The NeuroML ecosystem for standardised multi-scale modelling in neuroscience

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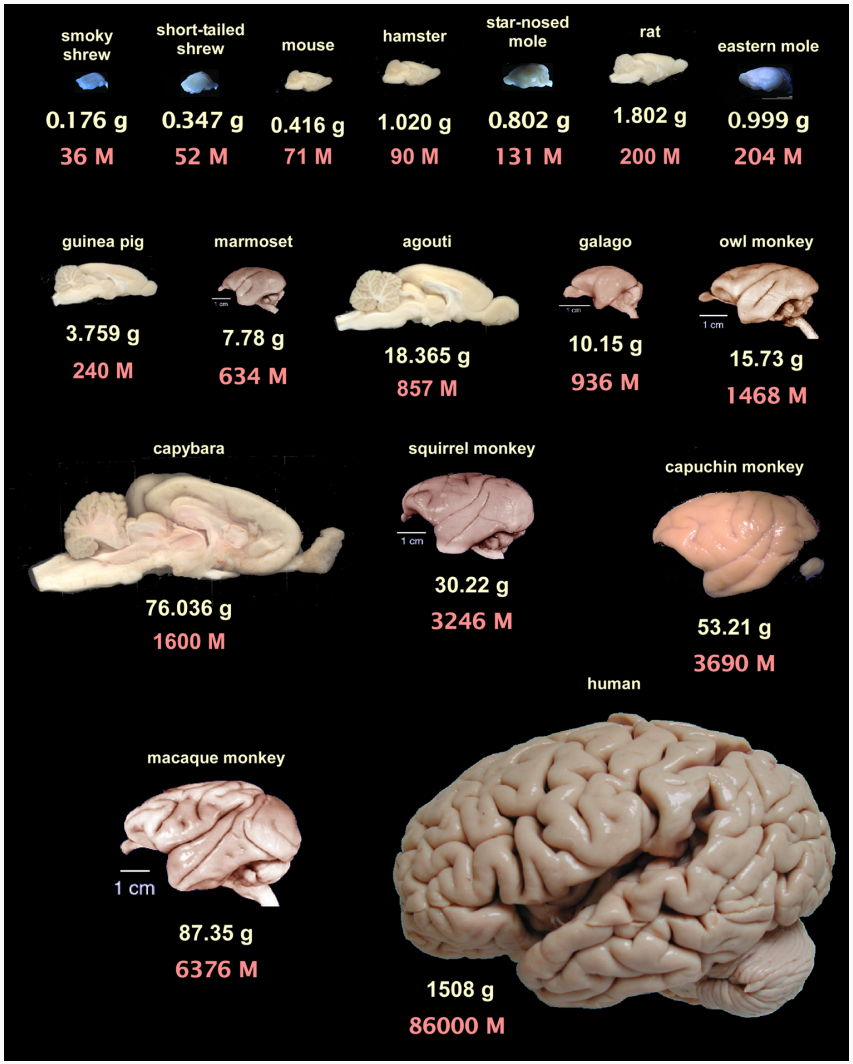
2024-05-10

An understanding of the brain



- ~86B neurons
- ~100T synapses
- also ~85B glia

[1] Herculano-Houzel, S. **The human brain in numbers: a linearly scaled-up primate brain.** *Frontiers in human neuroscience* **3,** 31 (2009)

[1] von Bartheld, C. S. *et al.* **The search for true numbers of neurons and glial cells in the human brain: A review of 150 years of cell counting.** *Journal of Comparative Neurology* **524,** 3865–3895. ISSN: 1096-9861 (June 2016)

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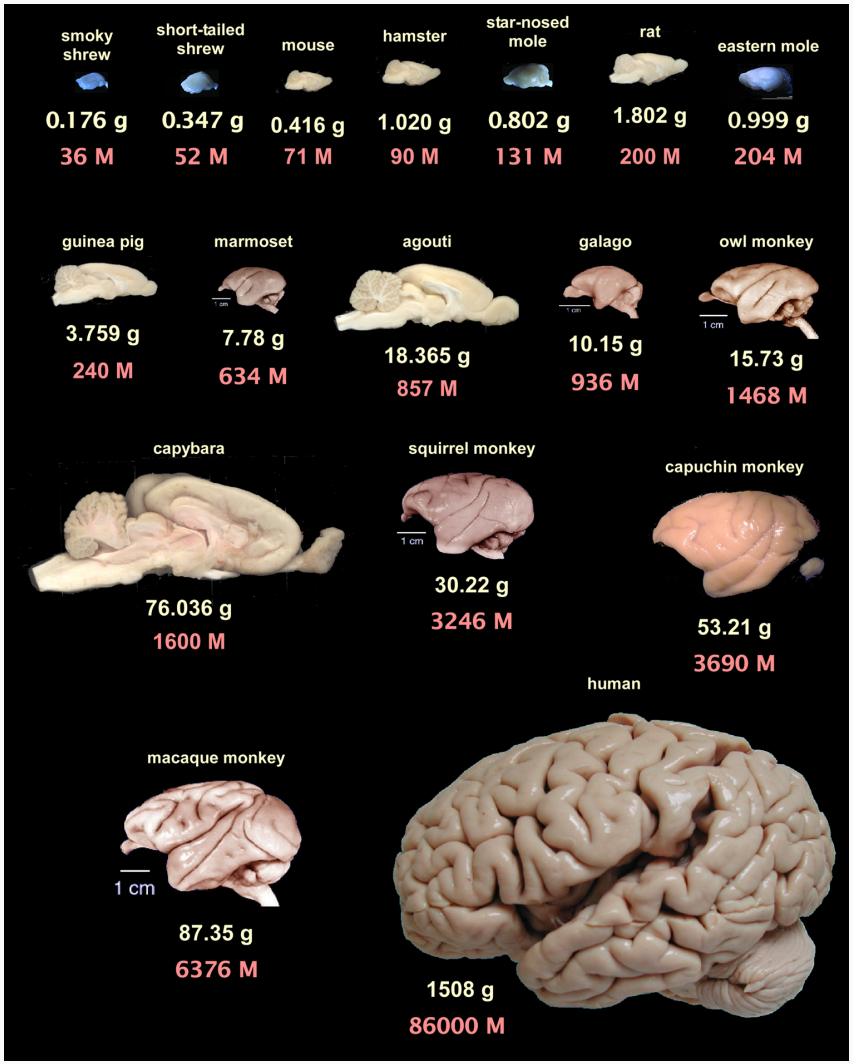

- specialised circuits
- different neuronal types
- synaptic connections
- complex sub-cellular processes

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Models complement experimental neuroscience

Models are fully observable, controllable.

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- Combine individual experimental results into unified theories
- Explore generalisability of experimental results over wider range of conditions
- Generate new experimentally testable, physically plausible hypotheses: dictate experiment design

Models: different scales

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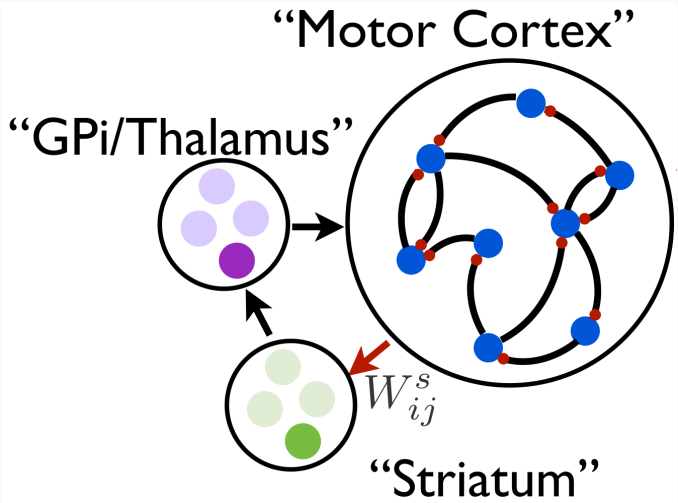

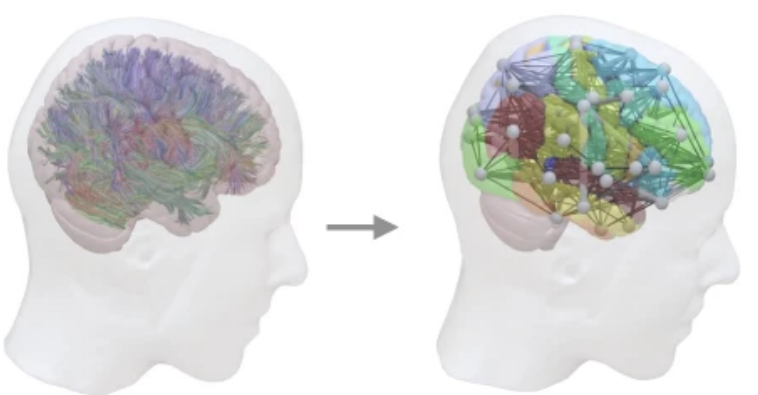

[1] Murray, J. M. **Local online learning in recurrent networks with random feedback.** *eLife* **8** (eds Latham, P. *et al.*) e43299. ISSN: 2050-084X (2019)

