Creating cortical models across scales in NeuroML

Padraig Gleeson
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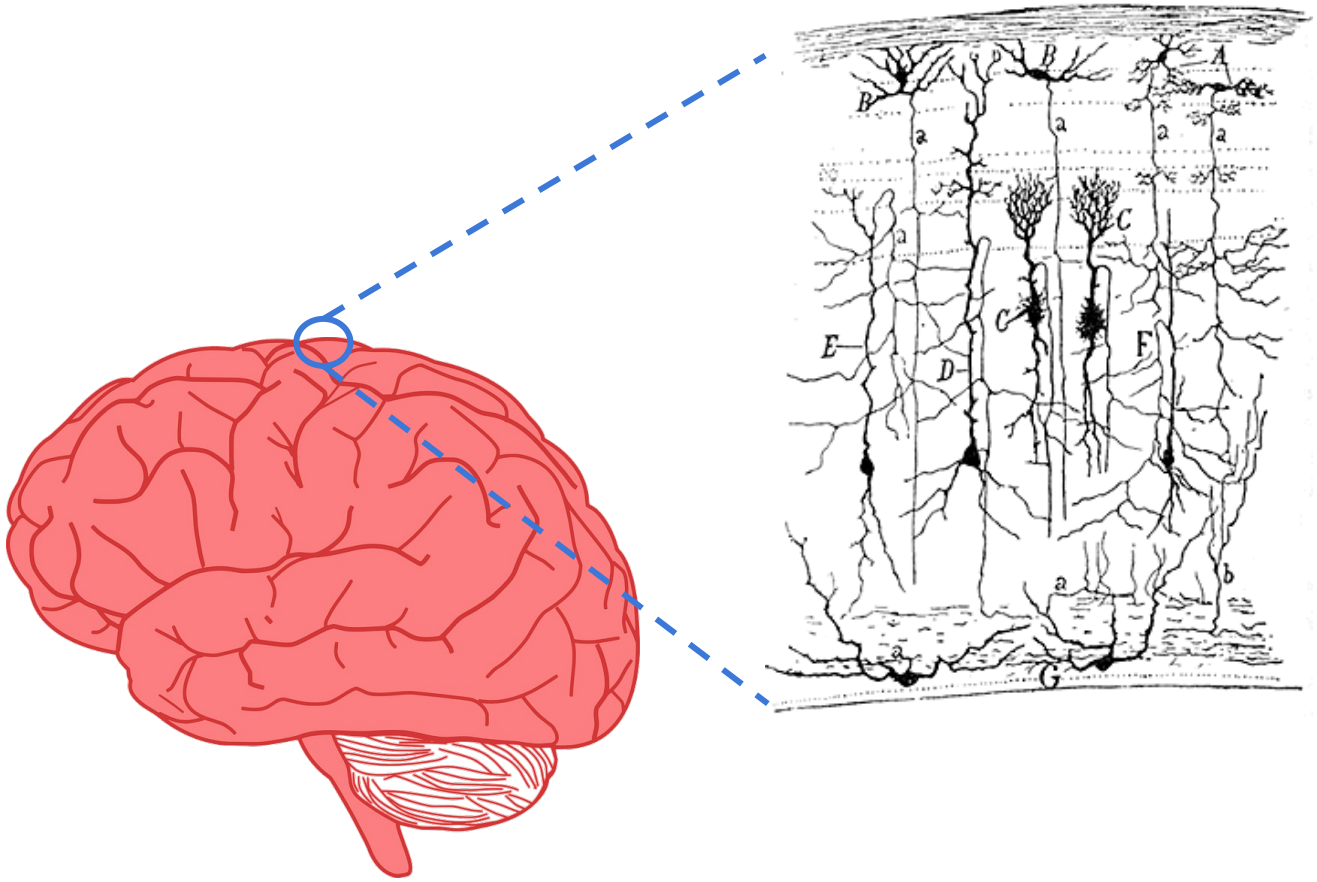
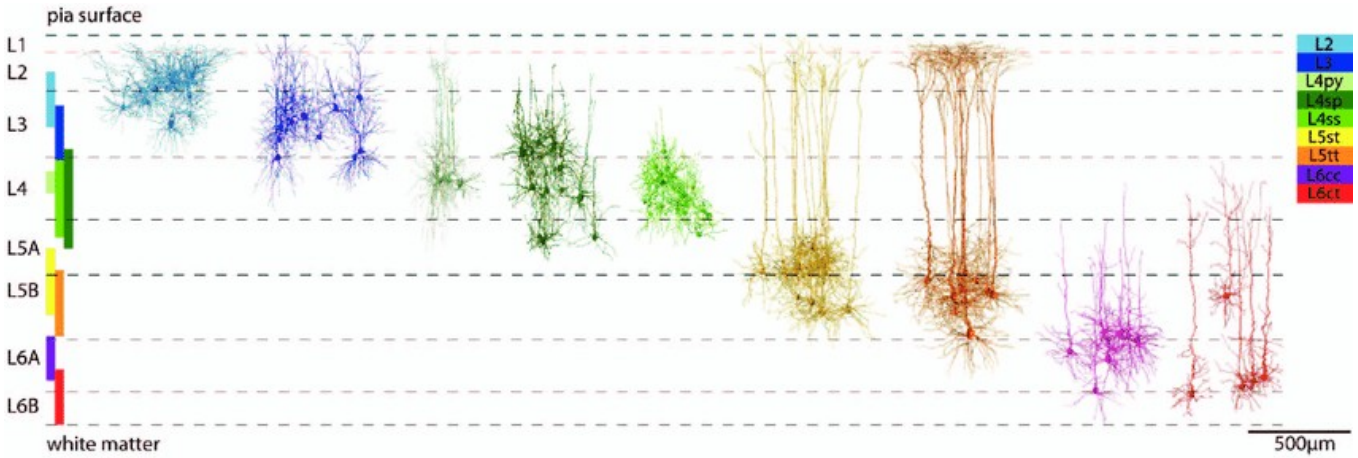
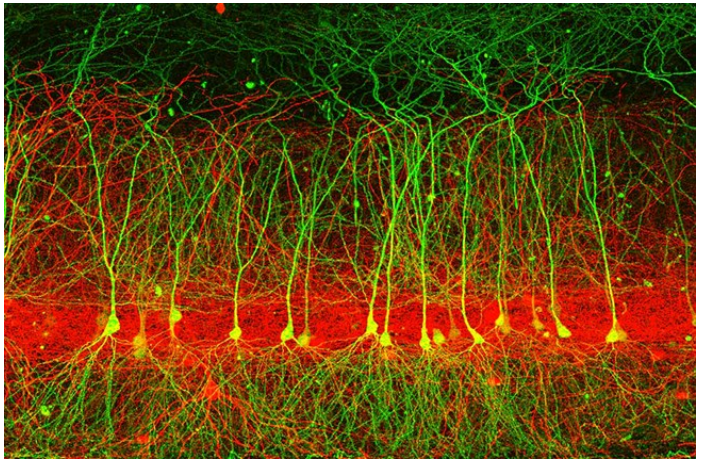
University College London

Open Source Brain workshop 2019

11th Sept 2019

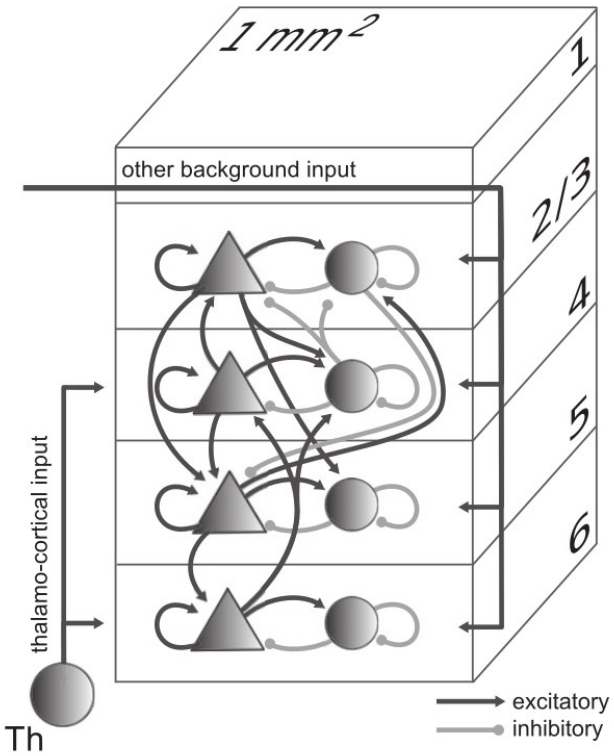




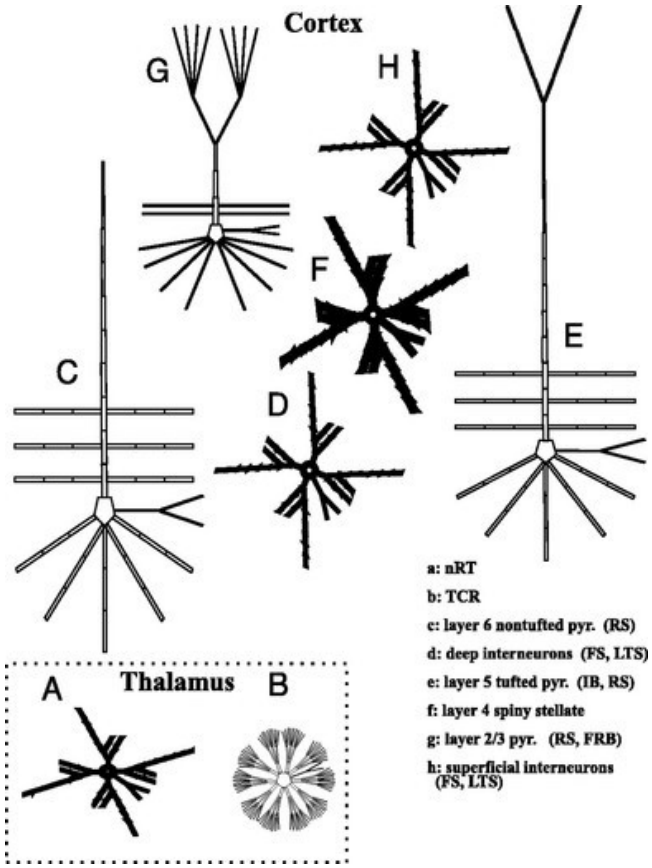


OPEN SOURCE BRAIN [NeuroML]

