

The NeuroML ecosystem for standardised multi-scale modelling in neuroscience

Ankur Sinha

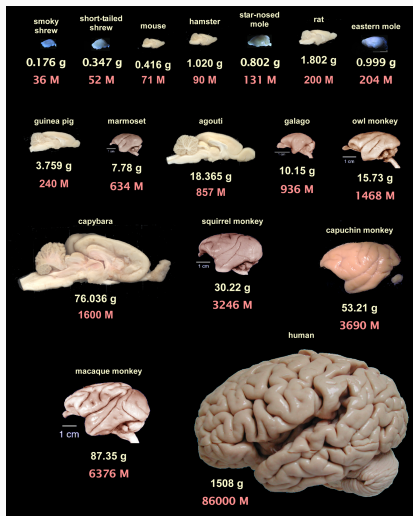
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University College London

2024-05-10

An understanding of the brain

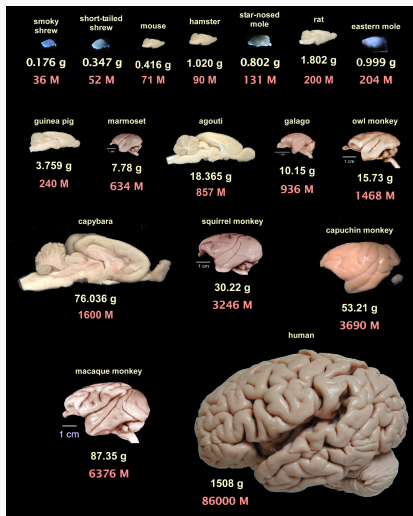


- ~86B neurons
- ~100T synapses
- also ~85B glia

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

¹von 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)

An understanding of the brain



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

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Models are fully **observable, controllable**.

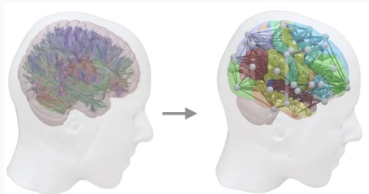
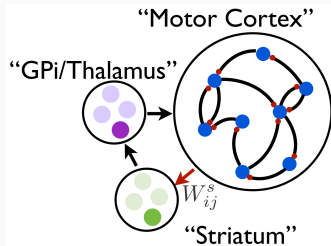
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- Combine individual experimental results into **unified theories**
- Explore **generalisability** of experimental results over wider range of conditions
- **Generate** new experimentally testable, physically plausible hypotheses: **dictate experiment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

Models: different scales

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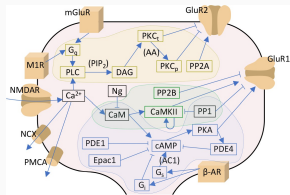
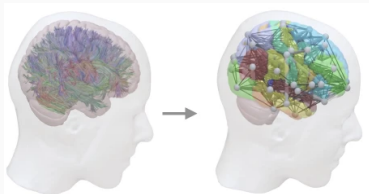
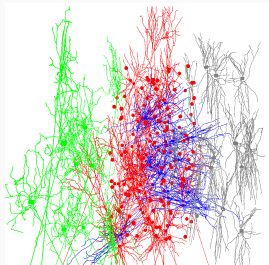
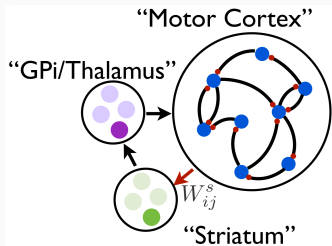
¹ Murray, J. M. Local online learning in recurrent networks with random feedback. *eLife* 8 (eds Latham, P. et al.) e43299. issn: 2050-084X (2019)