[1] Schirner, M. *et al.* **Learning how network structure shapes decision-making for bio-inspired computing.** *Nature Communications* **14.** ISSN: 2041-1723 (May 2023)

[1] Yao, H. K. *et al.* **Reduced inhibition in depression impairs stimulus processing in human cortical microcircuits.** *Cell Reports* **38.** ISSN: 2211-1247. https://doi.org/10.1016/j.celrep.2021.110232 (Jan. 2022)

[1] Mäki-Marttunen, T. *et al.* **A unified computational model for cortical post-synaptic plasticity.** *eLife* **9** (eds Shouval, H. Z. *et al.*) e55714. ISSN: 2050-084X. https://doi.org/10.7554/eLife.55714 (July 2020)

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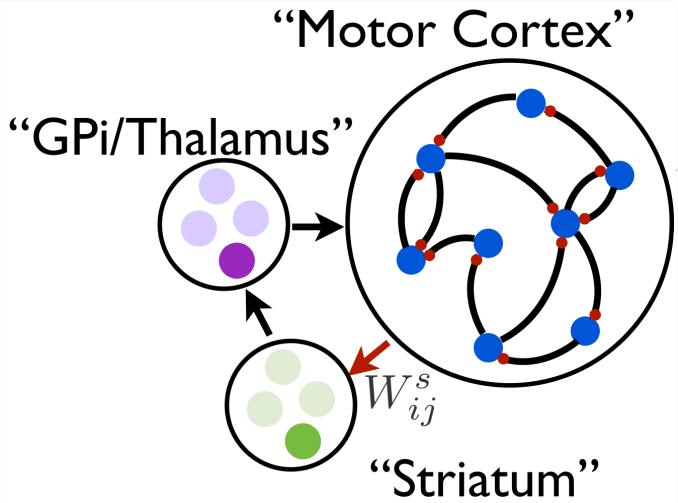

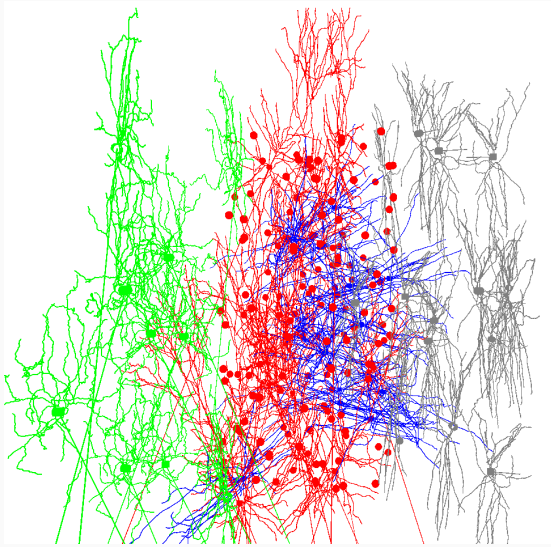

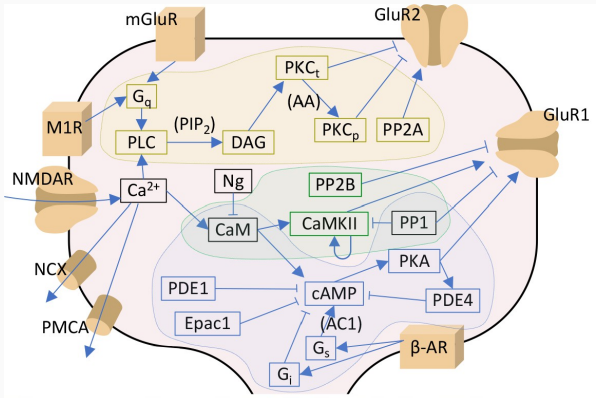

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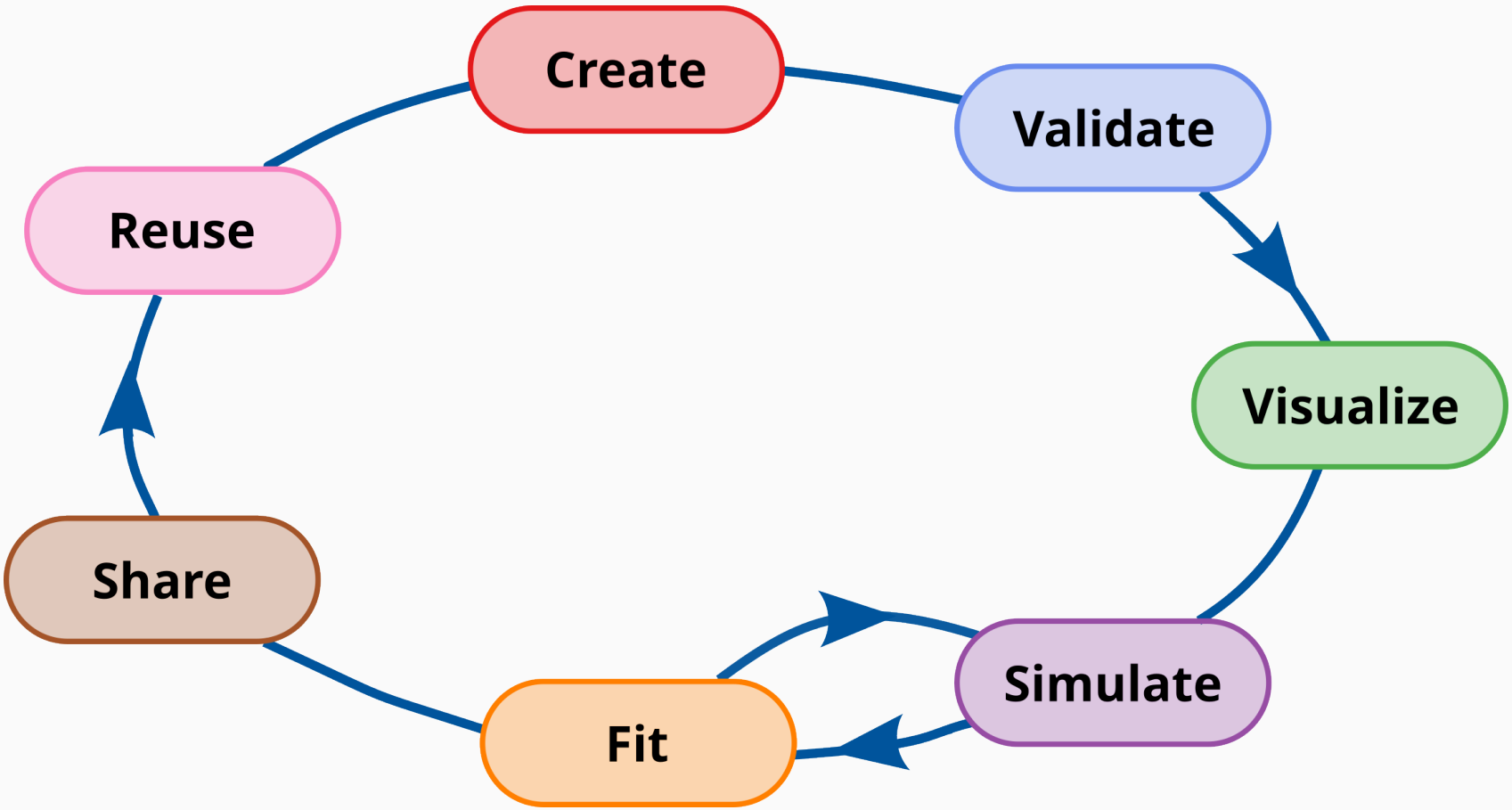
A *mechanistic* understanding of the brain requires biophysically detailed modelling

The model life cycle



Computational modelling software ecosystem is fragmented

- many specialist tools:
  - NEURON, NEST, Brian, GENESIS, MOOSE, STEPS, ANNarchy, TVB, LFPy, NeuroLib, EDEN, Arbor, NetPyNE...