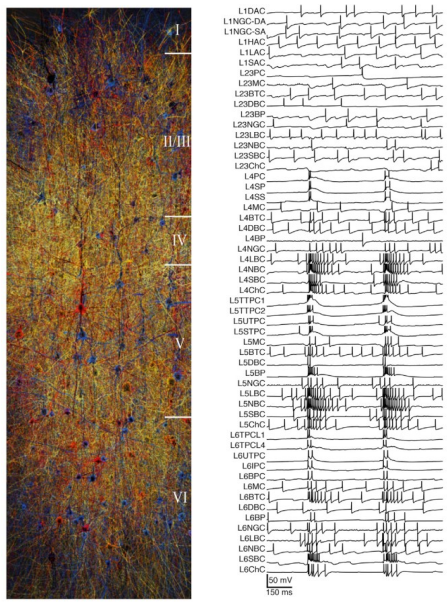
wellcome



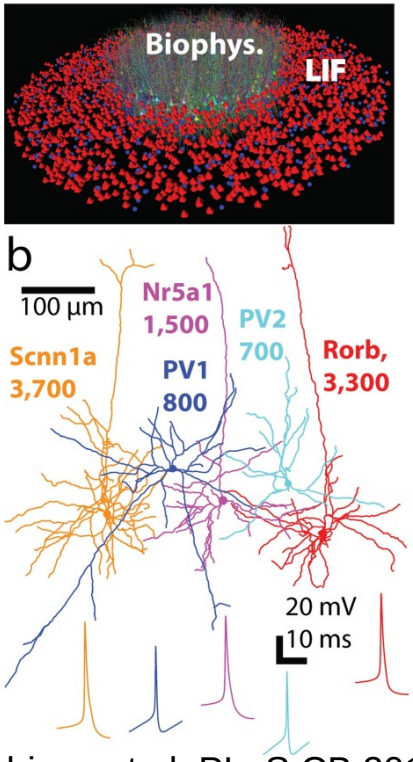
Potjans & Diesmann,
Cereb. Cortex 2014



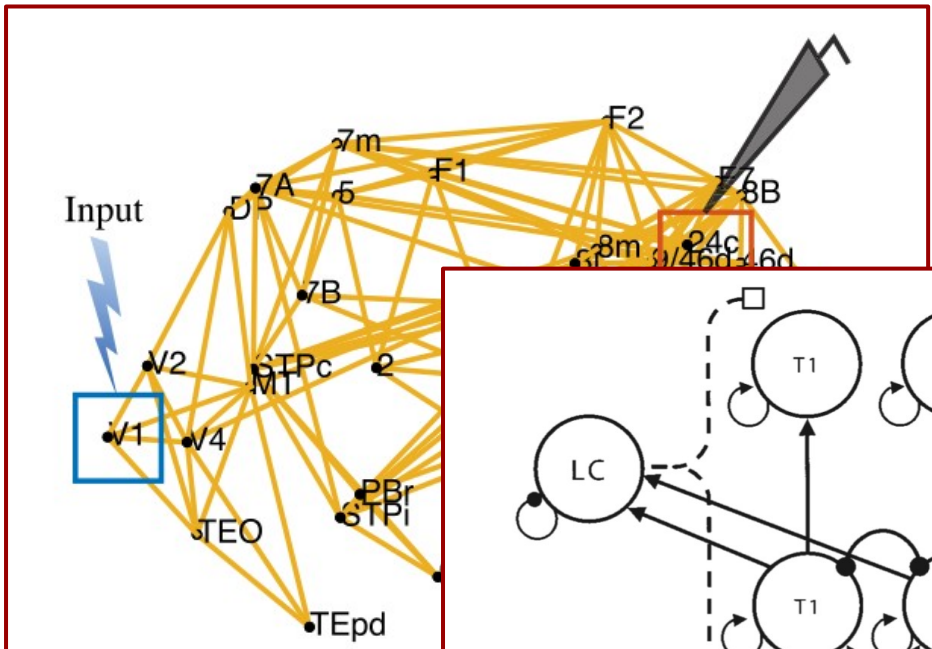
Traub et al., J. Neurophysiol. 2005



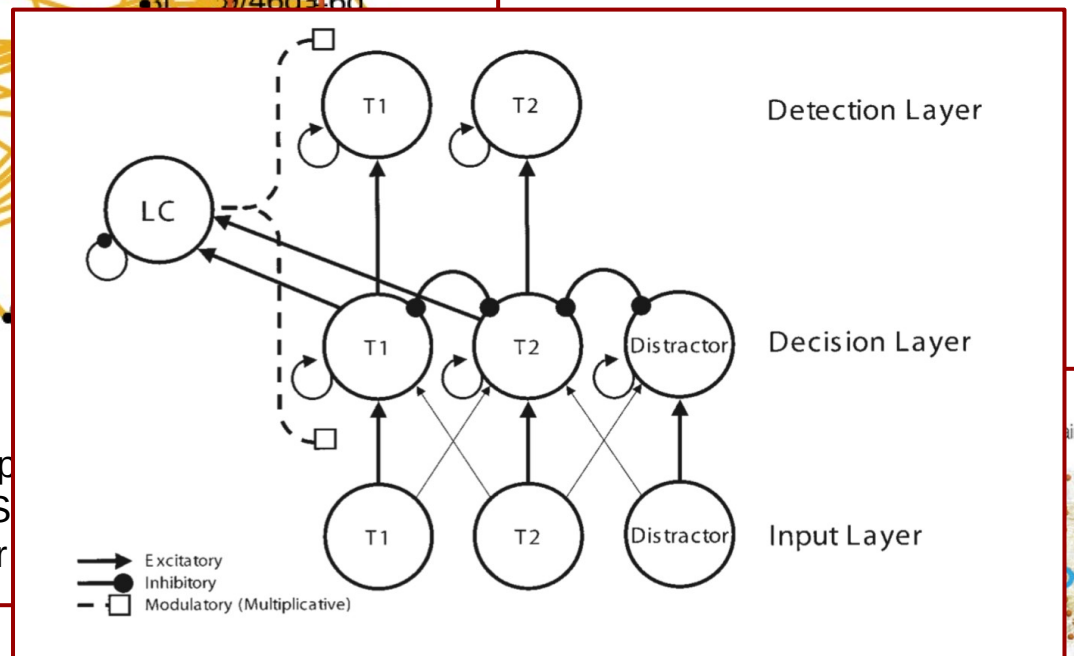
Markram et al. Cell 2015



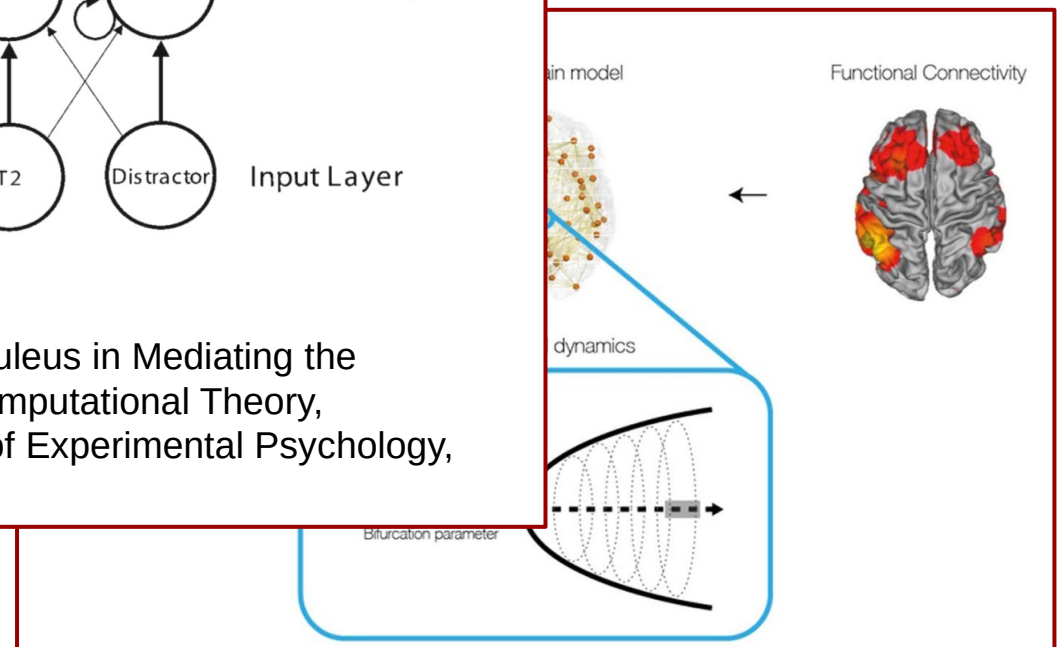
Arkhipov et al. PLoS CB 2018



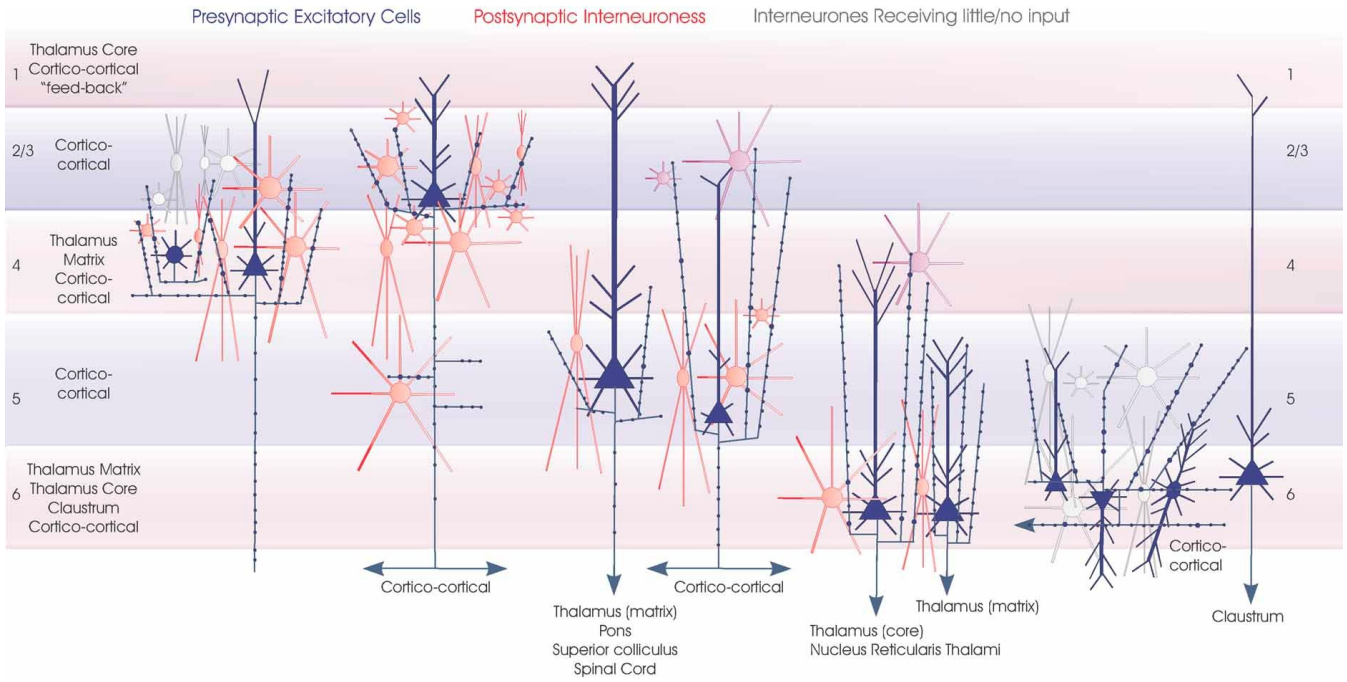
Inter-areal Balanced Amp
Propagation in a Large-S
Primate Cortex, Joglekar



