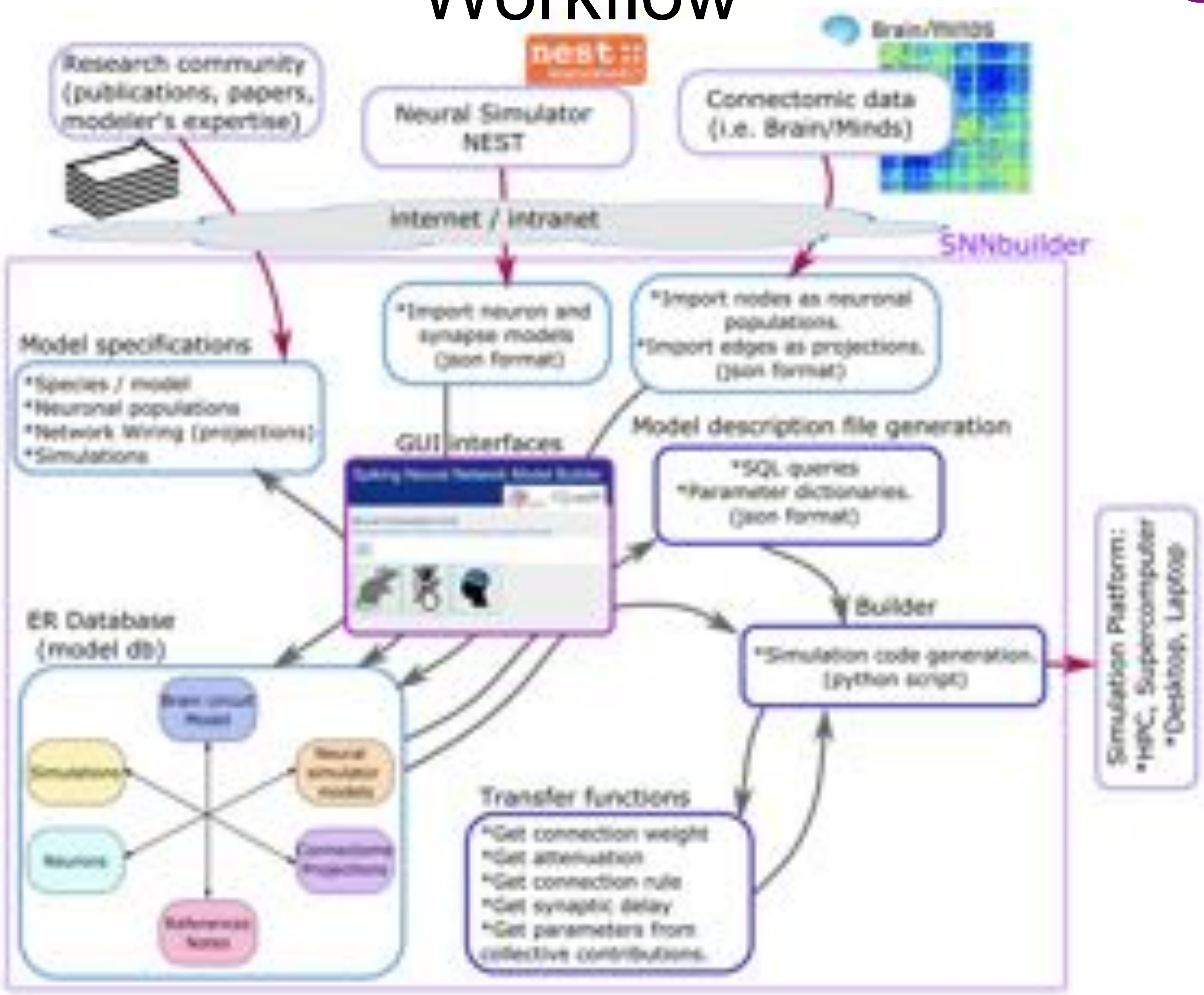
ER (entity-relation) data model