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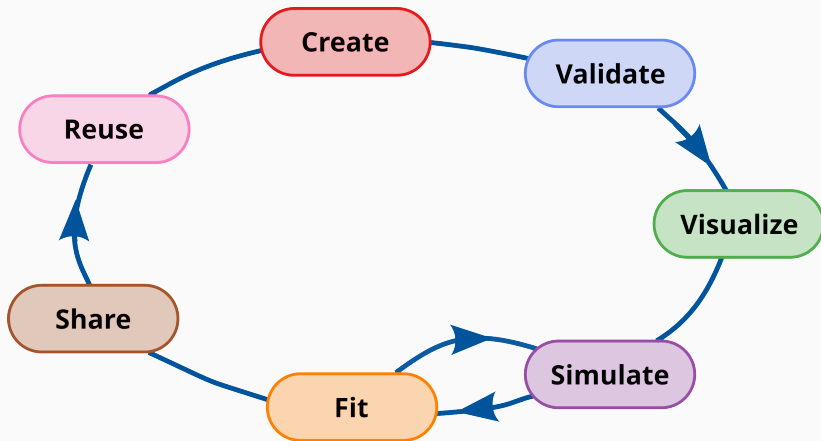
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A *mechanistic* understanding of the brain
requires **biophysically detailed** modelling

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:
 - models cannot be easily inspected/analysed

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- **but:**
 - different APIs, syntax:
 - increased difficulty for users
 - 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/>

Standards enable FAIR neuroscience



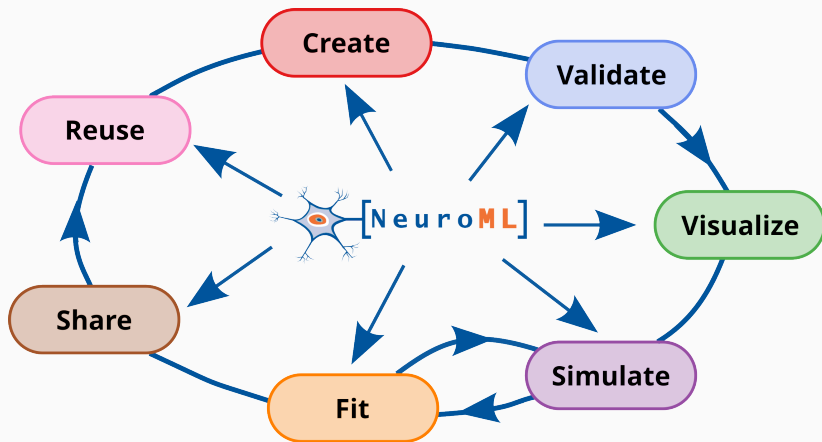
COMBINE



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NeuroML ecosystem supports all stages of the model cycle



- standard/specification
- software ecosystem

Model specification (**schema**: XSD)

- elements
- attributes
- hierarchical relationships

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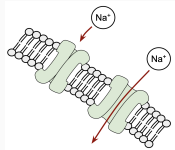
- elements
- attributes
- hierarchical relationships

Dynamics (**LEMS component type definitions**)

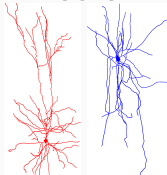
- dynamical behaviour

NeuroML is declarative, modular, structured, hierarchical

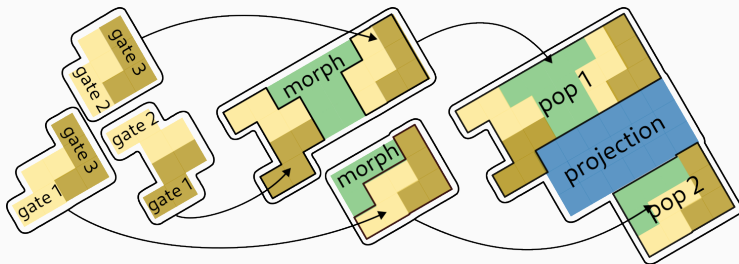
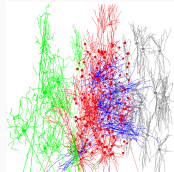
Conductances