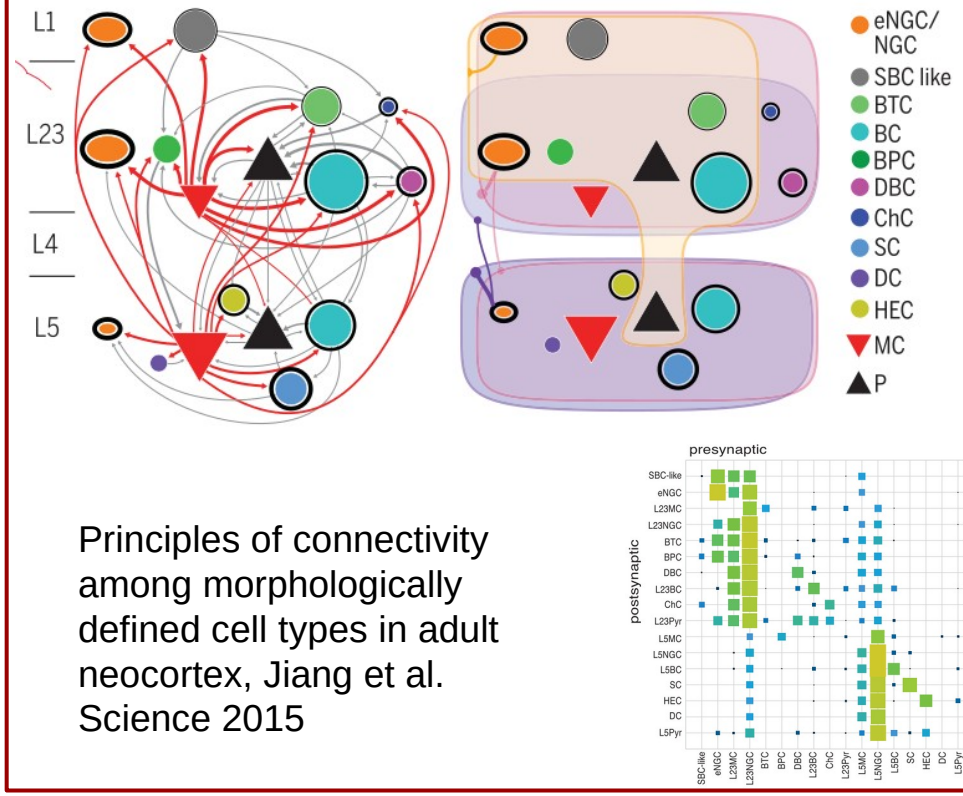
The Role of the Locus Coeruleus in Mediating the Attentional Blink: A Neurocomputational Theory, Nieuwenhuis et al. Journal of Experimental Psychology, 2005



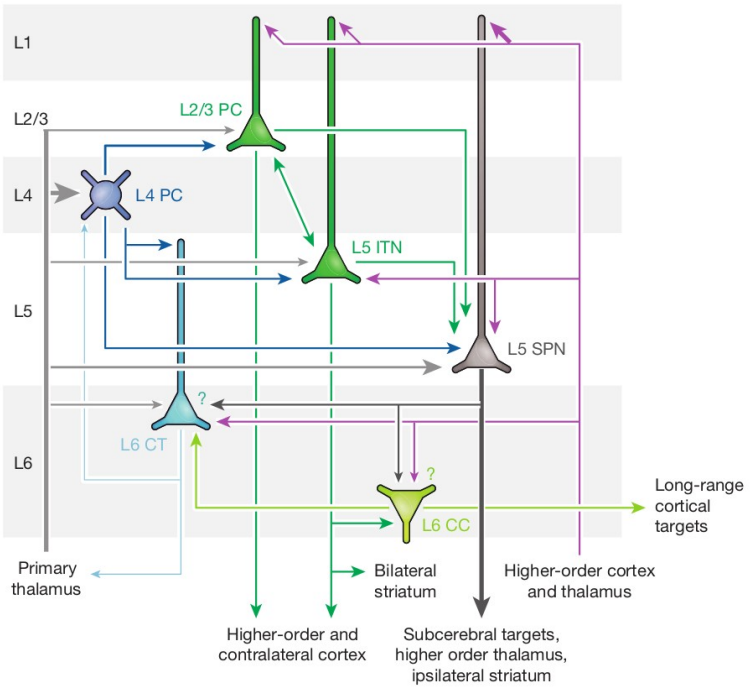
The dynamics of resting fluctuations in the brain: metastability and its dynamical cortical core, Deco et al. Scientific Reports 2017



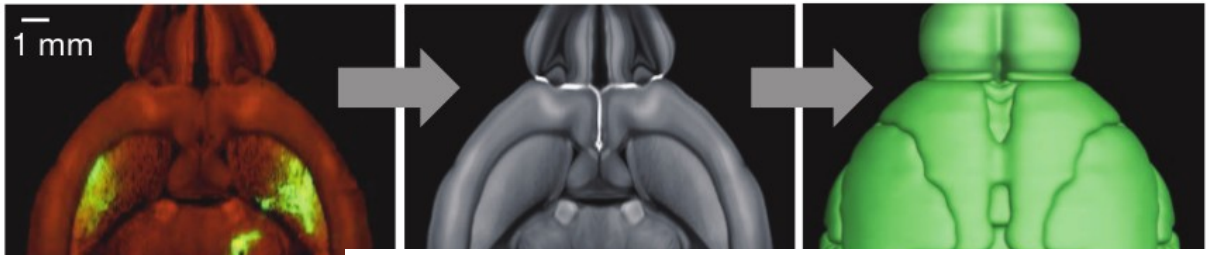
Functional maps of neocortical local circuitry, Thomson & Lamy, Front. Neurosci. 2007



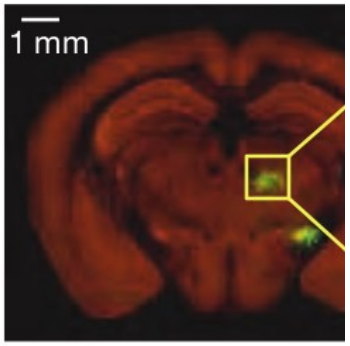
Principles of connectivity among morphologically defined cell types in adult neocortex, Jiang et al. Science 2015

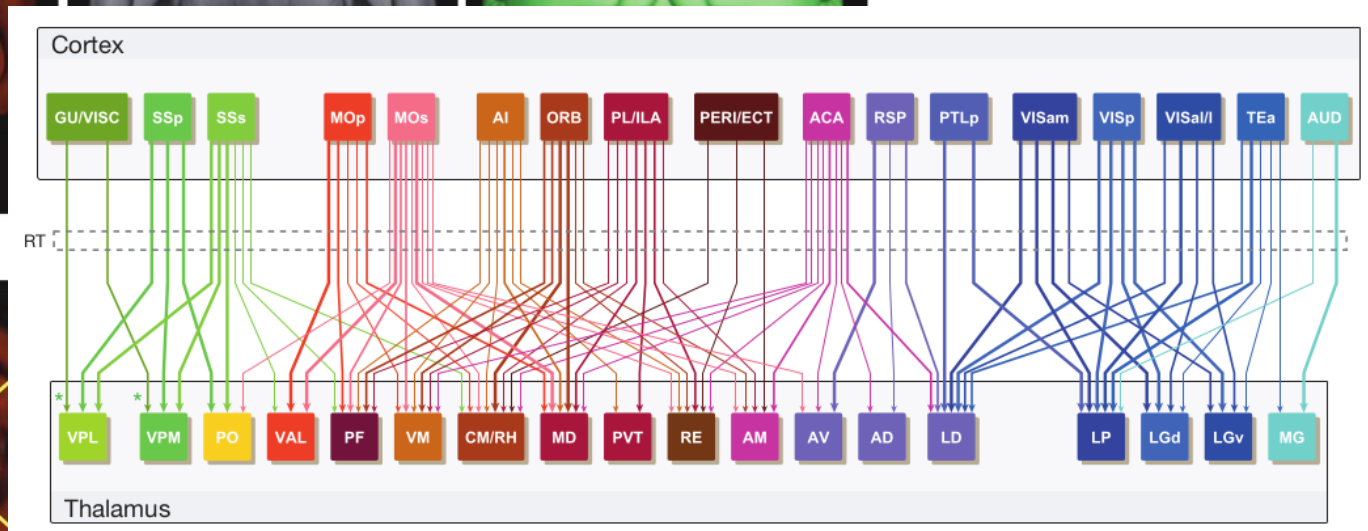


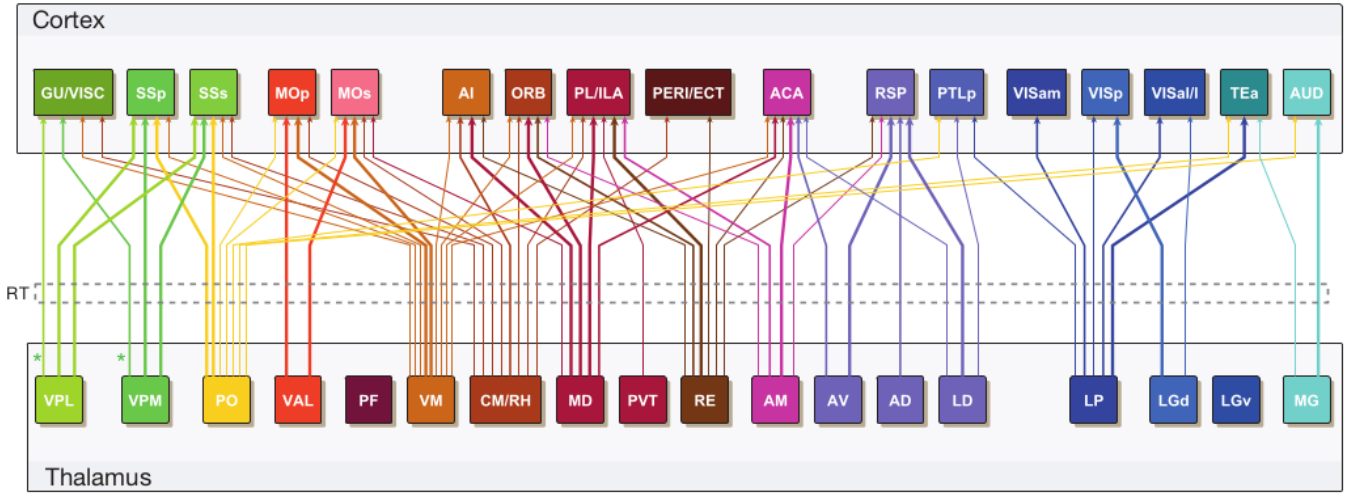
Cortical connectivity and sensory coding, Harris & Mrsic-Flogel, Nature 2013