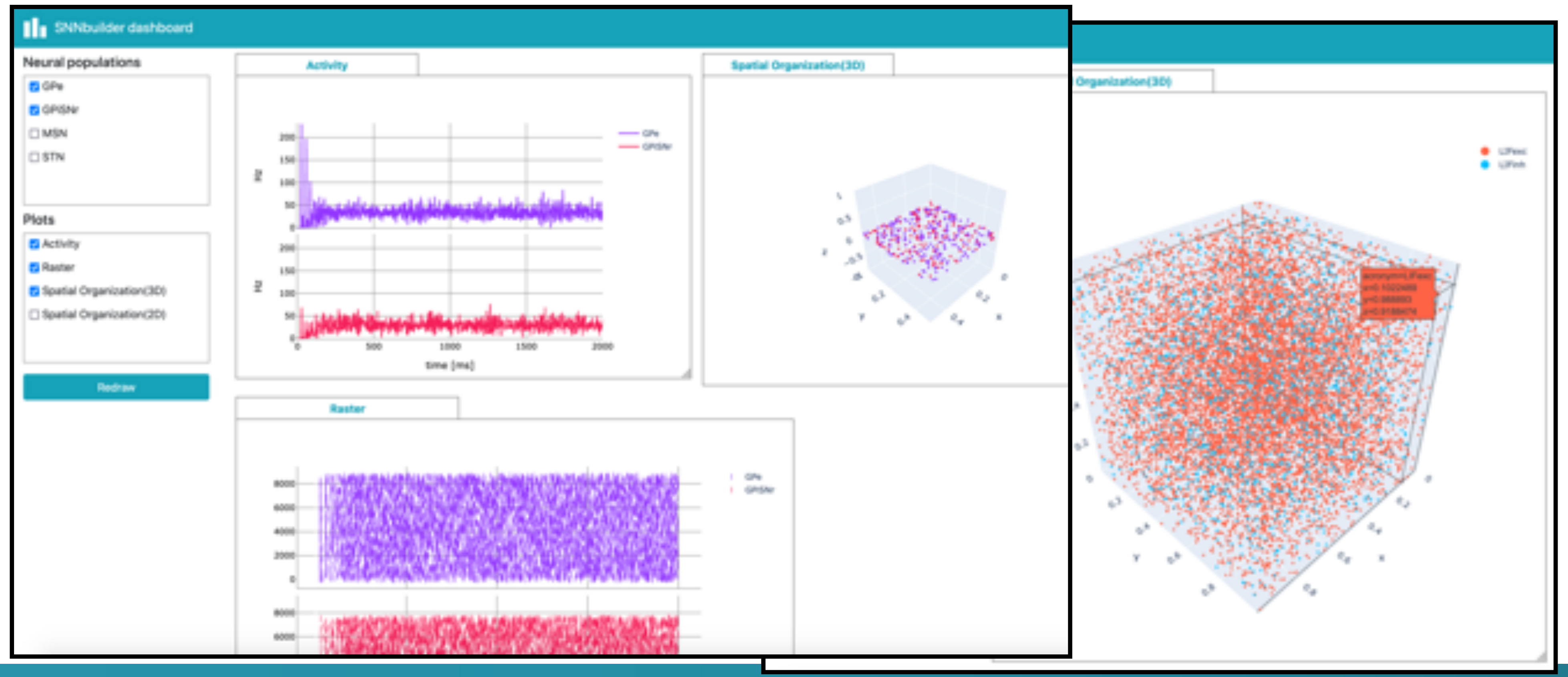
https://snnbuilder.riken.jp
User: testuser
Password: snnbuilder