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  - custom machine readable internal representations:
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  - not well defined model descriptions:
    - models cannot be easily validated
  - custom machine readable internal representations:
    - models cannot be easily inspected/analysed
  - ad-hoc utilities:
    - cannot be used with all tools

Makes computational neuroscience models

less

FAIR

(Findable, Accessible, Interoperable, Reusable)

Standards enable FAIR neuroscience

COMBINE

[1] Abrams, M. B. *et al.* **A Standards Organization for Open and FAIR Neuroscience: the International Neuroinformatics Coordinating Facility.** *Neuroinformatics* **20,** 25–36. ISSN: 1559-0089. https://doi.org/10.1007/s12021-020-09509-0 (2022): https://incf.org

[1] COmputational Modeling in BIology NEtwork (COMBINE): https://co.mbine.org/

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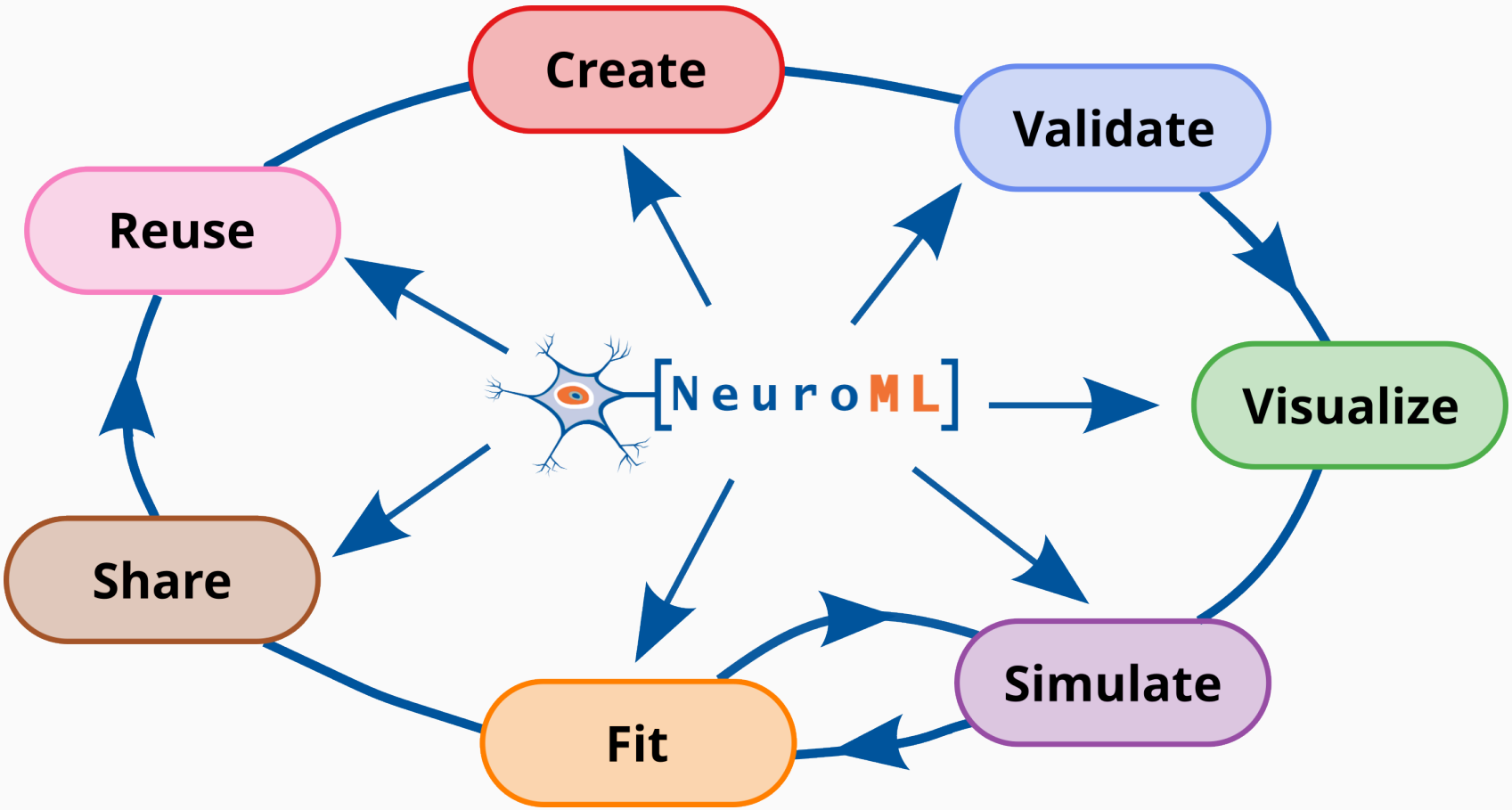
NeuroML ecosystem supports all stages of the model cycle



NeuroML ecosystem

- standard/specification
- software ecosystem

NeuroML standard

Model specification (schema: XSD)

- elements
- attributes
- hierarchical relationships

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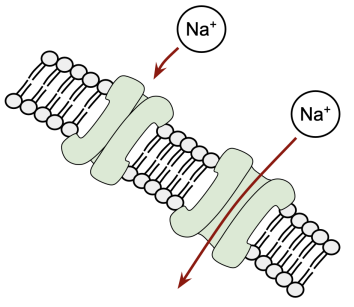
Dynamics (LEMS component type definitions)