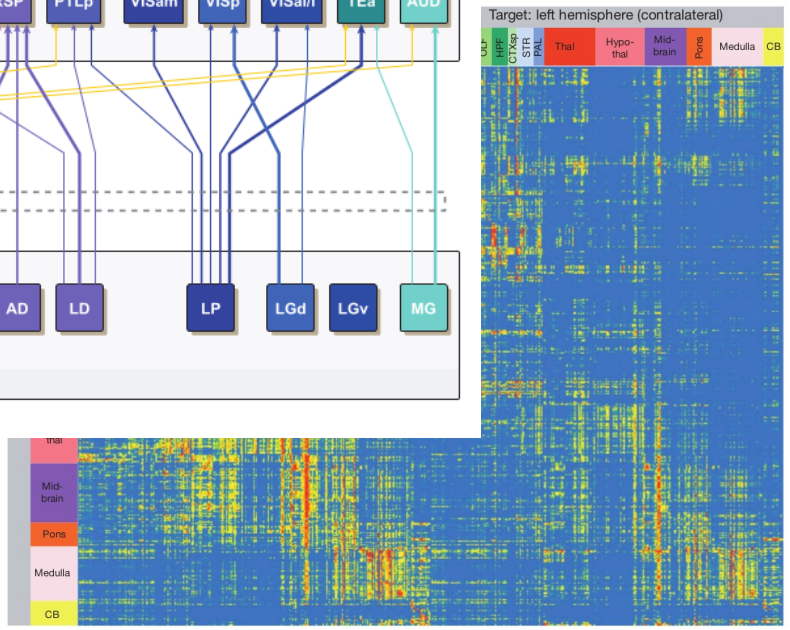


Single specimen

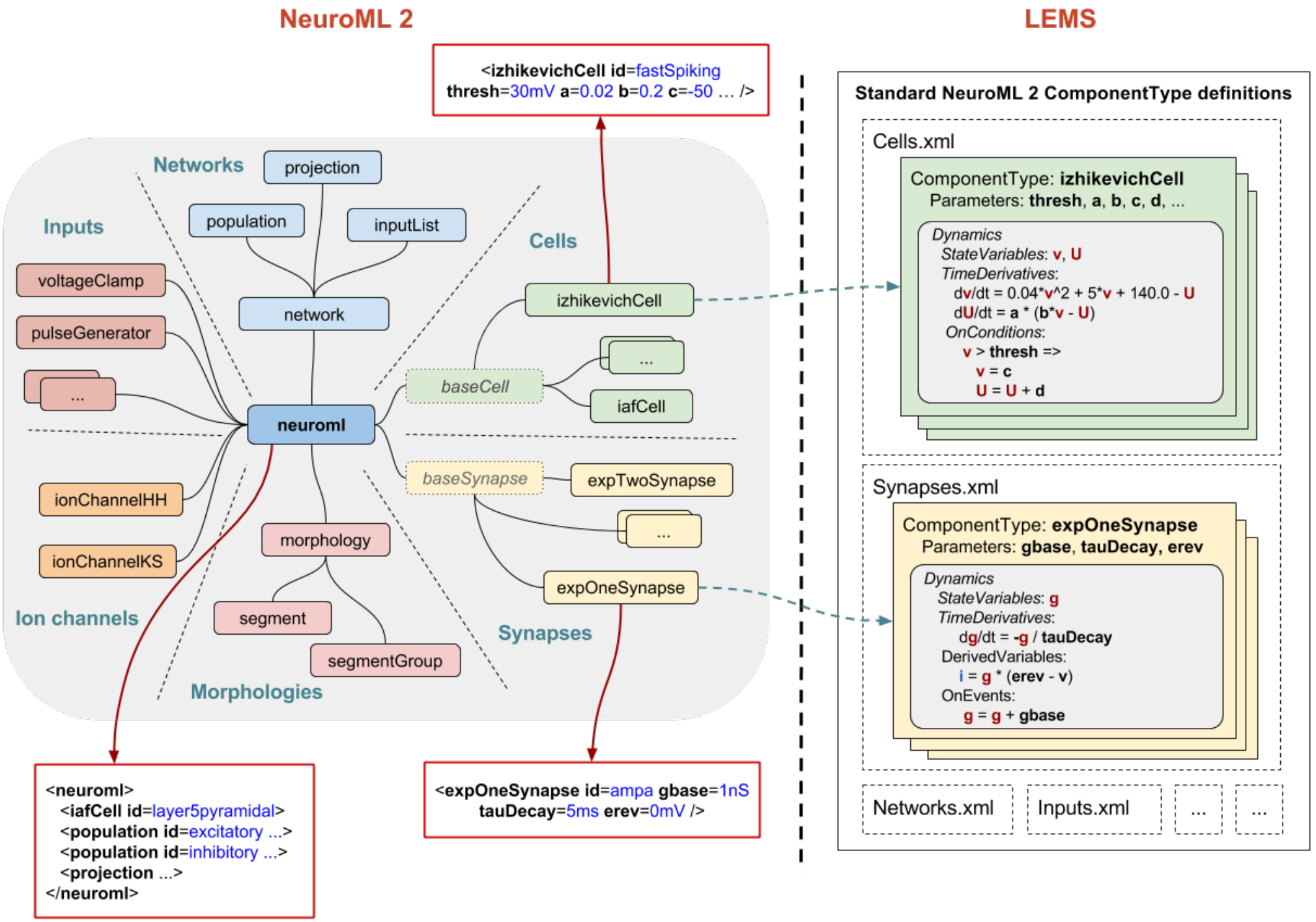








A mesoscale connectome of the mouse brain, Oh et al.
Nature 2014


NeuroML 2
LEMS
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thresh=30mV a=0.02 b=0.2 c=-50 … />
Networks
projection
population
inputList
Inputs
Cells
voltageClamp
pulseGenerator
network
izhikevichCell
...
baseCell
iafCell
...
neuroml
baseSynapse
expTwoSynapse
ionChannelHH
...
morphology
ionChannelKS
expOneSynapse
Ion channels
segment
Synapses
segmentGroup
Morphologies
<neuroml>
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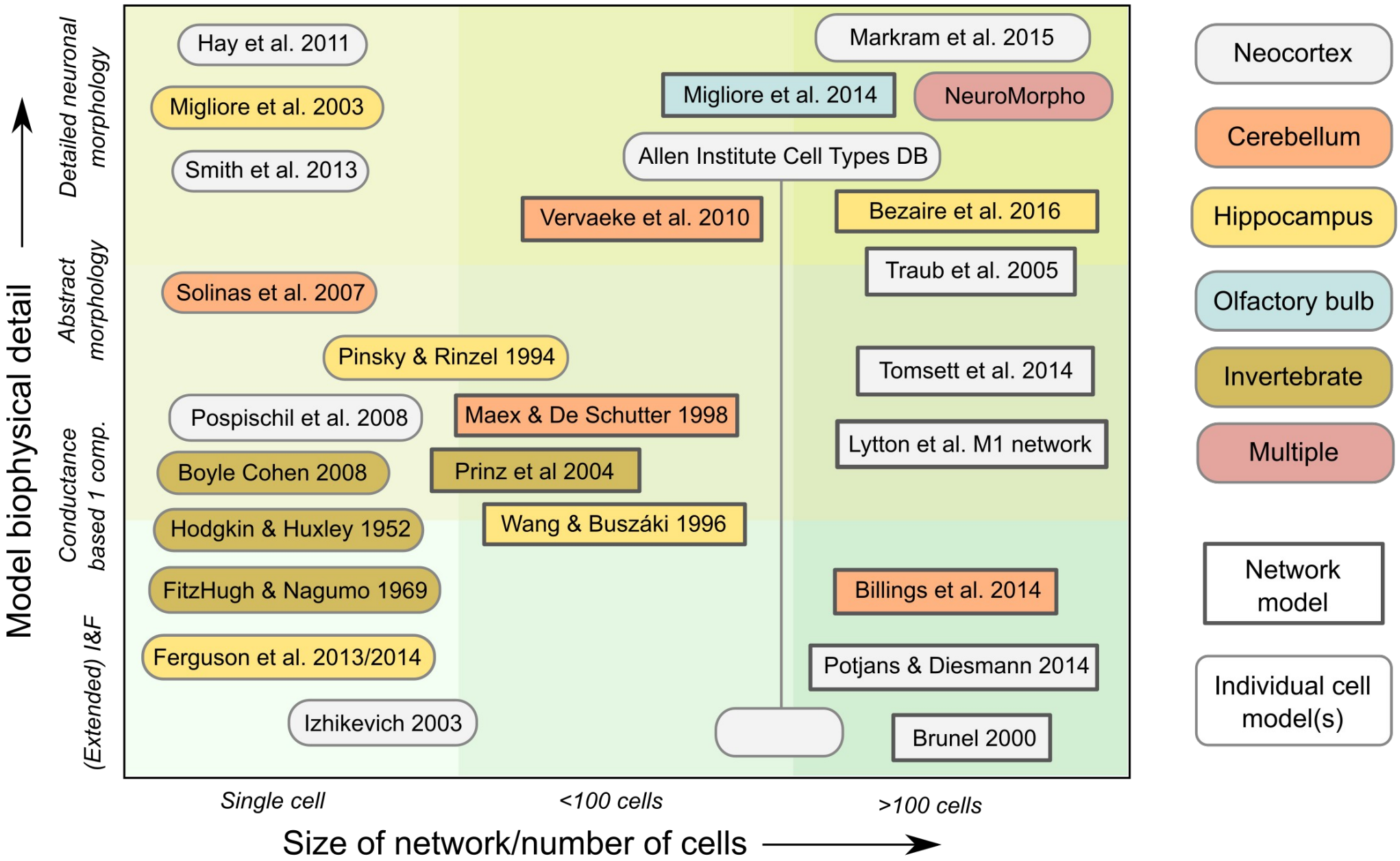
<population id=excitatory ...>
<population id=inhibitory ...>
<projection ...>
</neuroml>
<expOneSynapse id=ampa gbase=1nS
tauDecay=5ms erev=0mV />
Standard NeuroML 2 ComponentType definitions
Cells.xml
ComponentType: izhikevichCell
Parameters: thresh, a, b, c, d, ...
Dynamics
StateVariables: v, U
TimeDerivatives:
dv/dt = 0.04*v^2 + 5*v + 140.0 - U
dU/dt = a * (b*v - U)
OnConditions:
v > thresh =>
v = c
U = U + d
Synapses.xml
ComponentType: expOneSynapse
Parameters: gbase, tauDecay, erev
Dynamics
StateVariables: g
TimeDerivatives:
dg/dt = -g / tauDecay
DerivedVariables:
i = g * (erev - v)
OnEvents:
g = g + gbase
Networks.xml
Inputs.xml
...
...



OPEN SOURCE BRAIN [NeuroML]

Extending NeuroML

NeuroML geared towards (spiking) neuron networks

Need an extensible representation of populations & projections

Can be used for both models and experimental data

-> **NeuroMLlite**

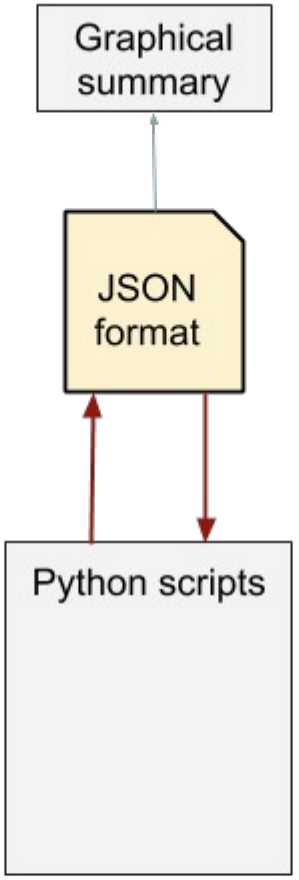
JSON

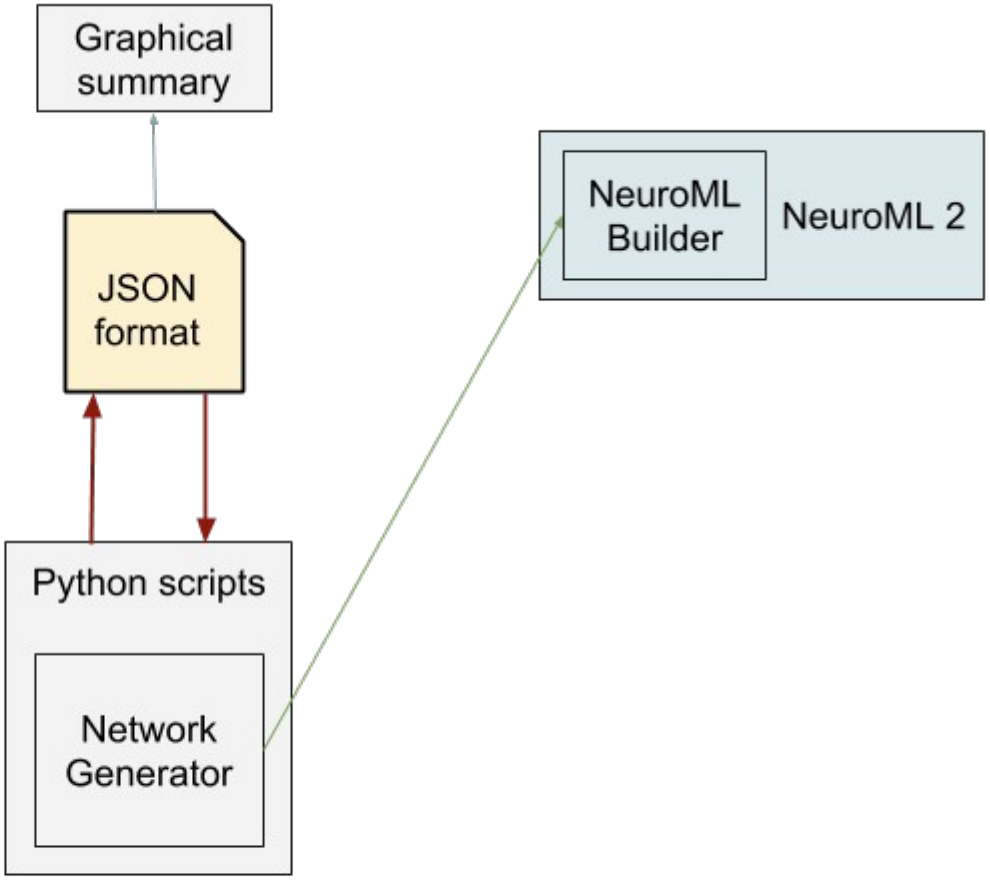
```
{
    "TestNetwork": {
      "populations": [
          {
             "pop0": {
                 "size": 5,
                 "component": "iaf"
             }
          },
          {
             "pop1": {
                 "size": 10,
                 "component": "iaf"
             }
          }
      ],
      "projections": [
         {
            "proj0": {
                "presynaptic": "pop0",
                "postsynaptic": "pop1",
                "synapse": "ampa",
                "random_connectivity": {
                    "probability": 0.5
                }
            }
         }
      ]
    }
}
```