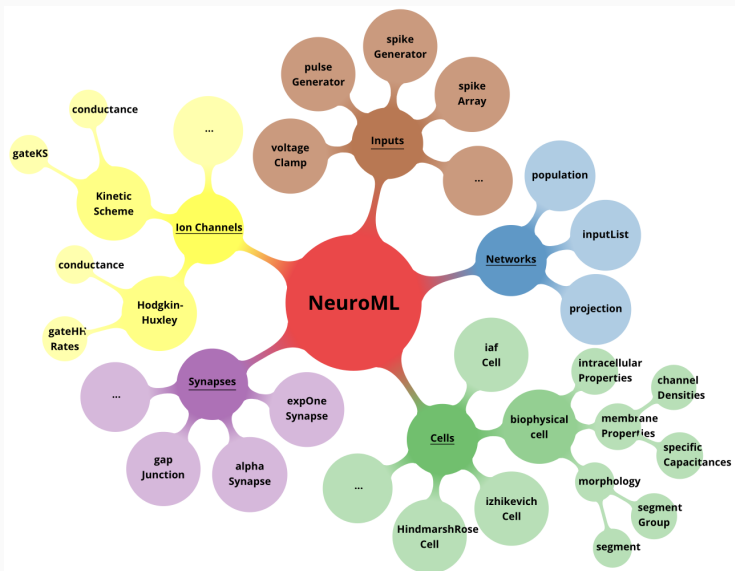
Cells



Networks

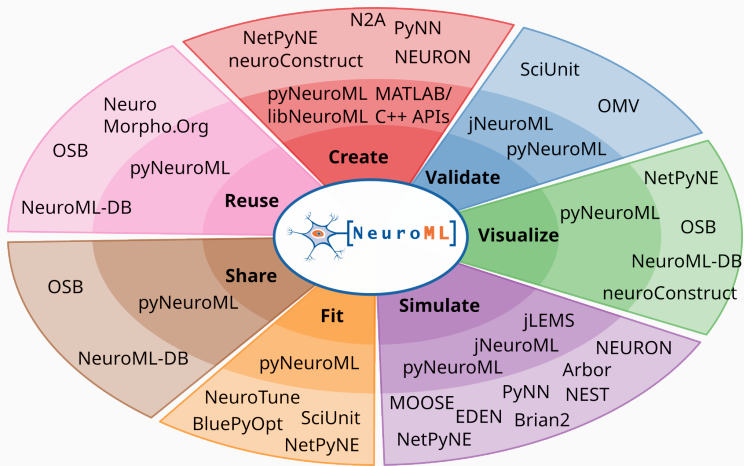


NeuroML provides users with a set of curated model elements

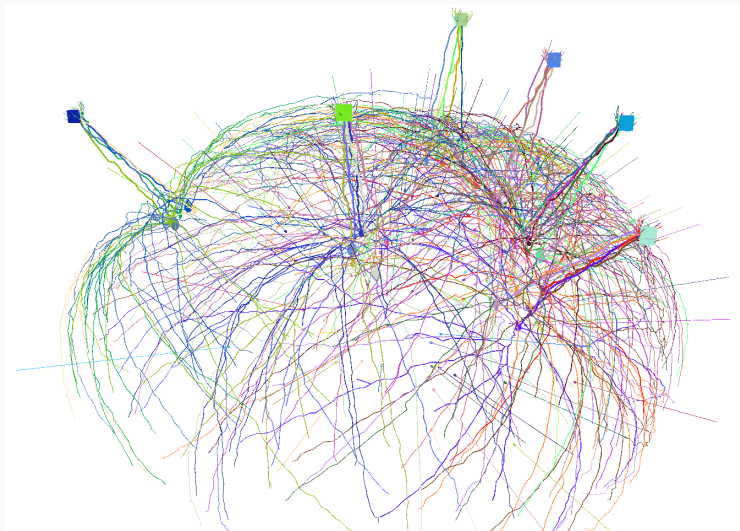


¹ Full standard is at: <https://docs.neuroml.org/Userdocs/Specification.html>

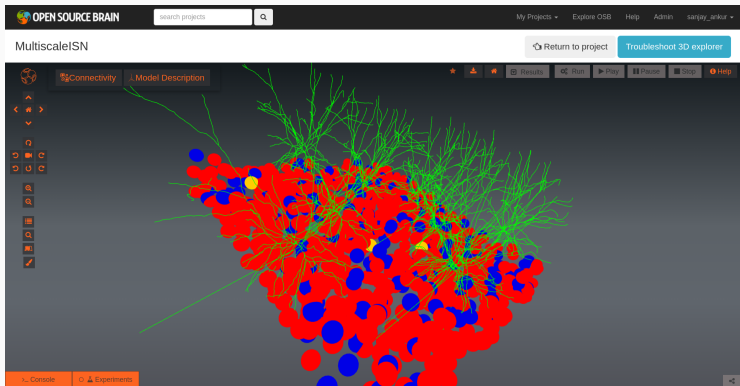
NeuroML software ecosystem



NeuroML: visualising/analysing models