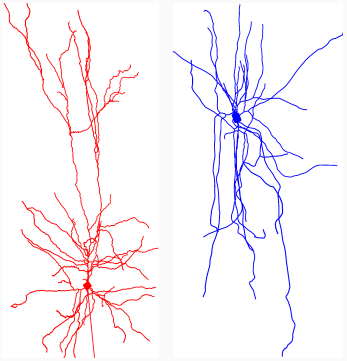
- dynamical behaviour

NeuroML is declarative, modular, structured, hierarchical

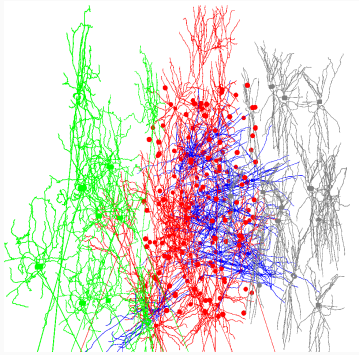
Conductances

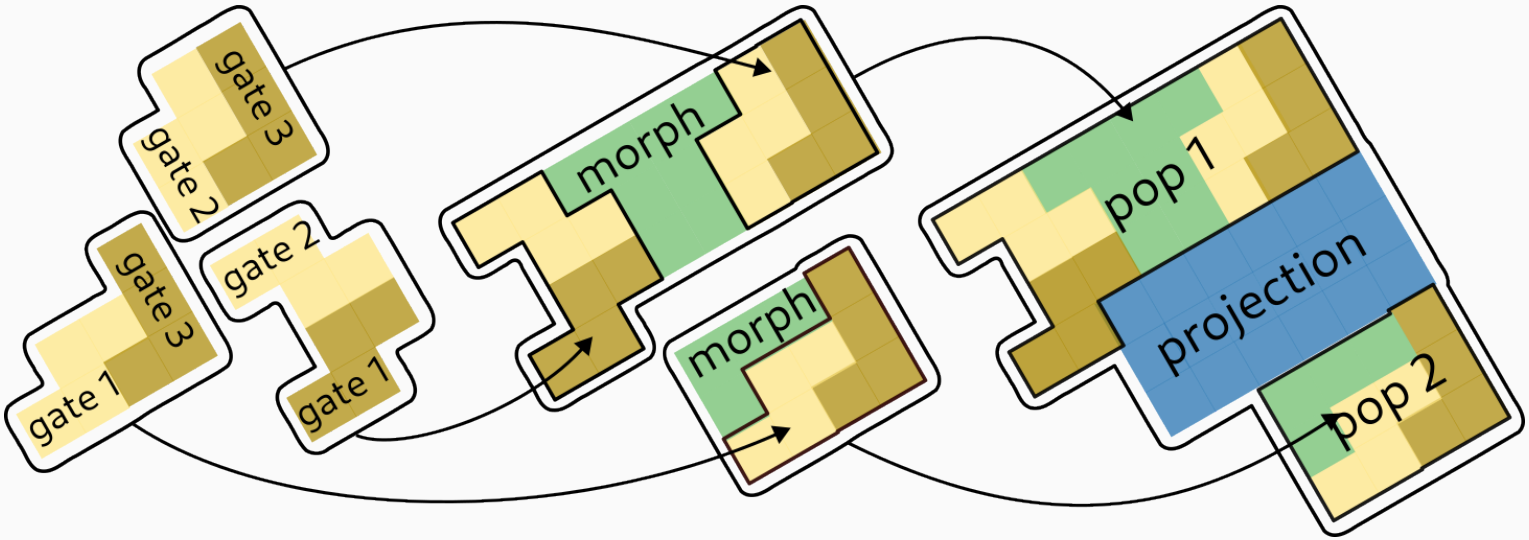


Cells

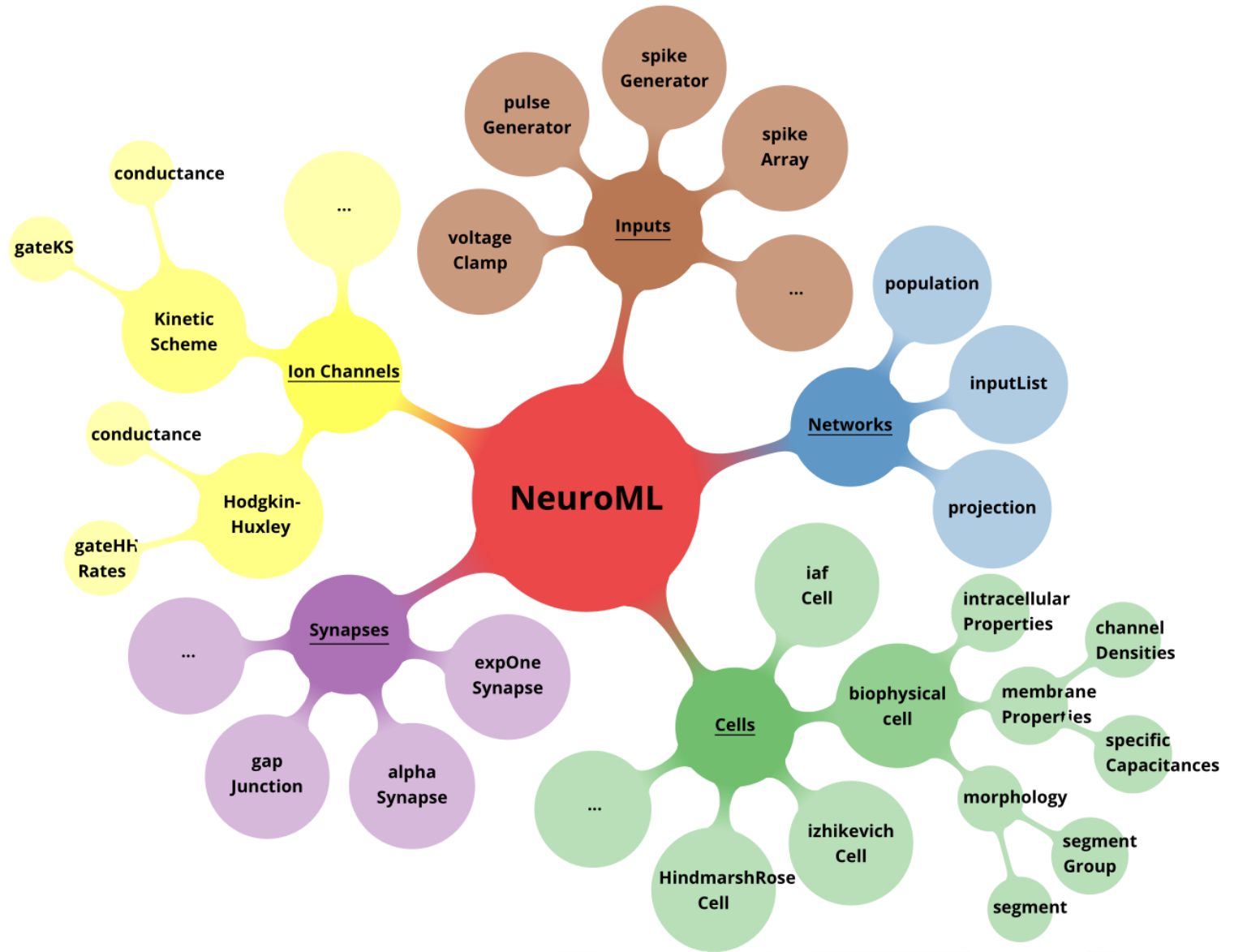


Networks



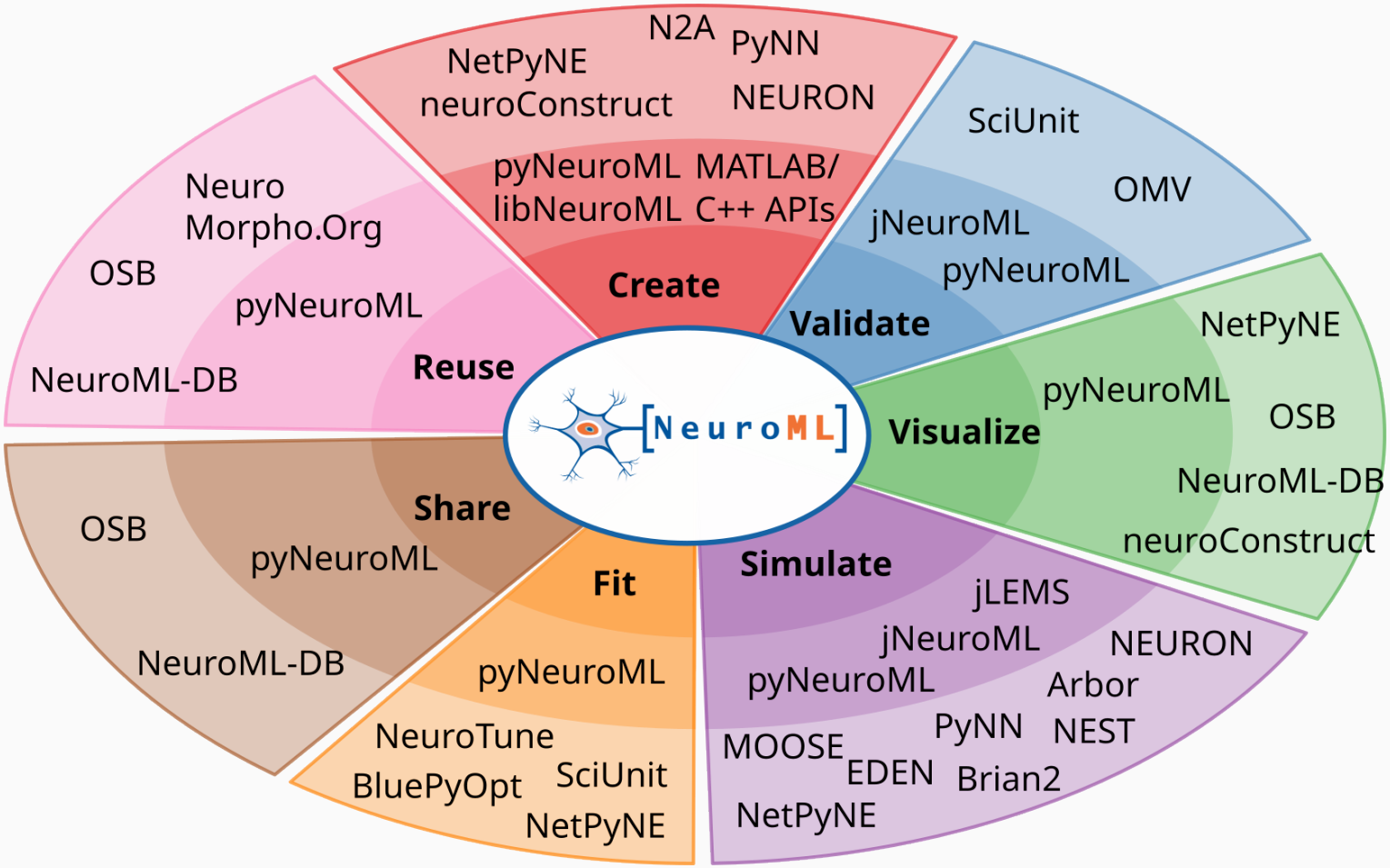


NeuroML provides users with a set of curated model elements

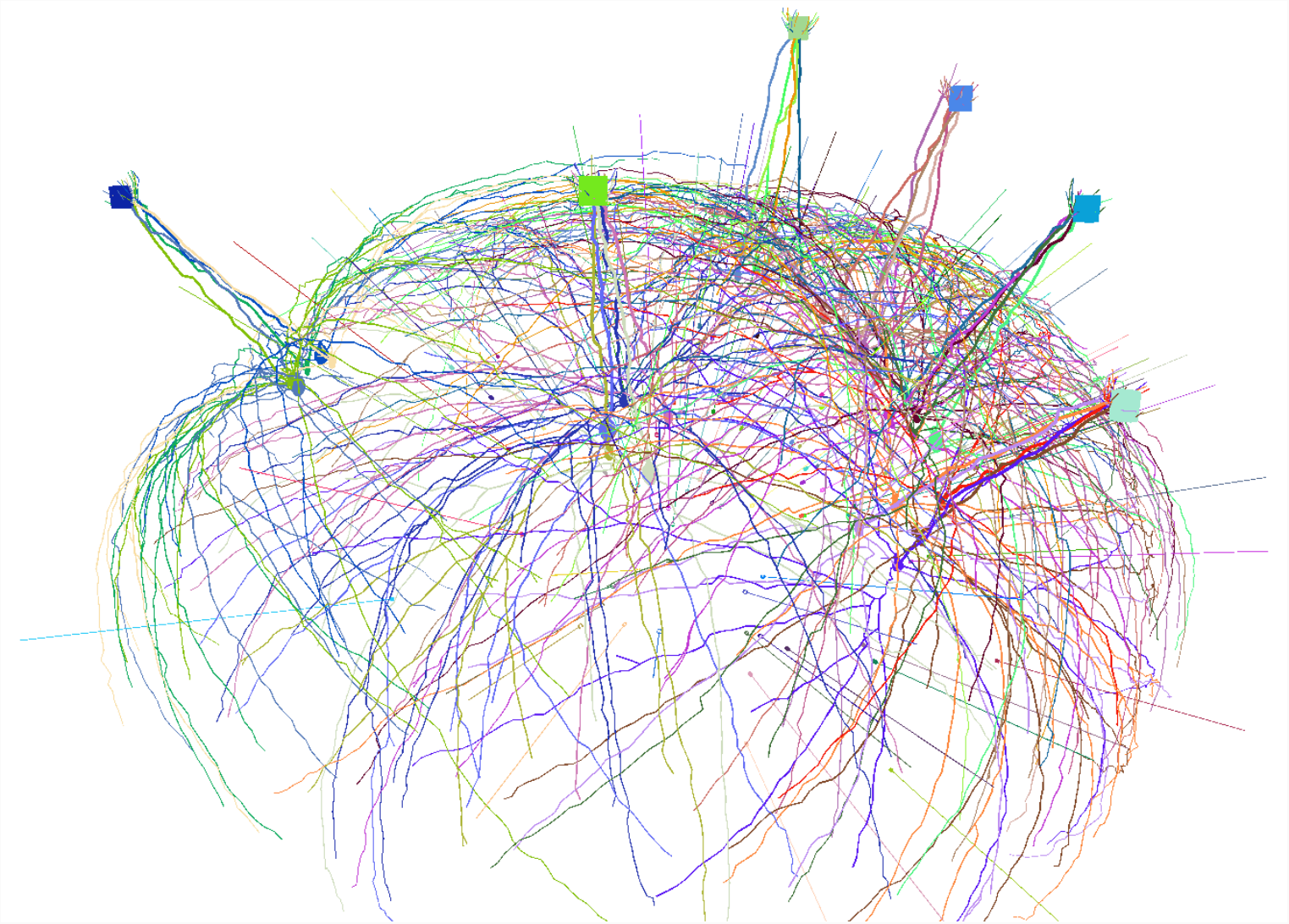