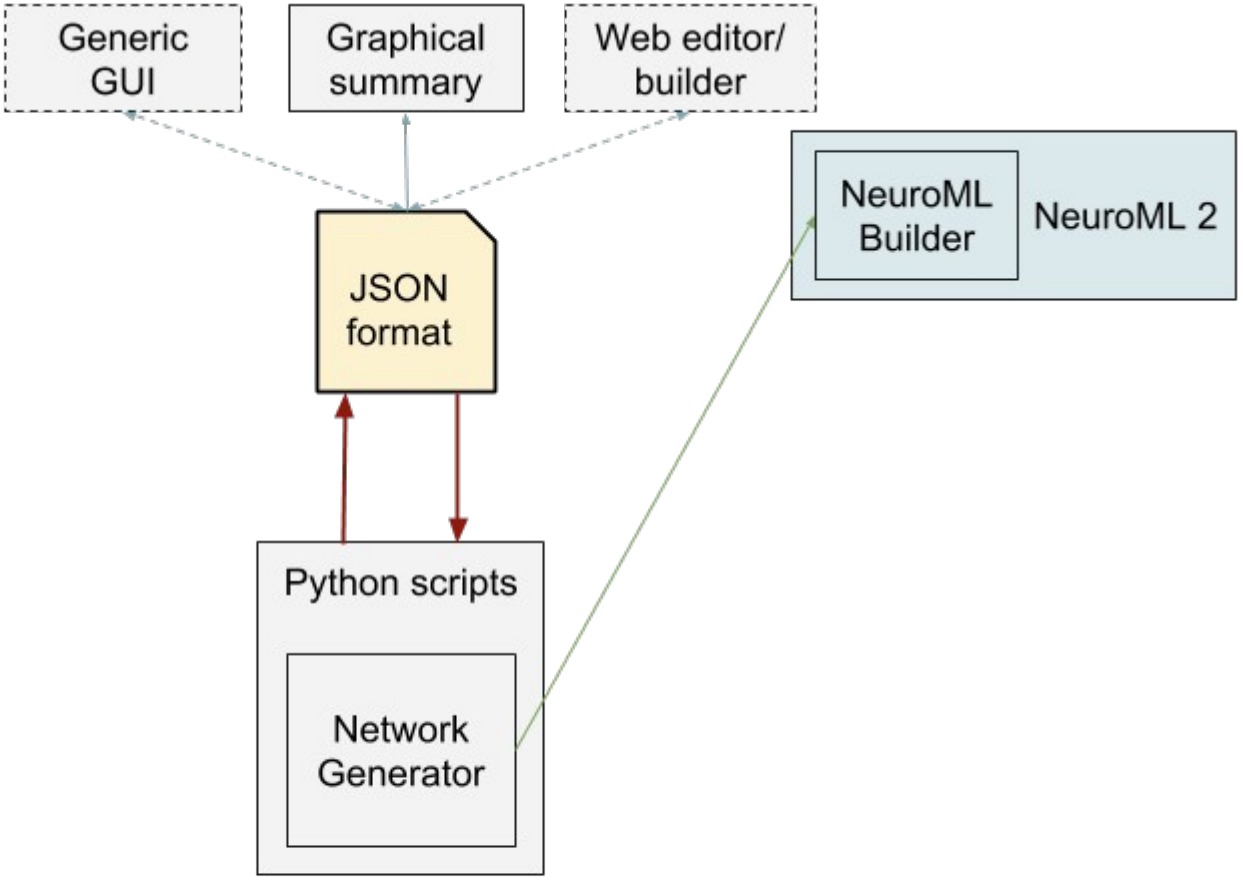
Python

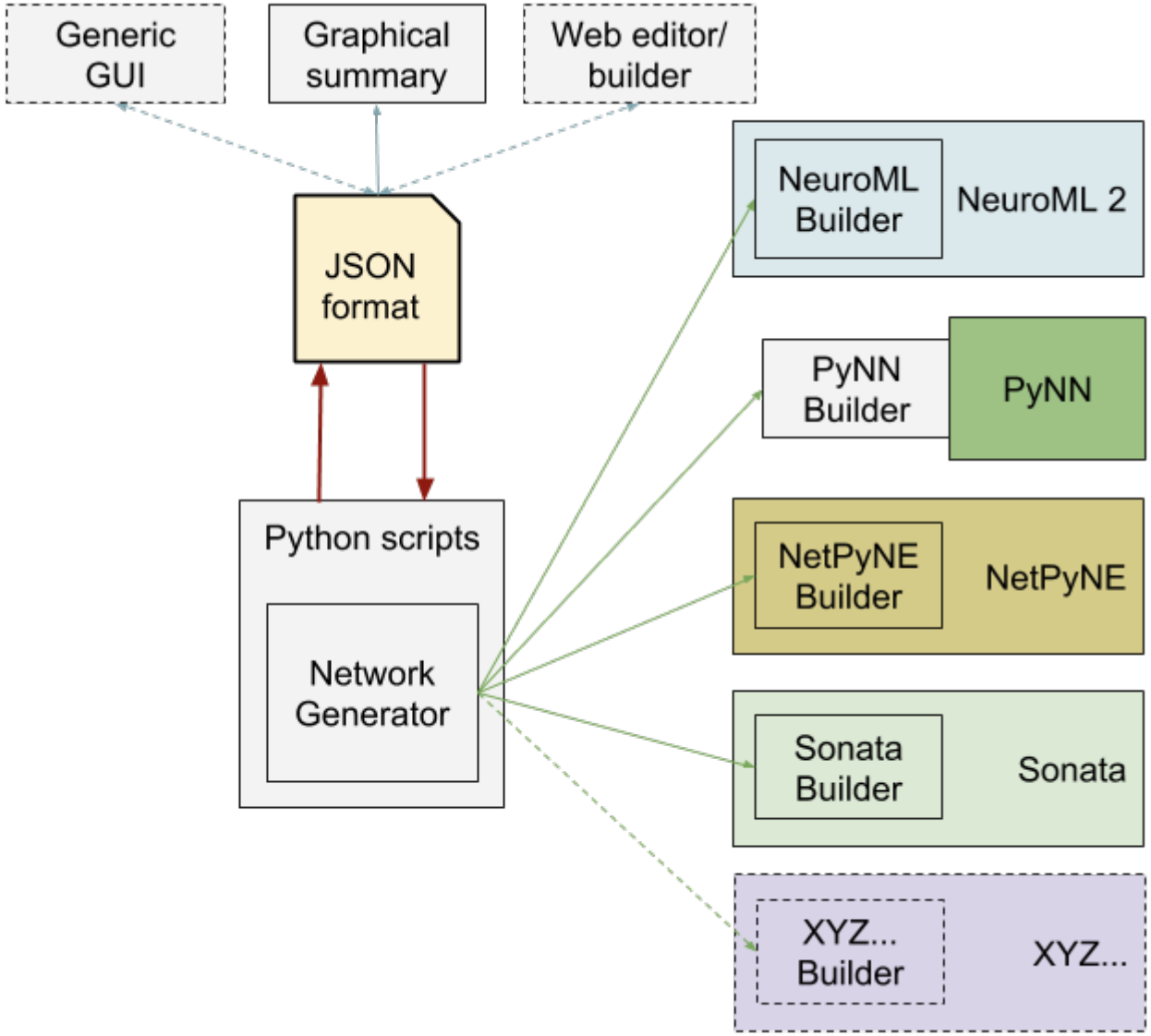
```
p0 = Population(id='pop0', size=5,  component='iaf')
p1 = Population(id='pop1', size=10, component='iaf')


proj = Projection(id='proj0',
       presynaptic=p0.id,
       postsynaptic=p1.id,
       synapse='ampa',
       random_connectivity
            = RandomConnectivity(probability=0.5))
```

OPEN SOURCE BRAIN [NeuroML]