SNNBuilder

Workflow



Dashboards



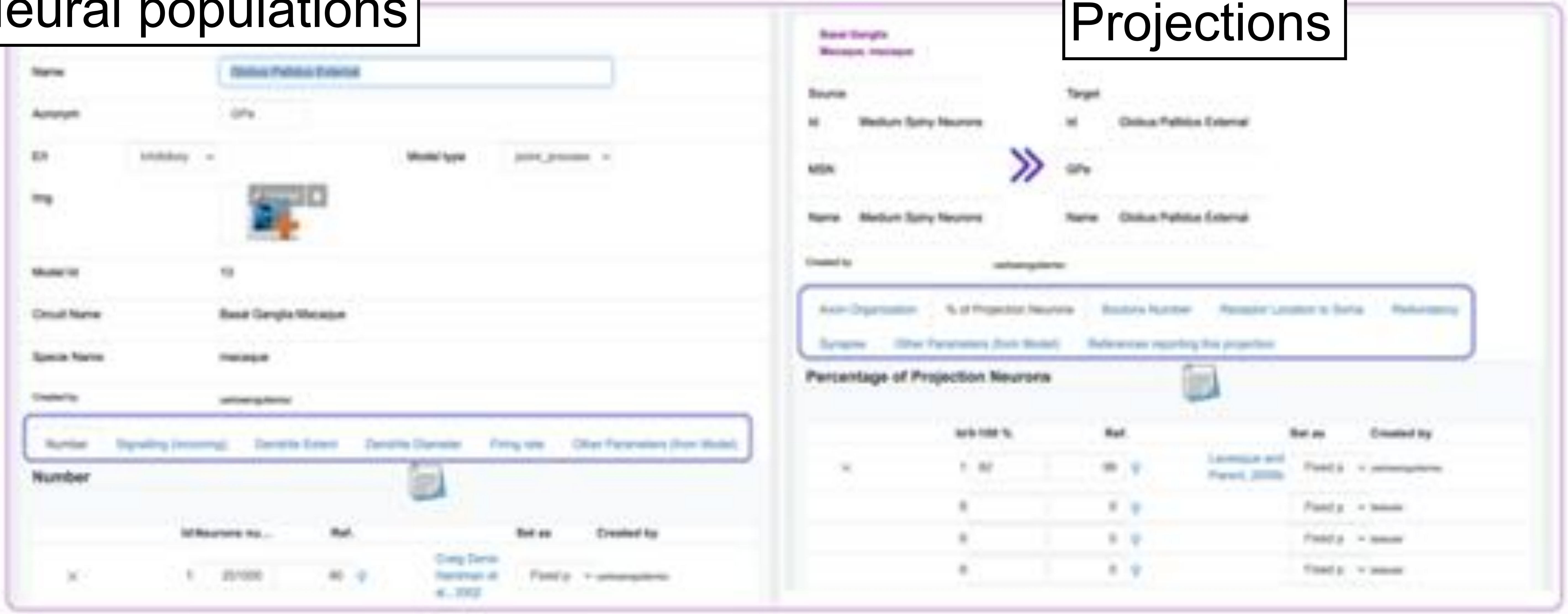
GUI

Model creation

Data organization