[1] Full standard is at: https://docs.neuroml.org/Userdocs/Specification.html

NeuroML software ecosystem



NeuroML: visualising/analysing models



[1] 3D interactive visualisation of Migliore *et al.* [8] using `pynml-plotmorph`

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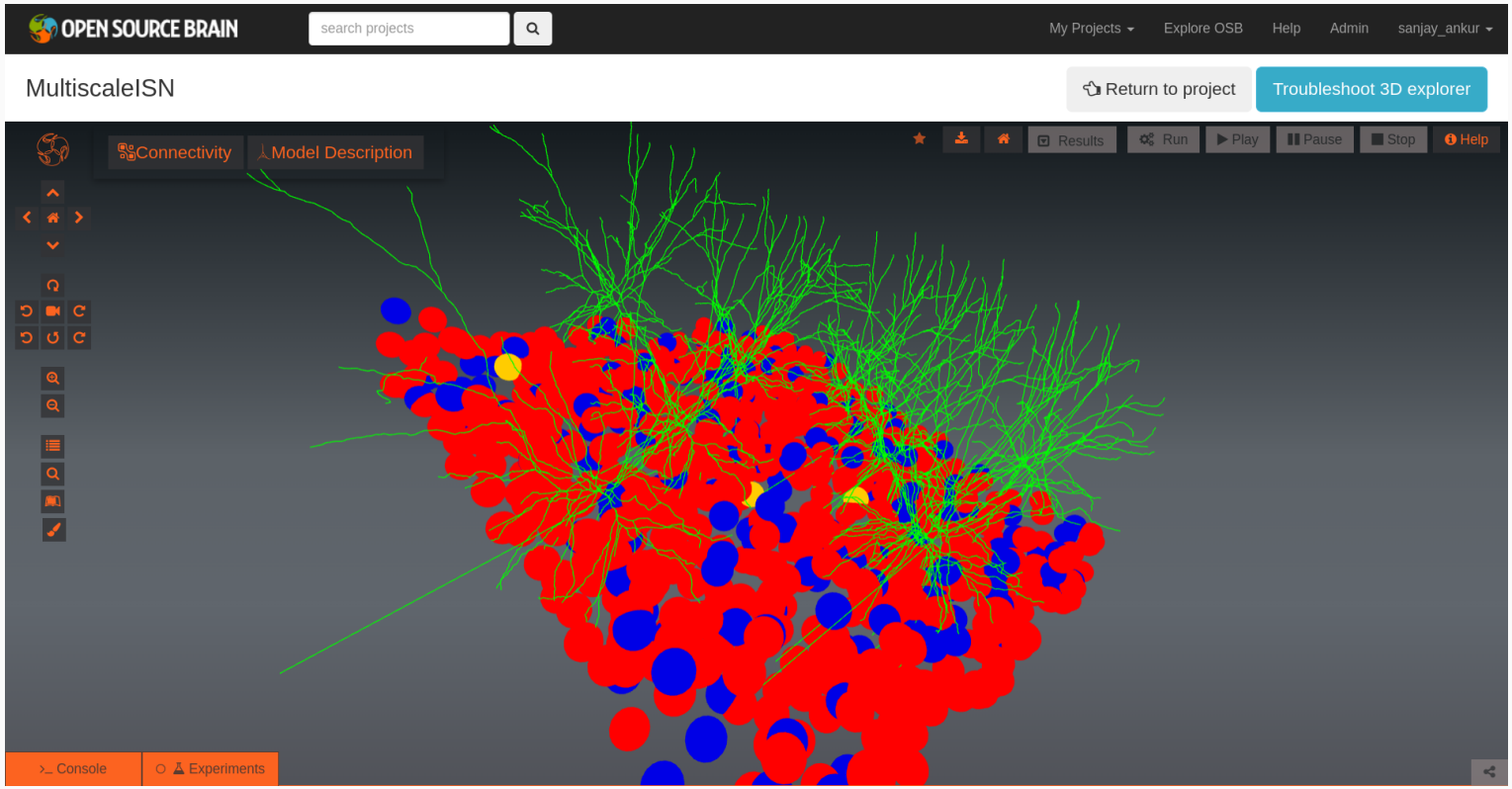

[1] 3D interactive visualisation of Sadeh *et al.* [9] on Open Source Brain: https://v1.opensourcebrain.org