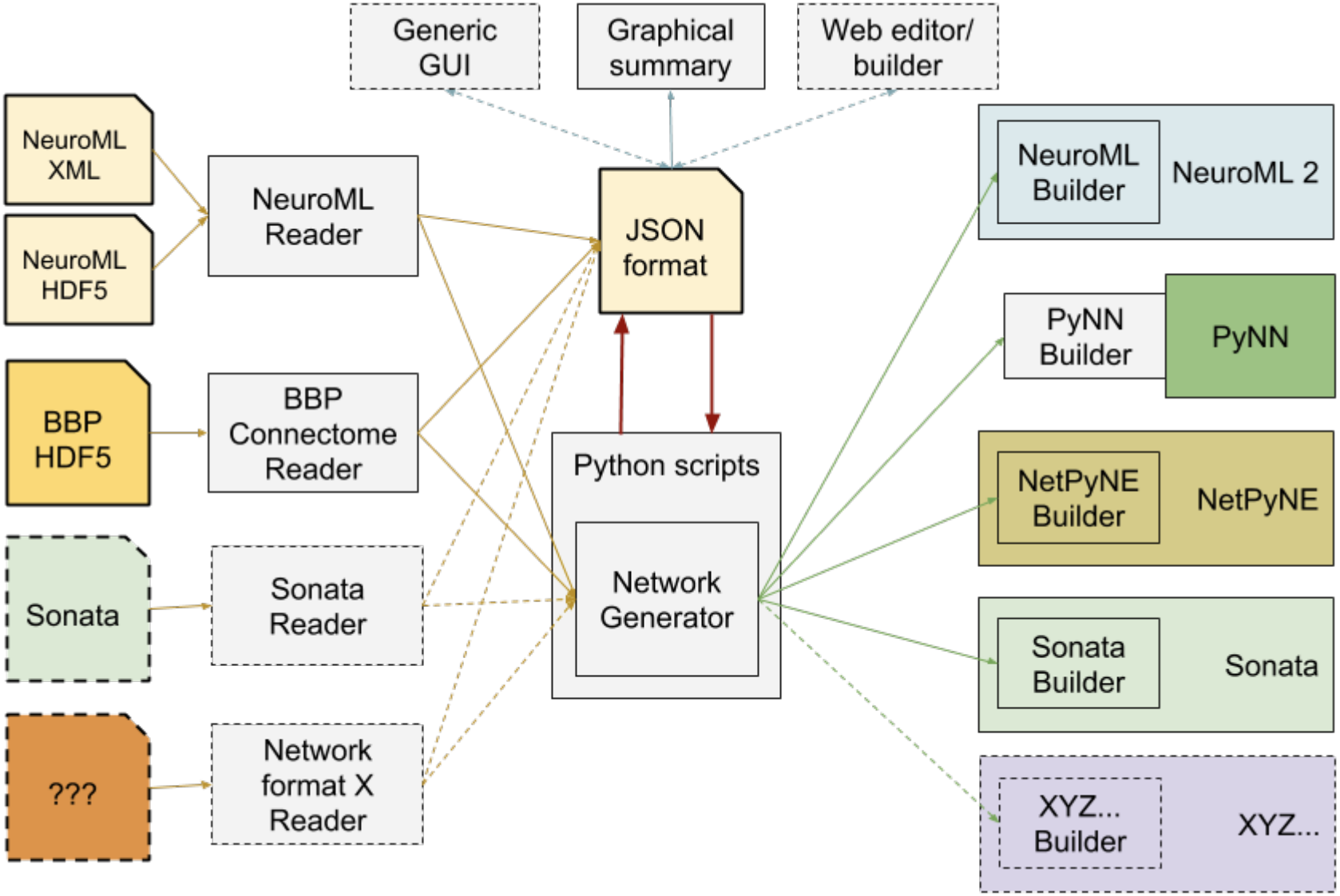

Graphical summary
JSON format
Python scripts


Graphical summary
JSON format
NeuroML Builder
NeuroML 2
Python scripts
Network Generator

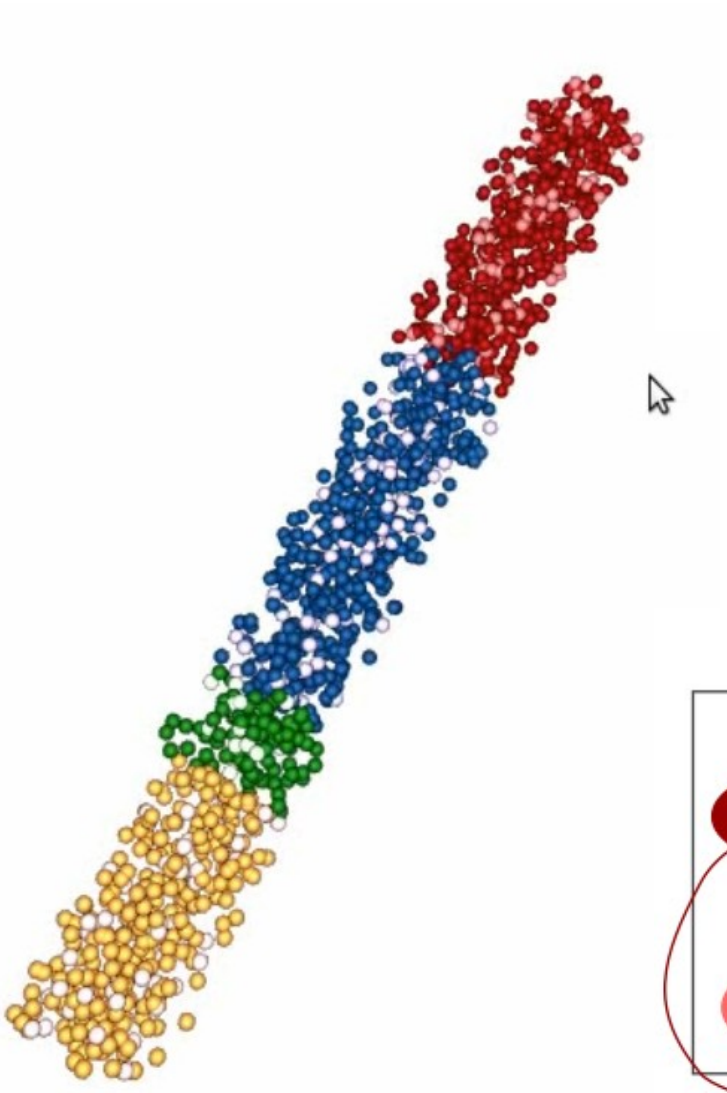

Generic GUI
Graphical summary
Web editor/ builder
NeuroML Builder
NeuroML 2
JSON format
Python scripts
Network Generator

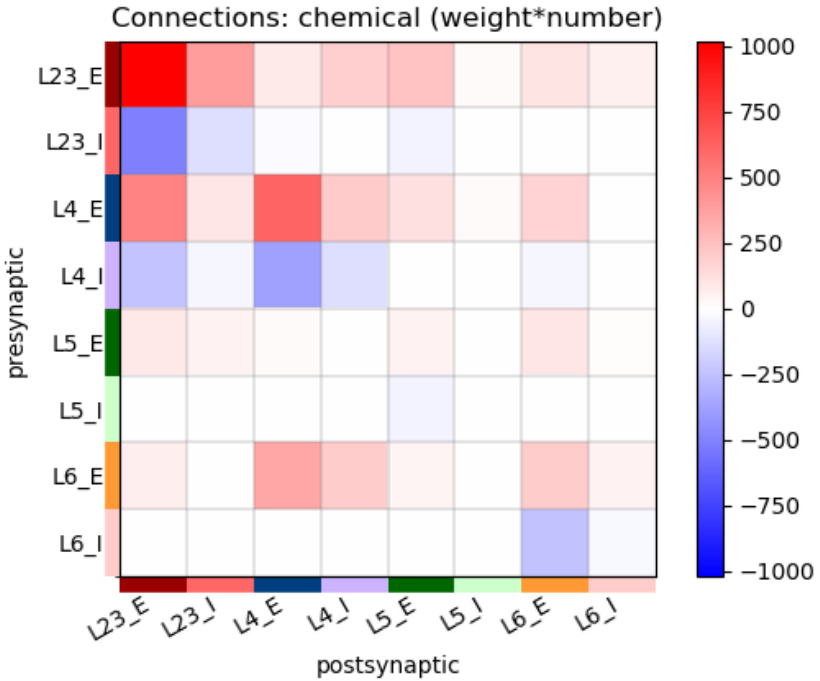


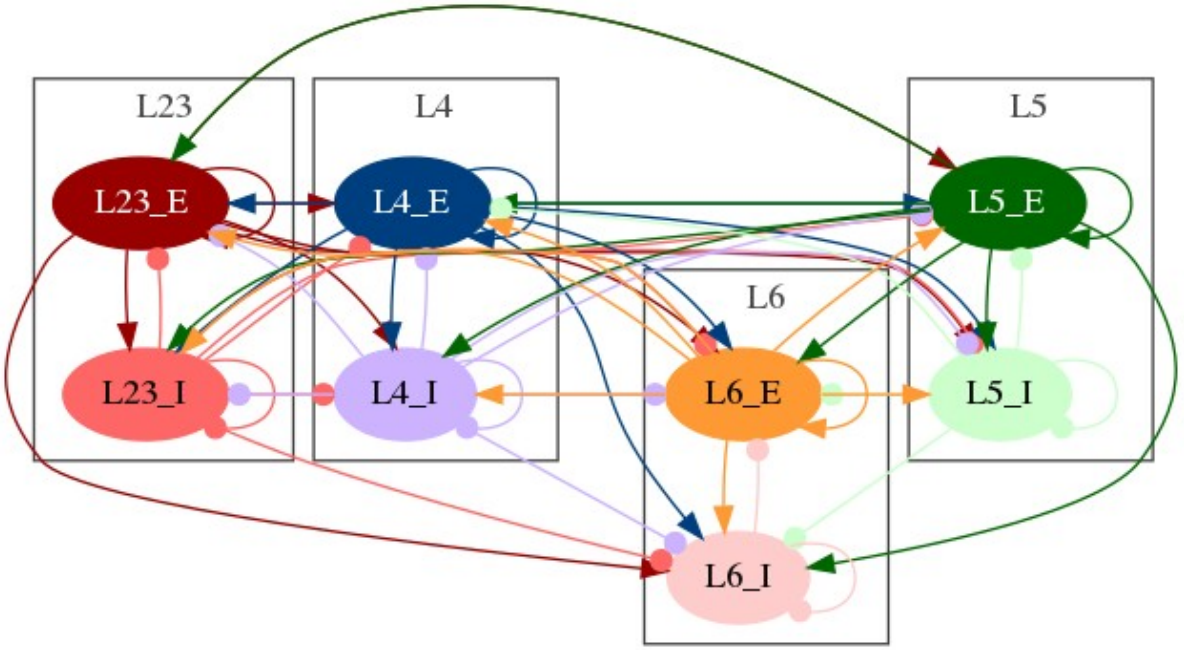
OPEN SOURCE BRAIN [NeuroML]



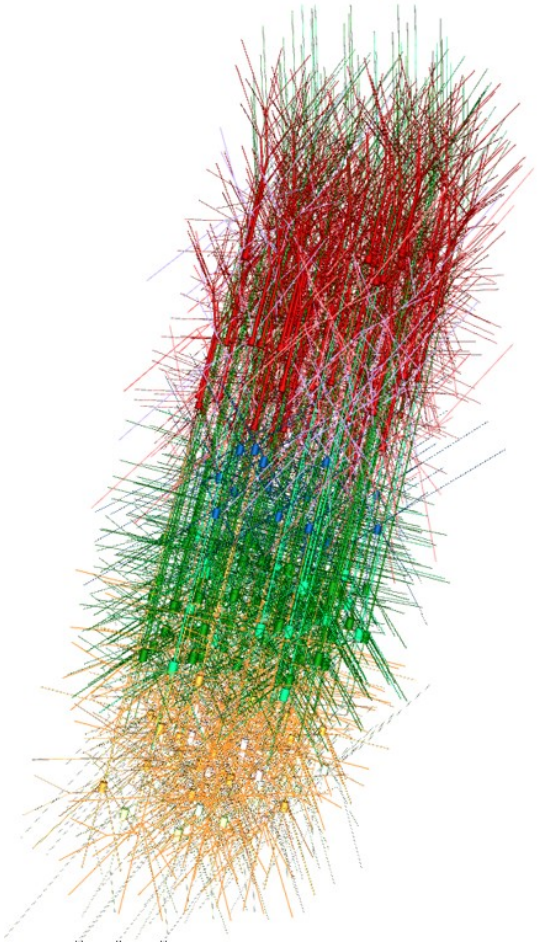
OPEN SOURCE BRAIN [NeuroML]