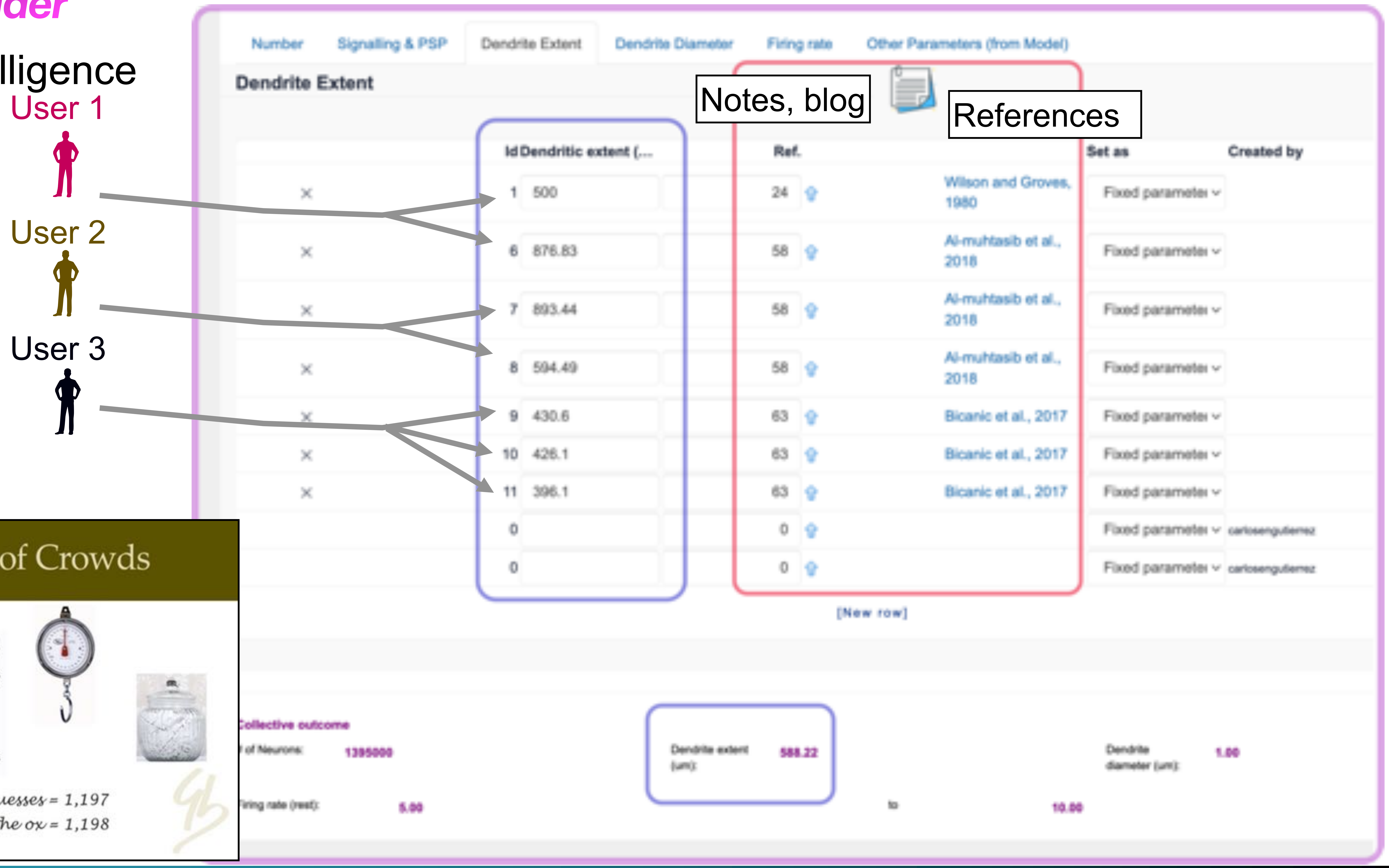
Neural populations

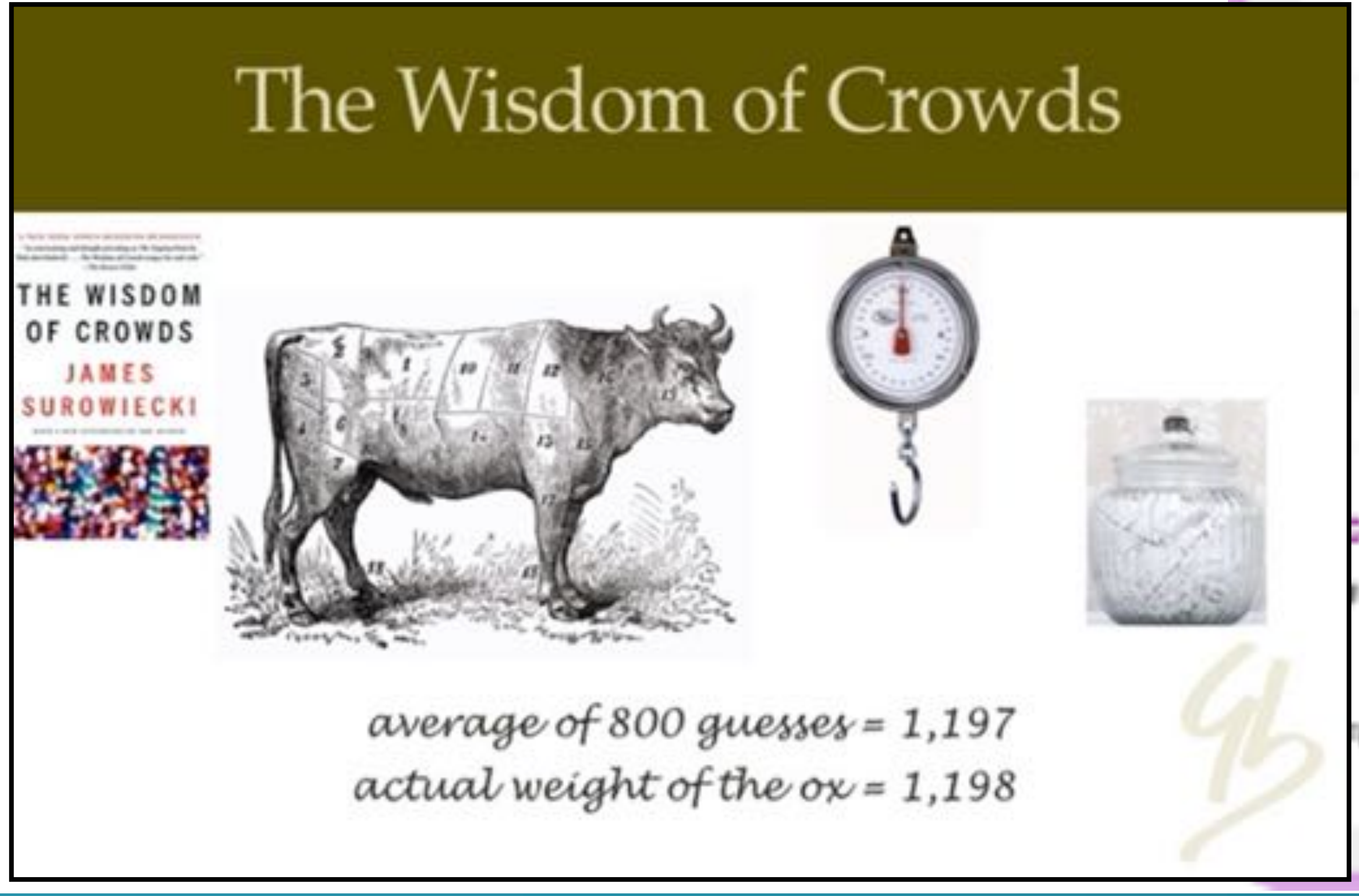
Projections



SNNBuilder

Collective Intelligence