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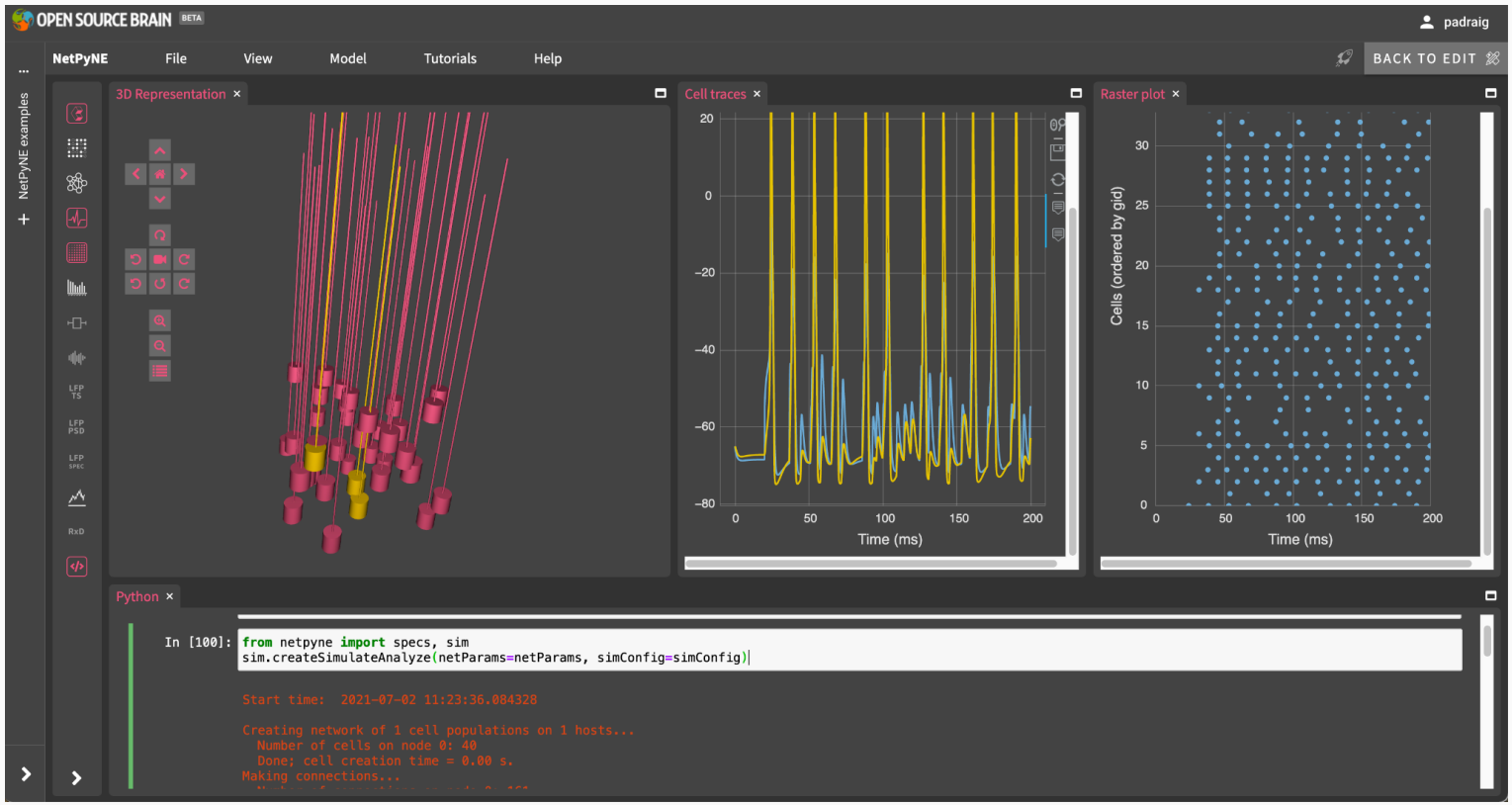

[1] 3D interactive visualisation using NetPyNE-UI on Open Source Brain v2: https://opensourcebrain.org

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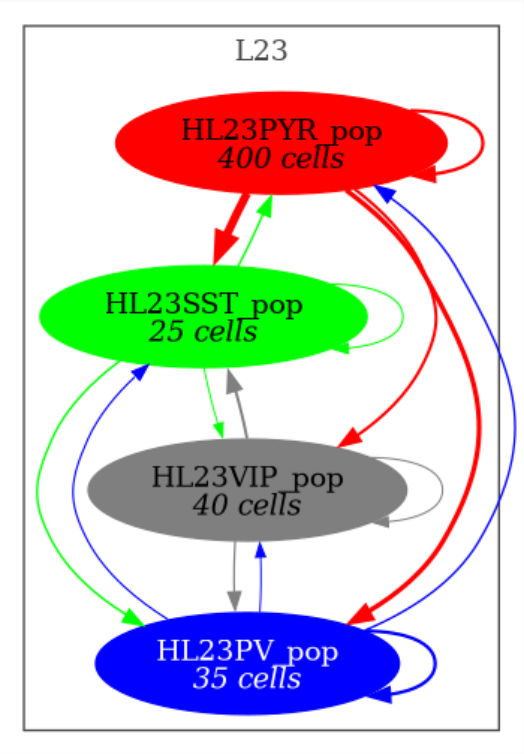