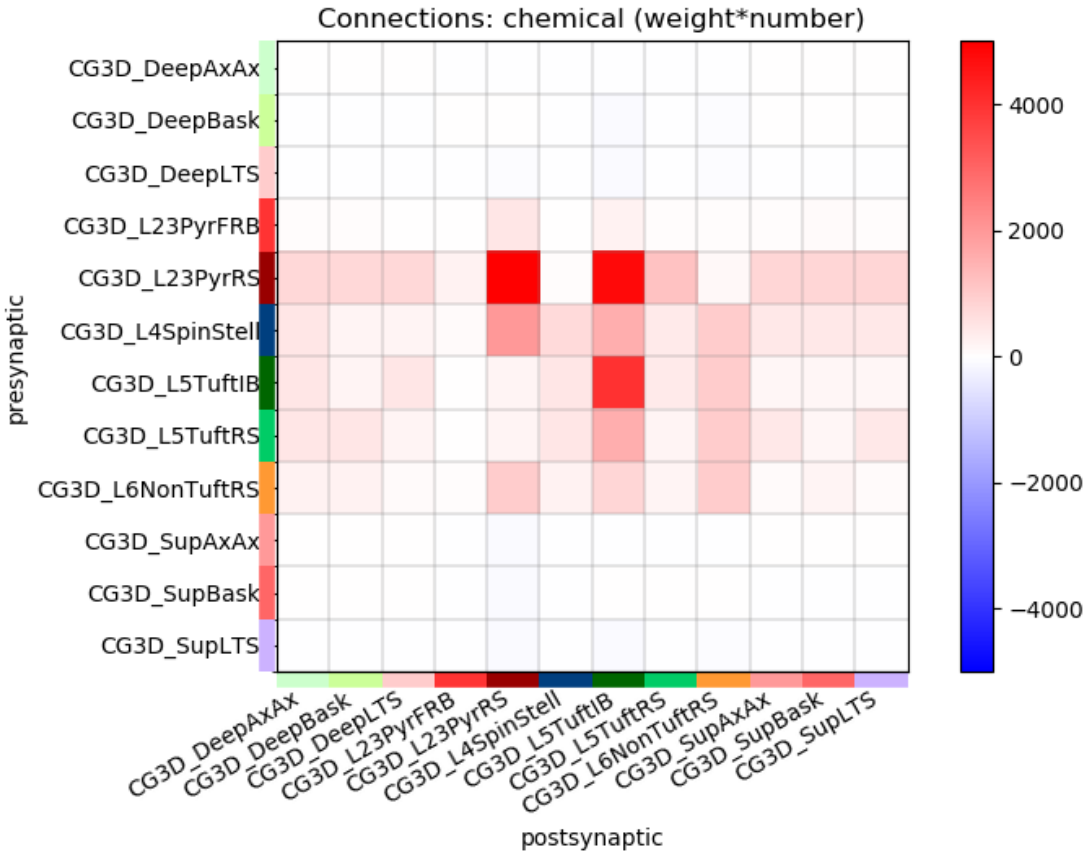






OPEN SOURCE BRAIN [NeuroML]

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postsynaptic
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CG3D_DeepBask
CG3D_DeepLTS
CG3D_L23PyrFRB
CG3D_L23PyrRS
CG3D_L4SpinStell
CG3D_L5TuftIB
CG3D_L5TuftRS
CG3D_L6NonTuftRS
CG3D_SupAxAx
CG3D_SupBask
CG3D_SupLTS
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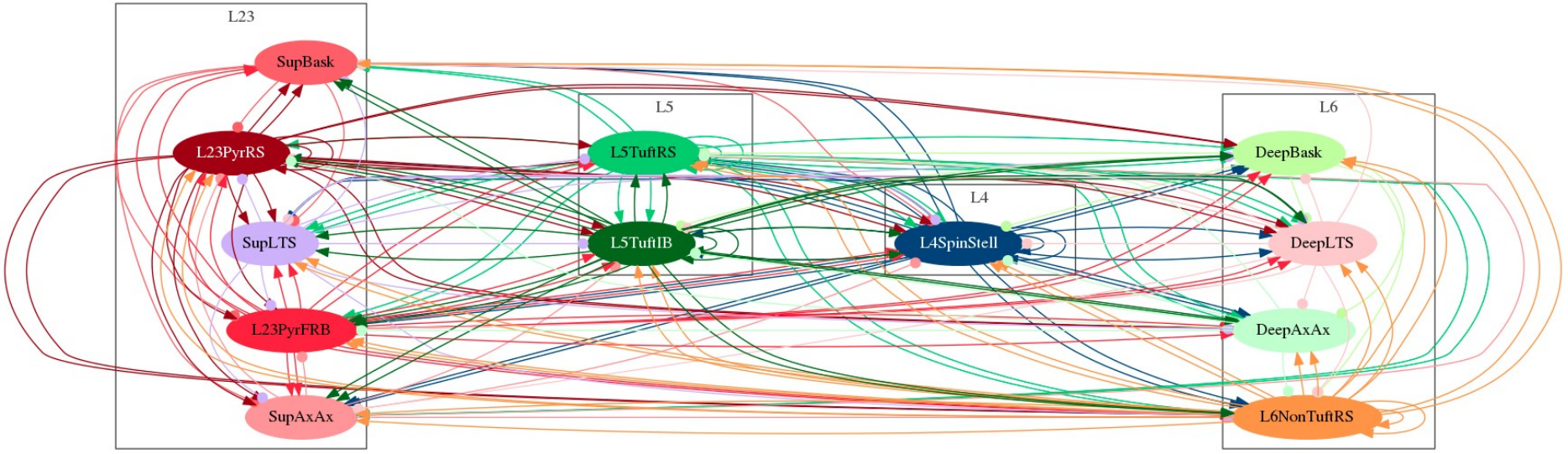
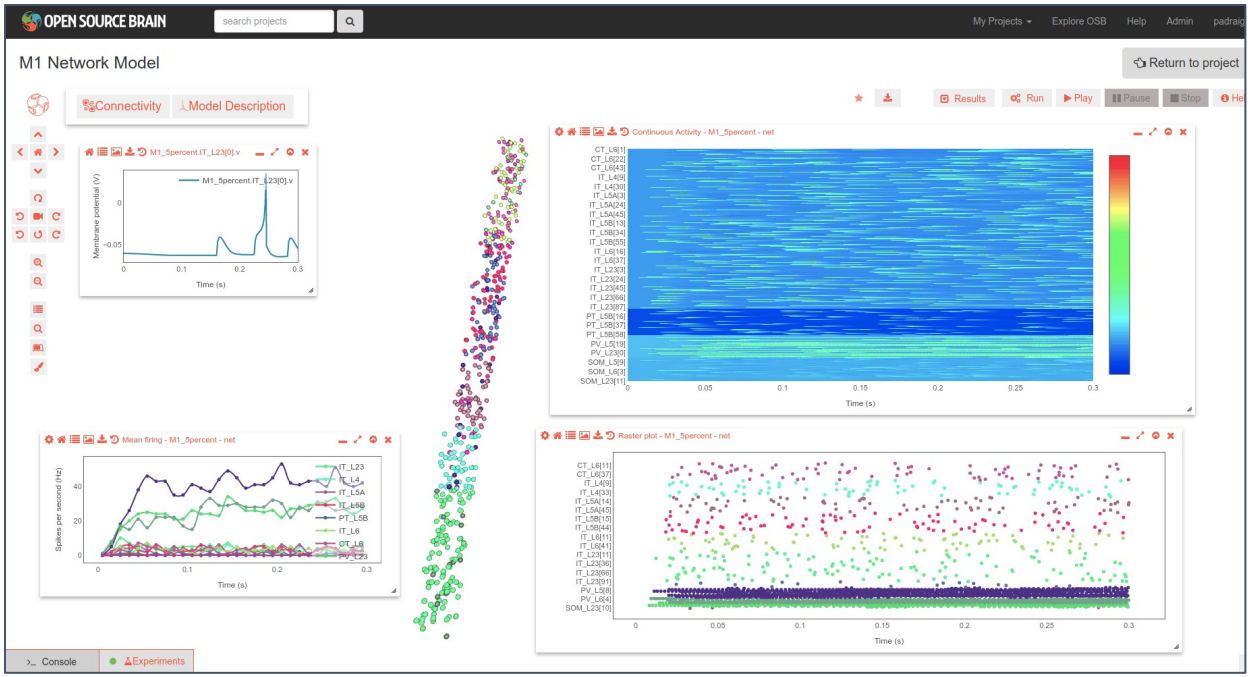
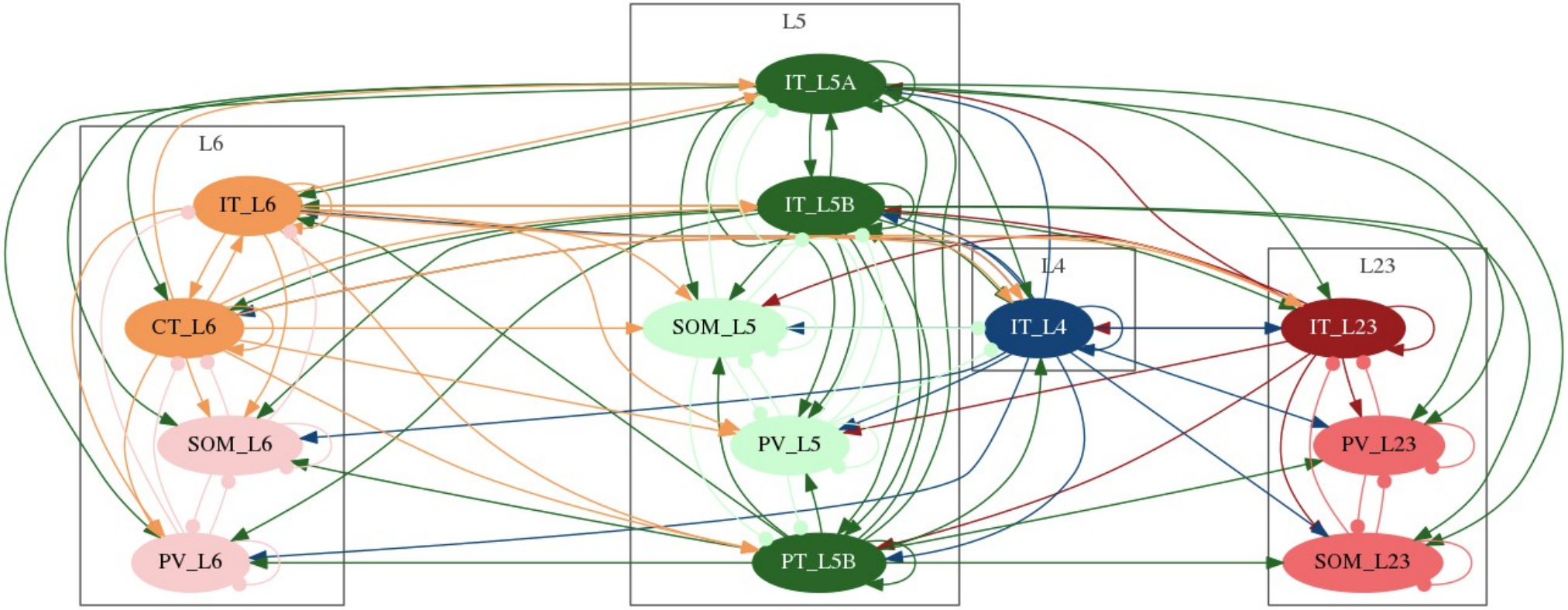
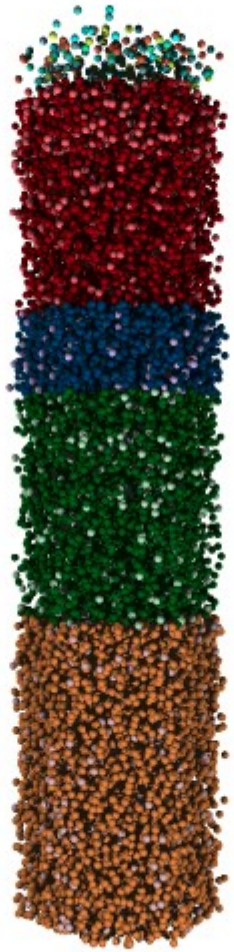
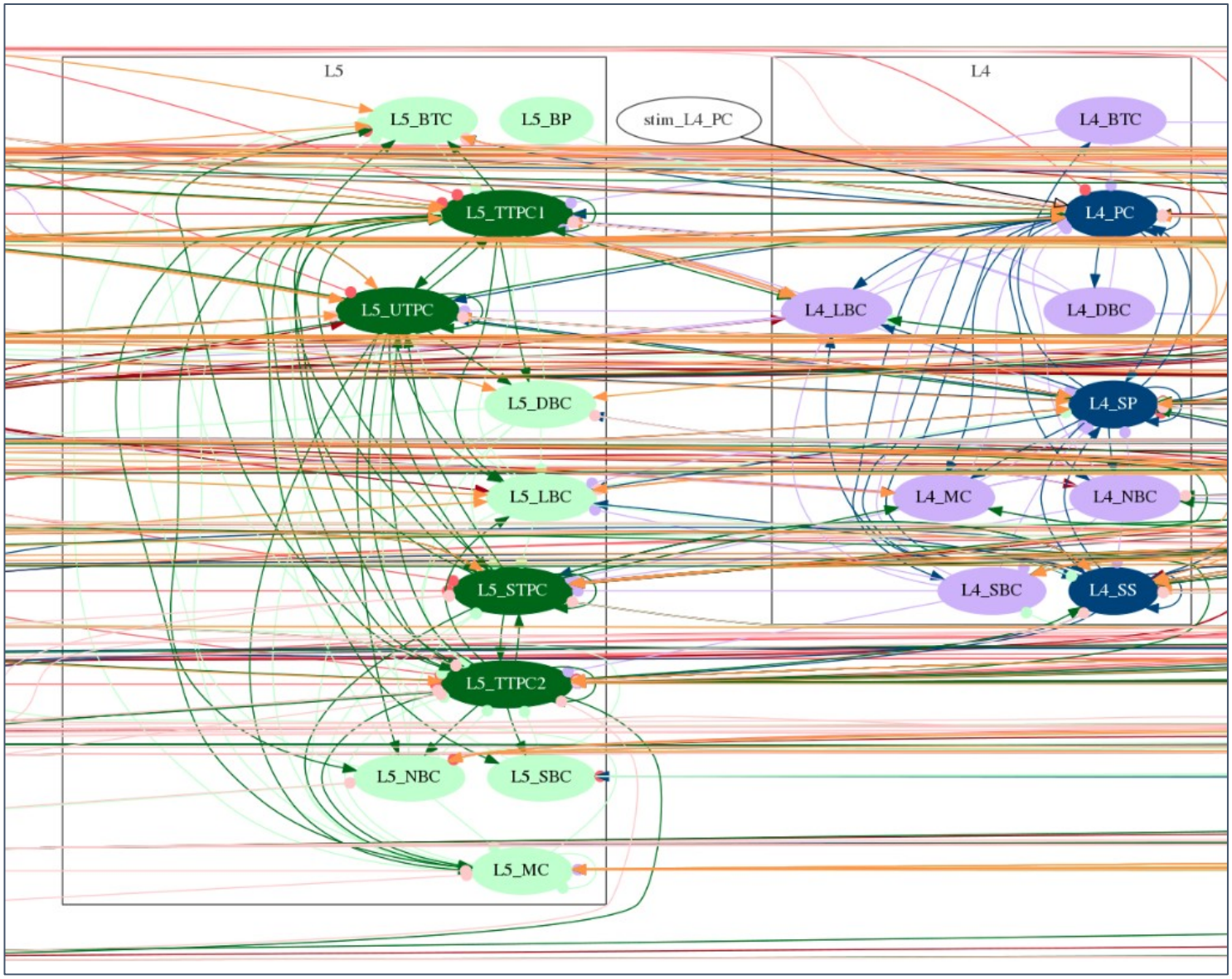
2000
0
−2000
−4000