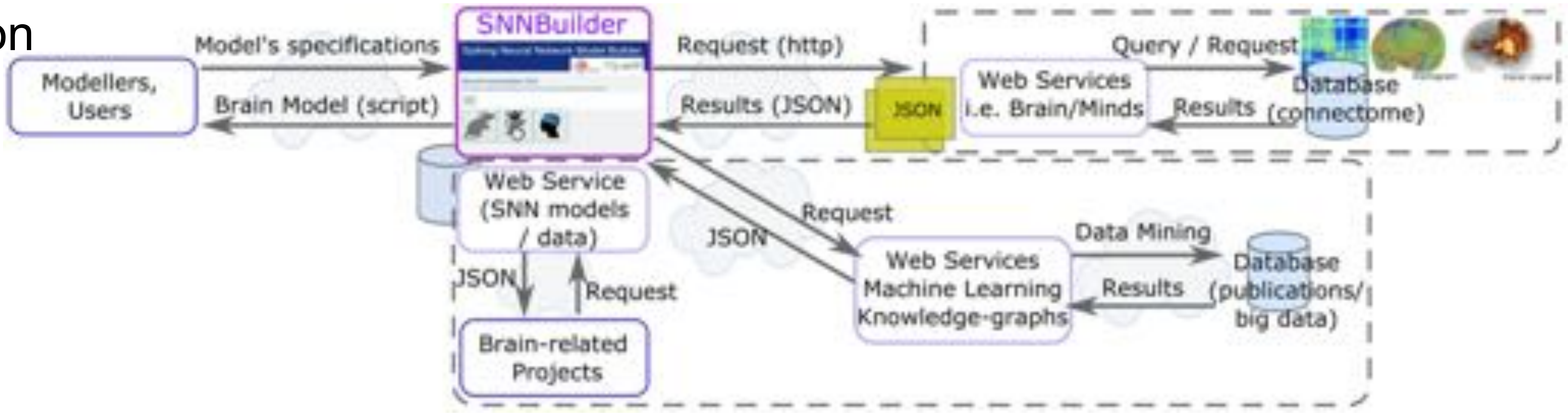




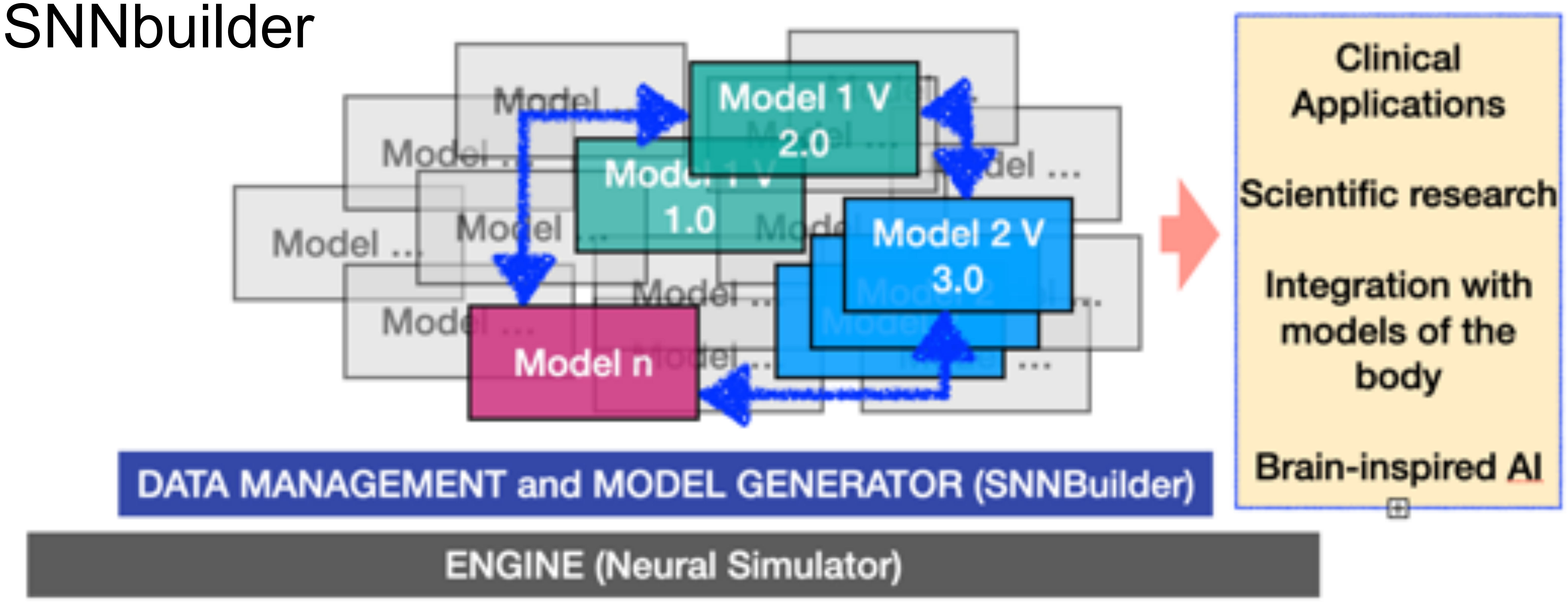
Future work

SNNbuilder integration with other systems and DBs
&
Online simulation

Brain/Minds



SNNbuilder



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NRP (Fabrice Morin & team)