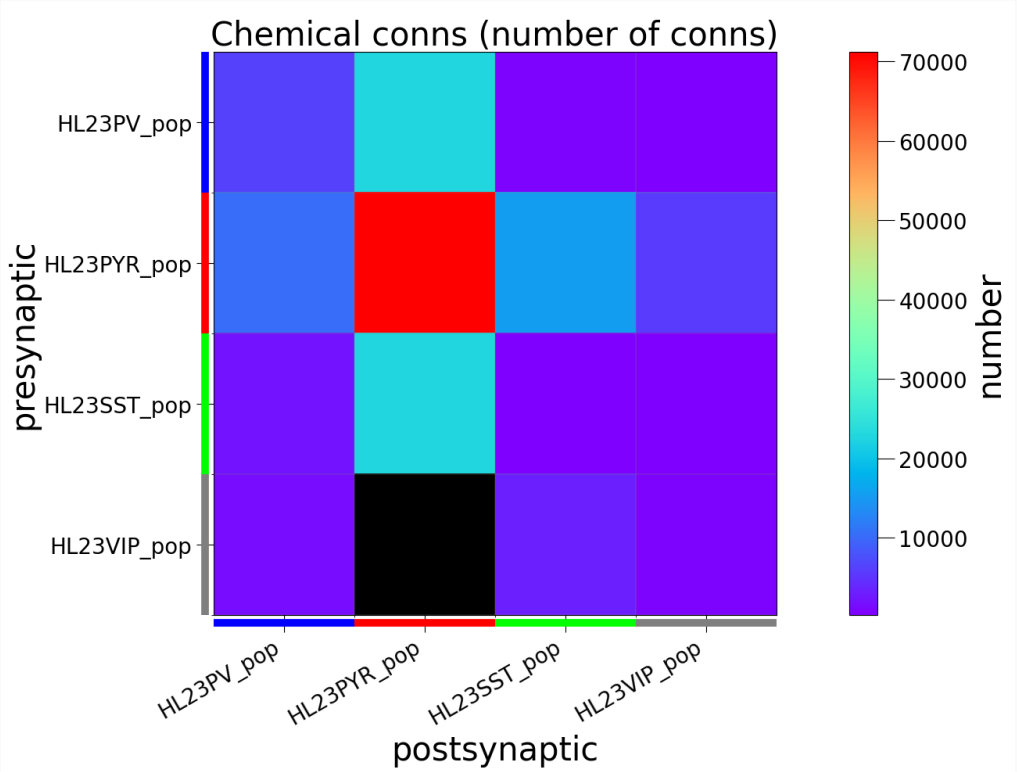

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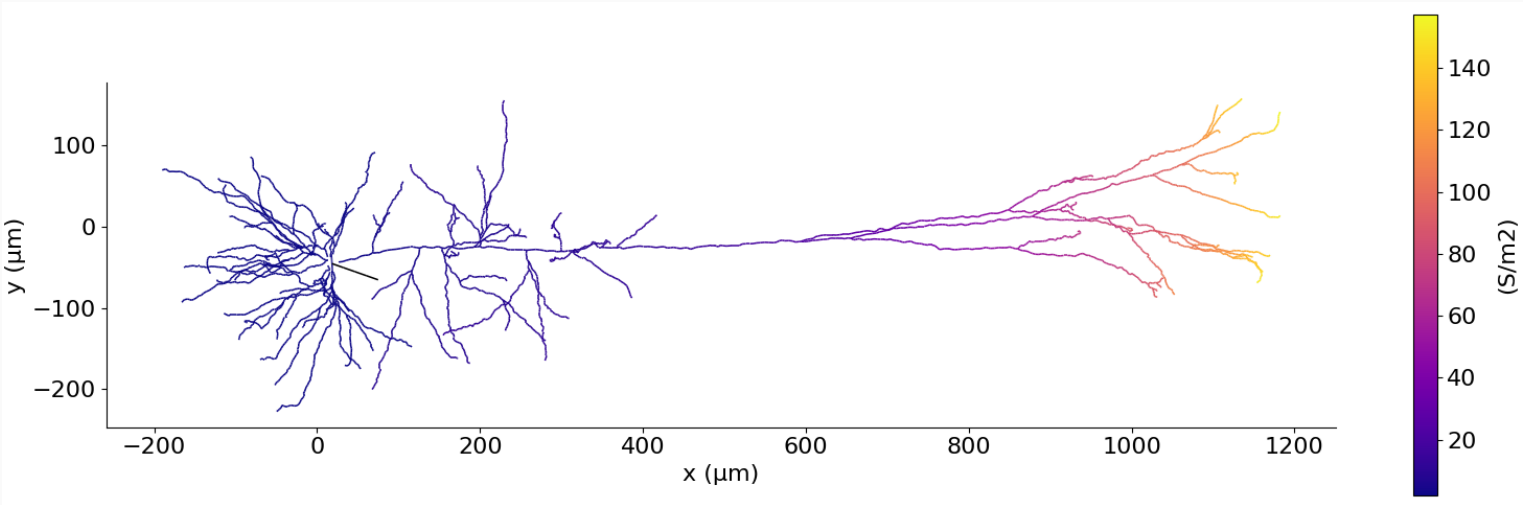
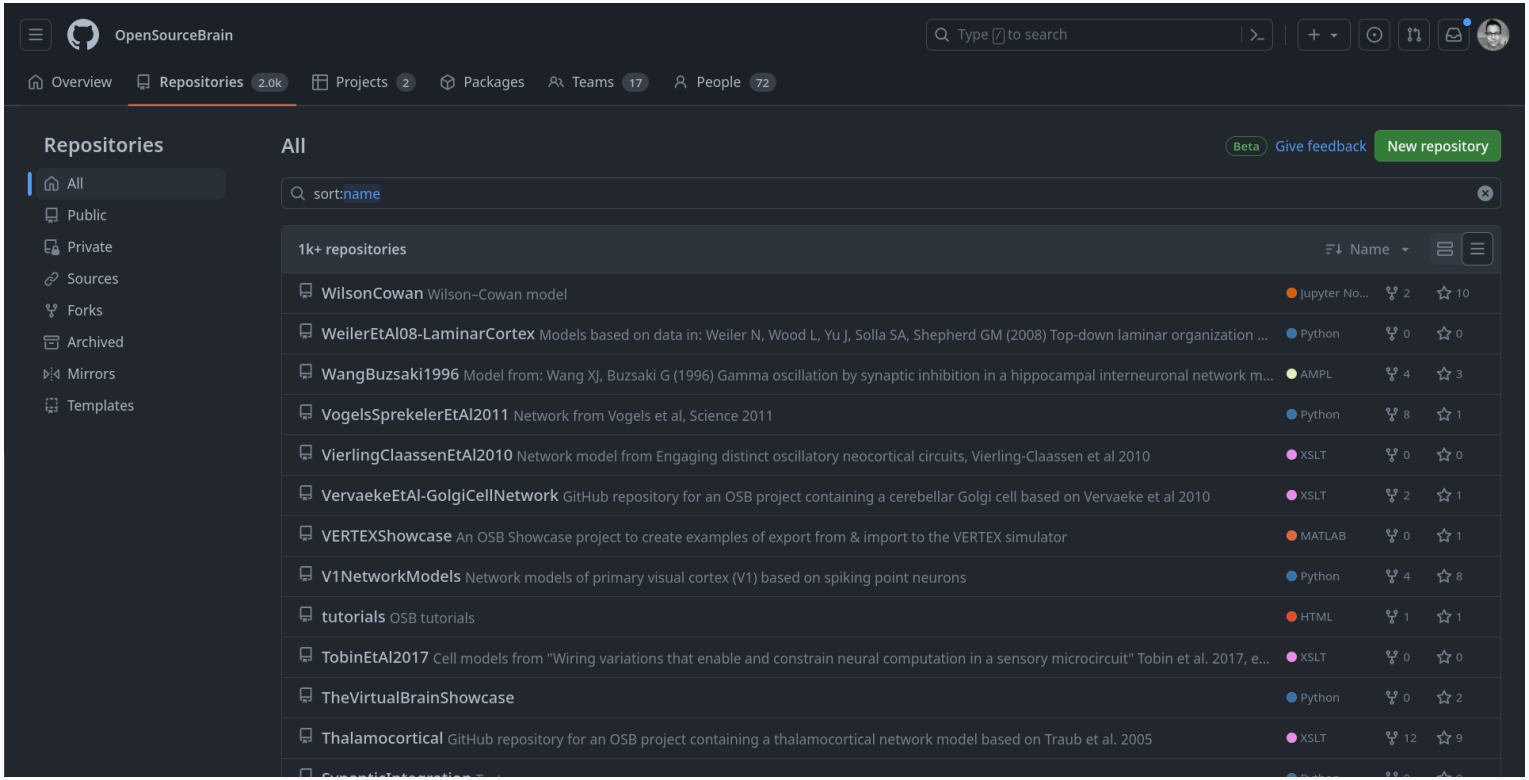
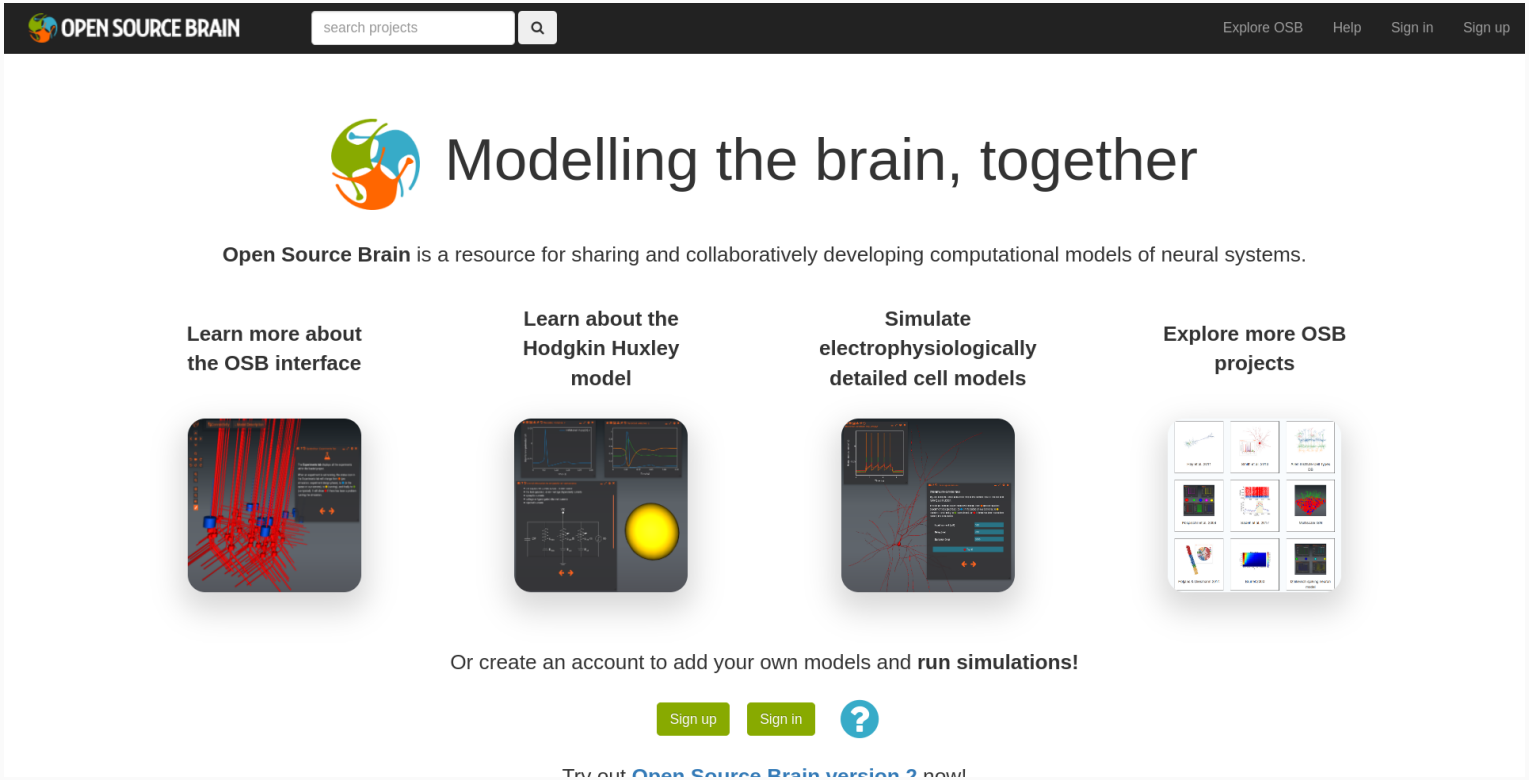