NeuroML: visualising/analysing models



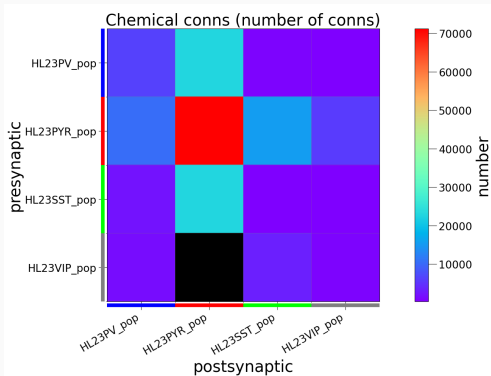
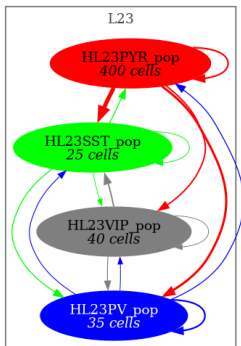
¹3D interactive visualisation of Sadeh *et al.* [9] on Open Source Brain: <https://v1.opensourcebrain.org>

NeuroML: visualising/analysing models

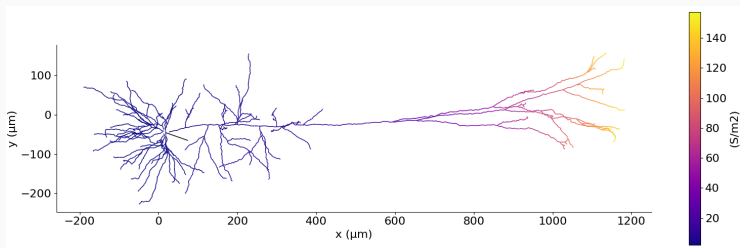


¹3D interactive visualisation using NetPyNE-UI on Open Source Brain v2: <https://opensourcebrain.org>