Japan

OIST, RIKEN, UEC

Human Brain Project

EBRAINS

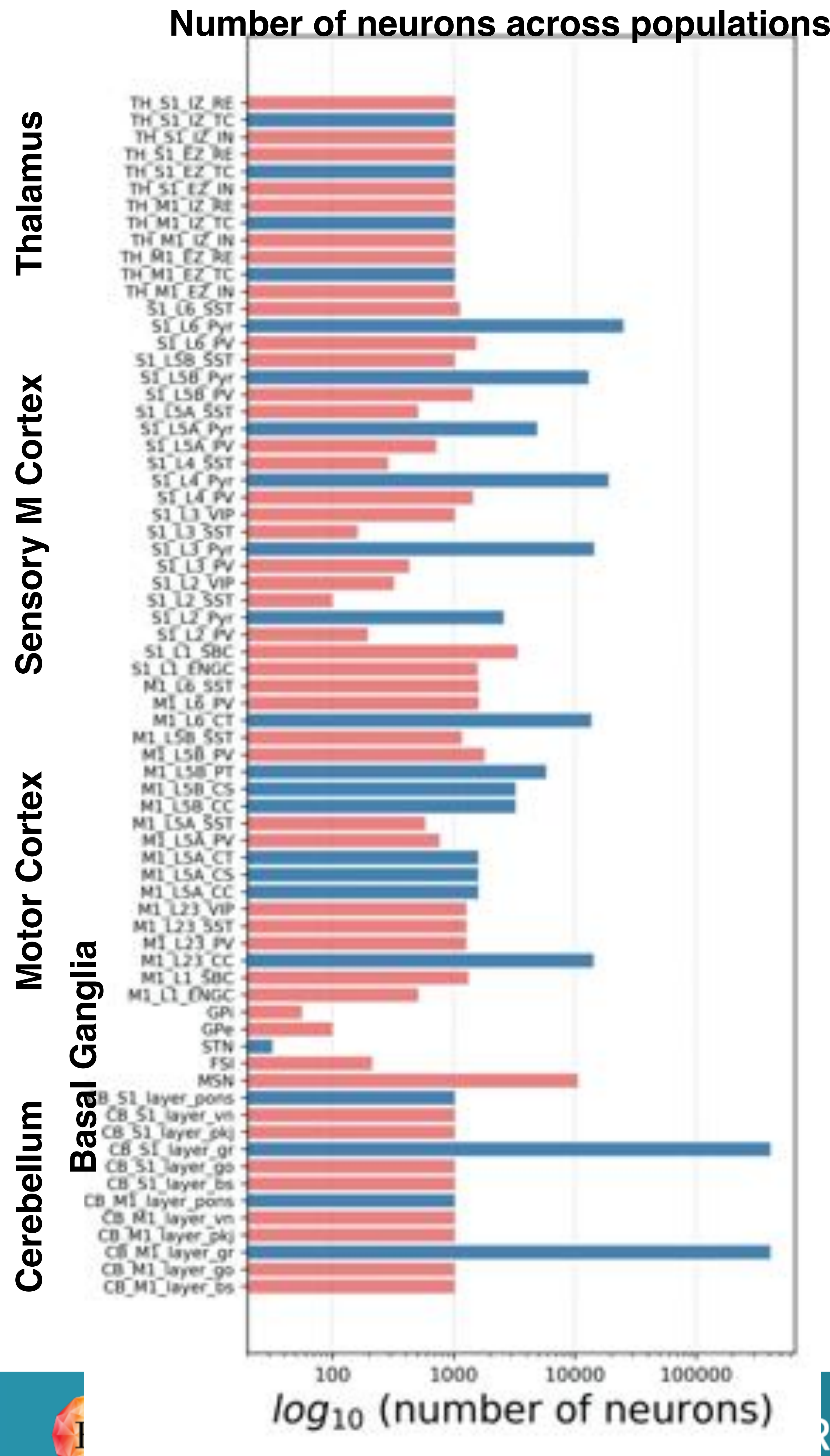
Thank you

www.humanbrainproject.eu

www.ebrains.eu

Co-funded by the European Union

Structure



Category	Region	#Neuron	#Layers	#Neuron types
Ctx	M1	58,805	5	19
	S1	94,396	7	21
TH	VL	8,192	2	4
	VM	8,192	2	4
BG	-	10,976	5	5
CB	M1	414,720	6	6
	S1	414,720	6	6
Total	-	1,010,001	33	65

[Yamazaki and Nagao, PLoS ONE 20...]