NeuroML: sharing and re-using models



[1] Standardized models on Github: Open Source Brain: https://github.com/OpenSourceBrain

NeuroML: sharing and re-using models



[1] Standardized models on Open Source Brain v1: https://v1.opensourcebrain.org

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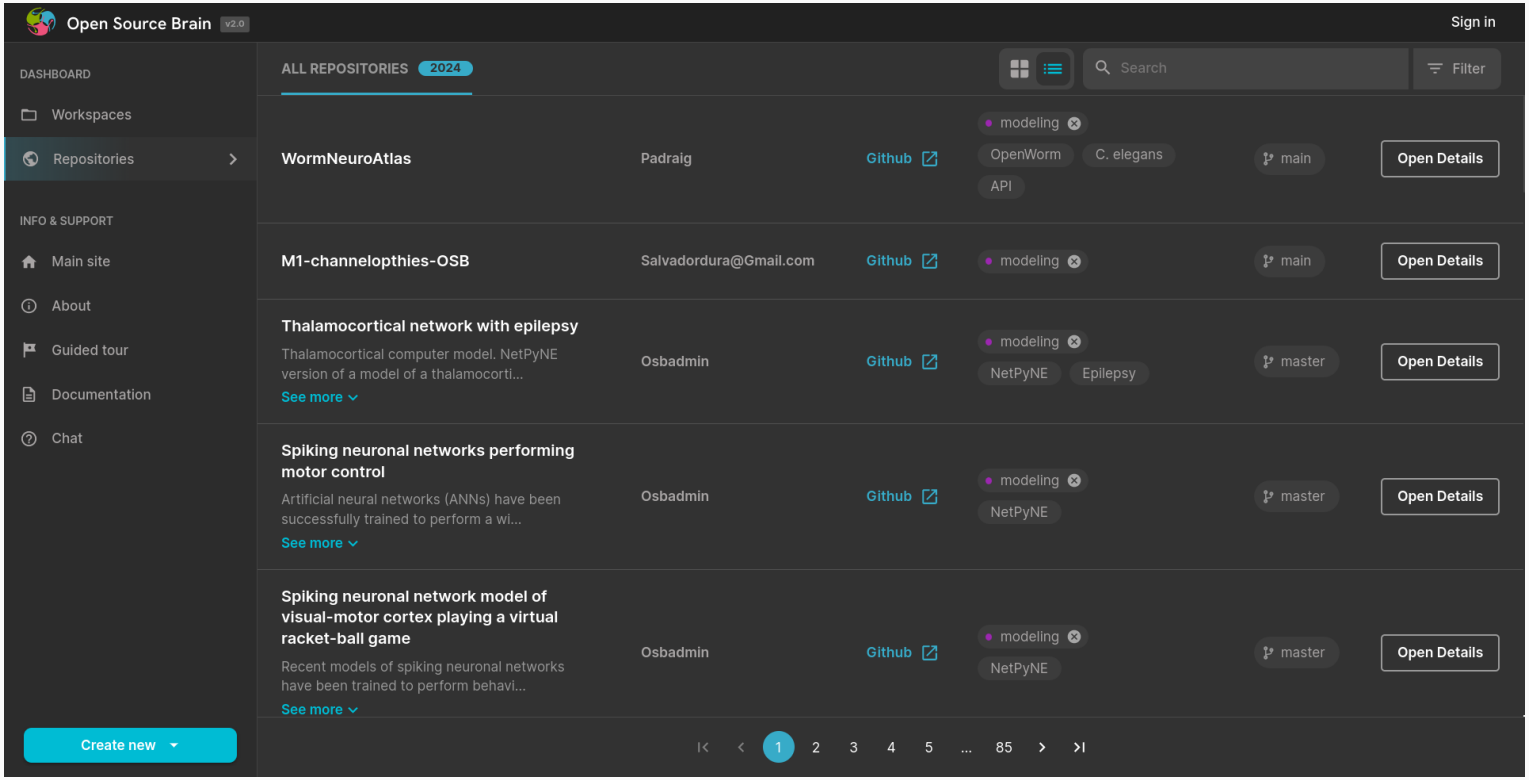

[1] Standardized models on Open Source Brain v2: https://v2.opensourcebrain.org

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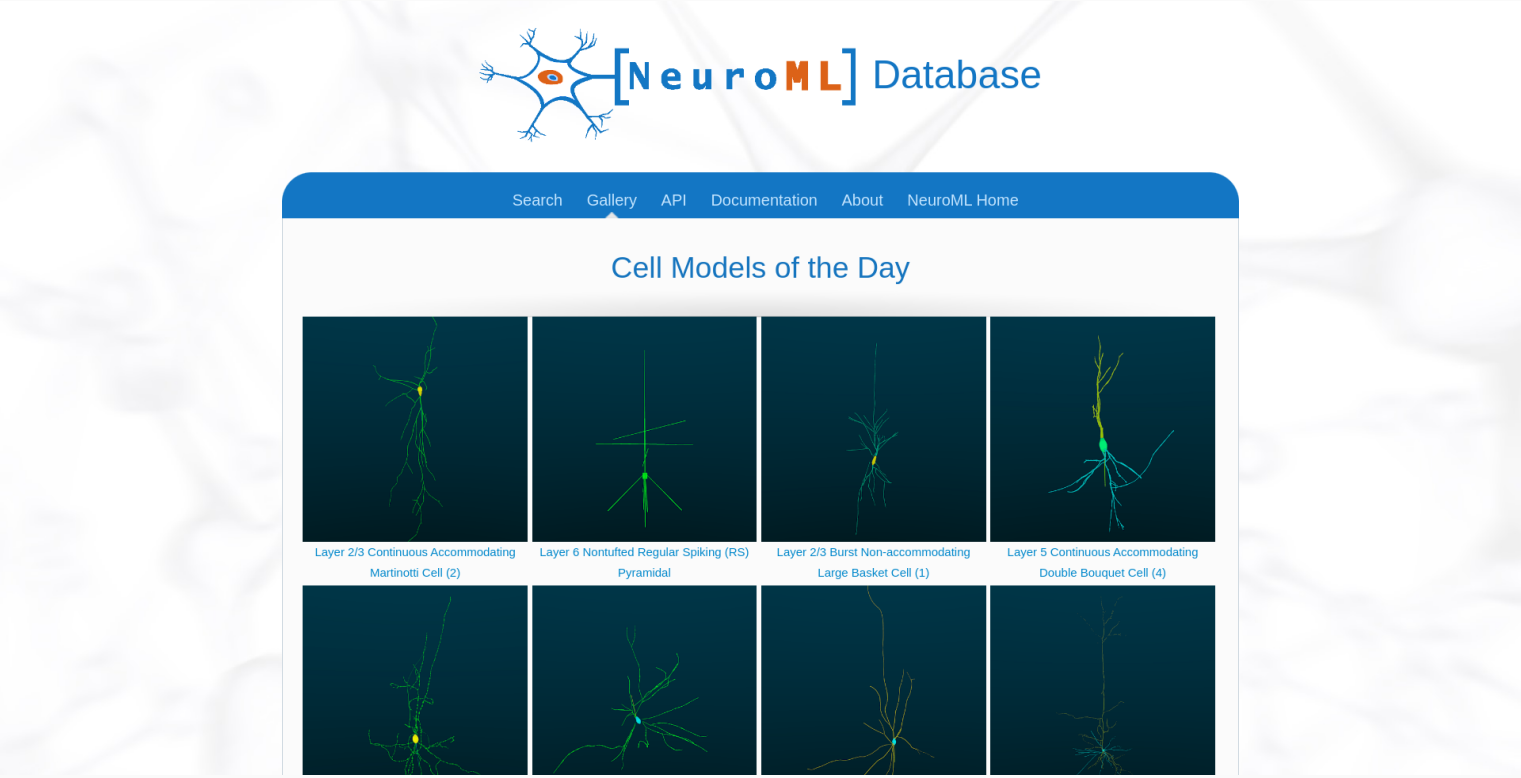

[1] Standardized models on NeuroML-DB: https://neuroml-db.org

NeuroML: resources

Sinha, A. *et al.* **The NeuroML ecosystem for standardized multi-scale modeling in neuroscience.** *bioRxiv.* eprint: https://www.biorxiv.org/content/early/2023/12/11/2023.12.07.570537.full.pdf. https://www.biorxiv.org/content/early/2023/12/11/2023.12.07.570537 (2023)(in review)

https://docs.neuroml.org

https://opensourcebrain.org