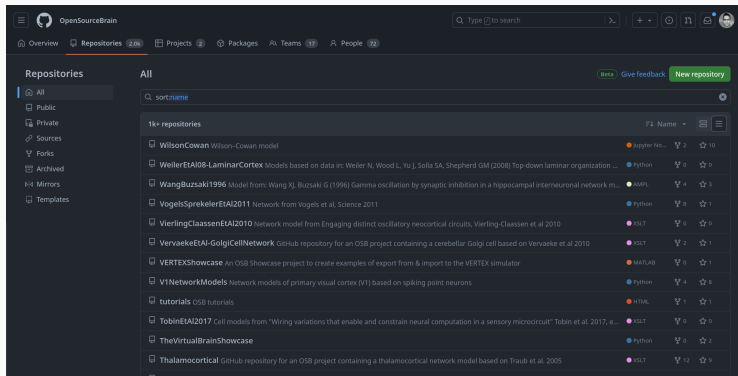
NeuroML: visualising/analysing models



NeuroML: visualising/analysing models



NeuroML: sharing and re-using models

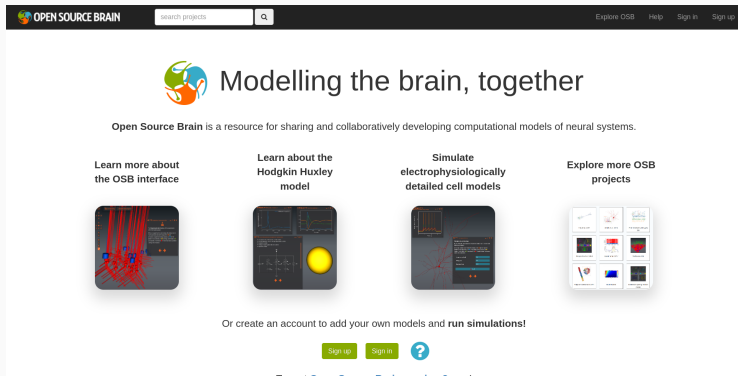


The screenshot displays the Open Source Brain GitHub repository page. The interface includes a navigation bar with 'Overview', 'Repositories' (2.6k), 'Projects' (2), 'Packages', 'AI Teams' (17), and 'People' (92). A search bar is located at the top right. The left sidebar shows repository filters: 'All', 'Public', 'Private', 'Sources', 'Forks', 'Archived', 'Mirrors', and 'Templates'. The main content area is titled 'All' and shows a list of 1k+ repositories. The list includes the following entries:

Name	Language	Forks	Stars
WilsonCowan Wilson-Cowan model	Jupyter No...	2	10
WellerEtAl08-LaminarCortex Models based on data in: Weller N, Wood L, Yu J, Solla SA, Shepherd GM (2008) Top-down laminar organization ...	Python	9	8
WangBuzsaki1996 Model from: Wang XJ, Buzsaki G (1996) Gamma oscillation by synaptic inhibition in a hippocampal interneuronal network m...	AMPL	4	3
VogelsSprekelerEtAl2011 Network from Vogels et al. Science 2011	Python	8	1
VierlingClaassenEtAl2010 Network model from Engaging distinct oscillatory neocortical circuits, Vierling-Claassen et al 2010	XSLT	9	8
VervaekeEtAl-GolgiCellNetwork GitHub repository for an OSB project containing a cerebellar Golgi cell based on Vervaeke et al 2010	XSLT	2	1
VERTEXShowcase An OSB Showcase project to create examples of export from & import to the VERTEX simulator	MATLAB	0	1
V1NetworkModels Network models of primary visual cortex (V1) based on spiking point neurons	Python	4	8
tutorials OSB tutorials	HTML	1	1
TobinEtAl2017 Cell models from "Wiring variations that enable and constrain neural computation in a sensory microcircuit" Tobin et al. 2017, e...	XSLT	0	8
TheVirtualBrainShowcase	Python	0	2
Thalamocortical GitHub repository for an OSB project containing a thalamocortical network model based on Traub et al. 2005	XSLT	12	8

¹ Standardized models on Github: Open Source Brain: <https://github.com/OpenSourceBrain>

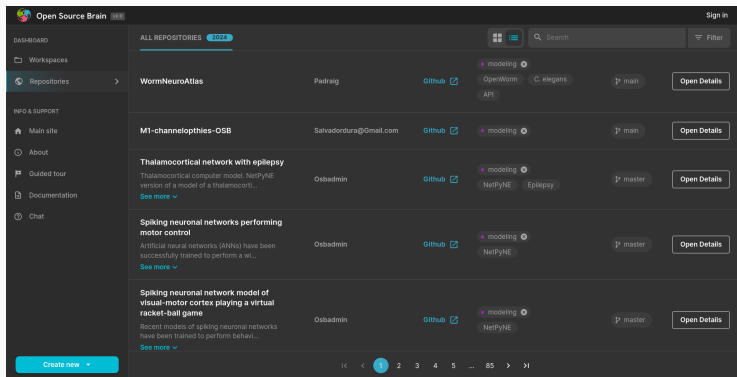
NeuroML: sharing and re-using models



The screenshot shows the Open Source Brain website homepage. At the top, there is a navigation bar with the logo, a search bar, and links for 'Explore OSB', 'Help', 'Sign in', and 'Sign up'. The main heading is 'Modelling the brain, together' with a globe icon. Below this, a paragraph states: 'Open Source Brain is a resource for sharing and collaboratively developing computational models of neural systems.' There are four main content blocks: 'Learn more about the OSB interface' (with a neuron diagram), 'Learn about the Hodgkin Huxley model' (with a plot and a yellow sphere), 'Simulate electrophysiologically detailed cell models' (with a neuron diagram and plot), and 'Explore more OSB projects' (with a grid of project thumbnails). At the bottom, there is a call to action: 'Or create an account to add your own models and run simulations!' with 'Sign up', 'Sign in', and a question mark icon buttons. A partially visible link at the bottom reads 'Try out Open Source Brain version 2 now!'.

¹ Standardized models on Open Source Brain v1: <https://v1.opensourcebrain.org>

NeuroML: sharing and re-using models



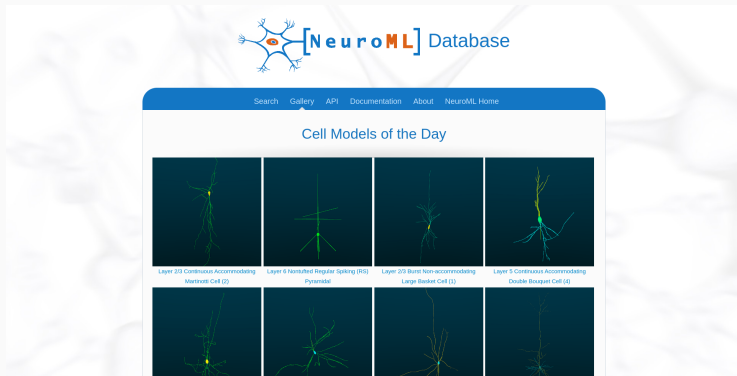
The screenshot displays the Open Source Brain dashboard. The left sidebar contains navigation options: BASHBOARD, Workspaces, Repositories (selected), INFO & SUPPORT (Main site, About, Guided tour, Documentation, Chat), and a 'Create new' button. The main content area is titled 'ALL REPOSITORIES' and shows a list of repositories. Each repository entry includes the repository name, the owner's name, a GitHub link, a 'modeling' tag, a 'main' branch indicator, and an 'Open Details' button. The repositories listed are:

- WormNeuroAtlas** by Padraig, with tags for 'modeling', 'OpenWorm', 'C. elegans', and 'API'.
- M1-channelopathies-OSB** by SalvadorDura@Gmail.com, with tags for 'modeling' and 'main'.
- Thalamocortical network with epilepsy** by Osbadmin, with tags for 'modeling', 'NetPyNE', and 'Epilepsy'.
- Spiking neuronal networks performing motor control** by Osbadmin, with tags for 'modeling' and 'NetPyNE'.
- Spiking neuronal network model of visual-motor cortex playing a virtual racket-ball game** by Osbadmin, with tags for 'modeling' and 'NetPyNE'.

A pagination bar at the bottom shows the current page is 1 of 85.

¹ Standardized models on Open Source Brain v2: <https://v2.opensourcebrain.org>

NeuroML: sharing and re-using models



¹Standardized models on NeuroML-DB: <https://neuroml-db.org>

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>