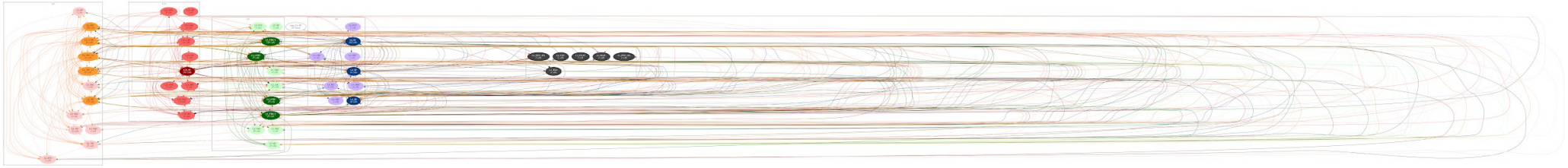

L23
L5
L4
L6
SupBask
L23PyrRS
SupLTS
L23PyrFRB
SupAxAx
L5TuftRS
L5TuftIB
L4SpinStell
DeepBask
DeepLTS
DeepAxAx
L6NonTuftRS


OPEN SOURCE BRAIN
search projects
My Projects
Explore OSB
Help
Admin
M1 Network Model
Return to project
Connectivity
Model Description
Results
Run
Play
Pause
Stop
M1_5percent.IT_L23[0].v
Membrane potential (V)
Time (s)
Continuous Activity - M1_5percent - net
Mean firing - M1_5percent - net
Spikes per second (Hz)
Raster plot - M1_5percent - net
Console
Experiments


L5
IT_L5A
IT_L5B
L6
IT_L6
CT_L6
SOM_L6
PV_L6
SOM_L5
PV_L5
PT_L5B
L4
IT_L4
L23
IT_L23
PV_L23
SOM_L23







OPEN SOURCE BRAIN

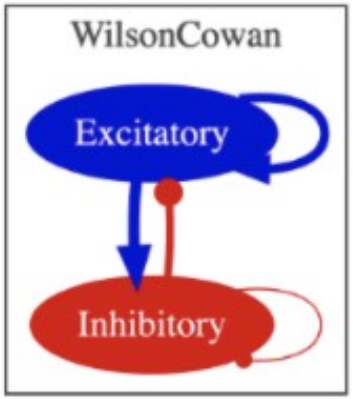
[NeuroML]

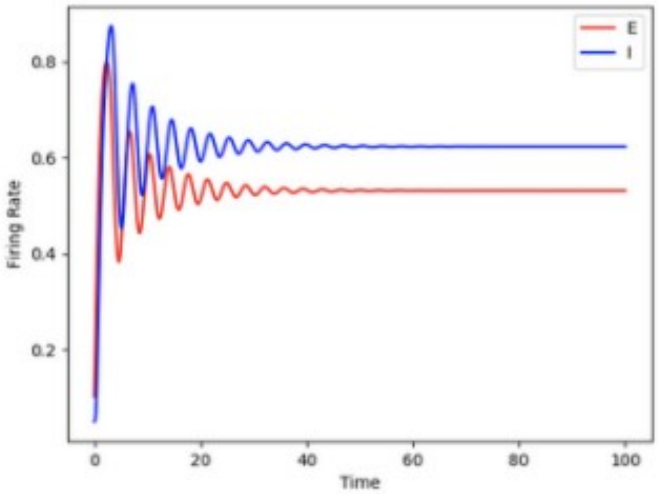
wellcome

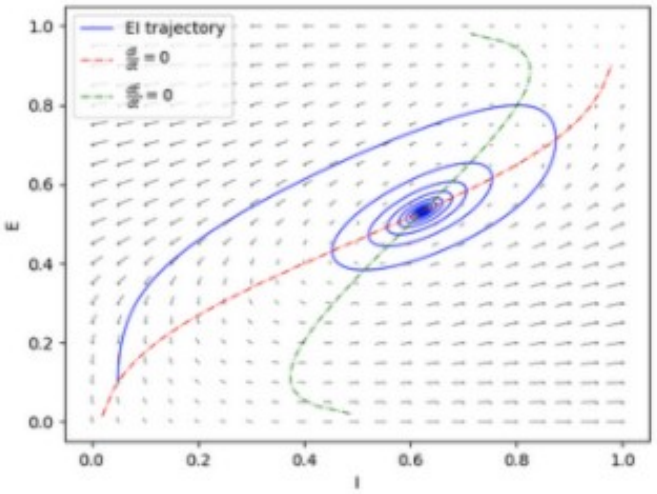
Wilson and Cowan – Excitatory and Inhibitory populations

$$\tau_e \frac{dr_e}{dt} = -r_e + \phi(w_{ee} \cdot r_e - w_{ei} \cdot r_i - z_e)$$

$$\tau_i \frac{dr_i}{dt} = -r_i + \phi(w_{ei} \cdot r_e - w_{ii} \cdot r_i - z_i)$$







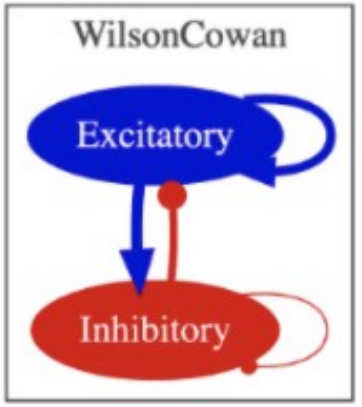

```
-wee 20. -wei 21. -wie 16. -wii 6 -ze 1.6 -zi 7. -ie1 0 -ii1 0 -w 0.25
```

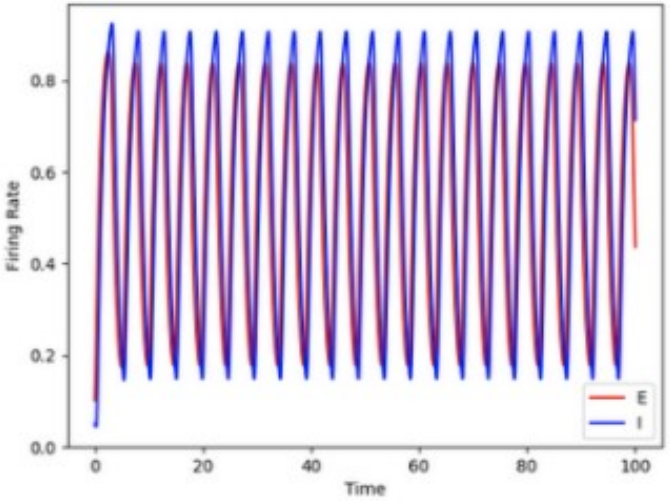
OPEN SOURCE BRAIN [NeuroML]

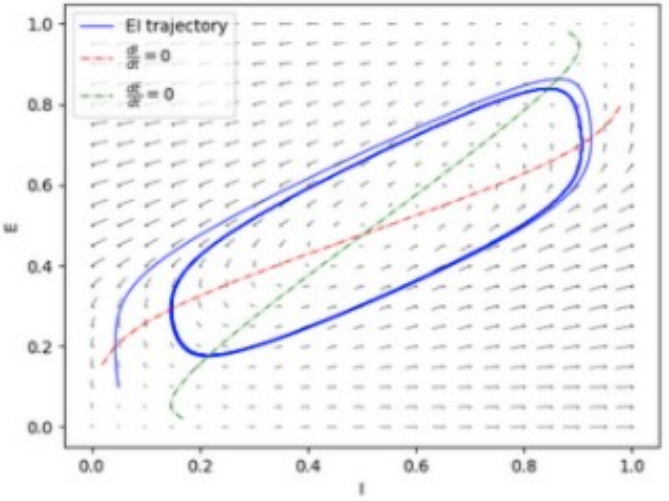
Wilson and Cowan – Excitatory and Inhibitory populations

$$\tau_e \frac{dr_e}{dt} = -r_e + \phi(w_{ee} \cdot r_e - w_{ei} \cdot r_i - z_e)$$

$$\tau_i \frac{dr_i}{dt} = -r_i + \phi(w_{ei} \cdot r_e - w_{ii} \cdot r_i - z_i)$$



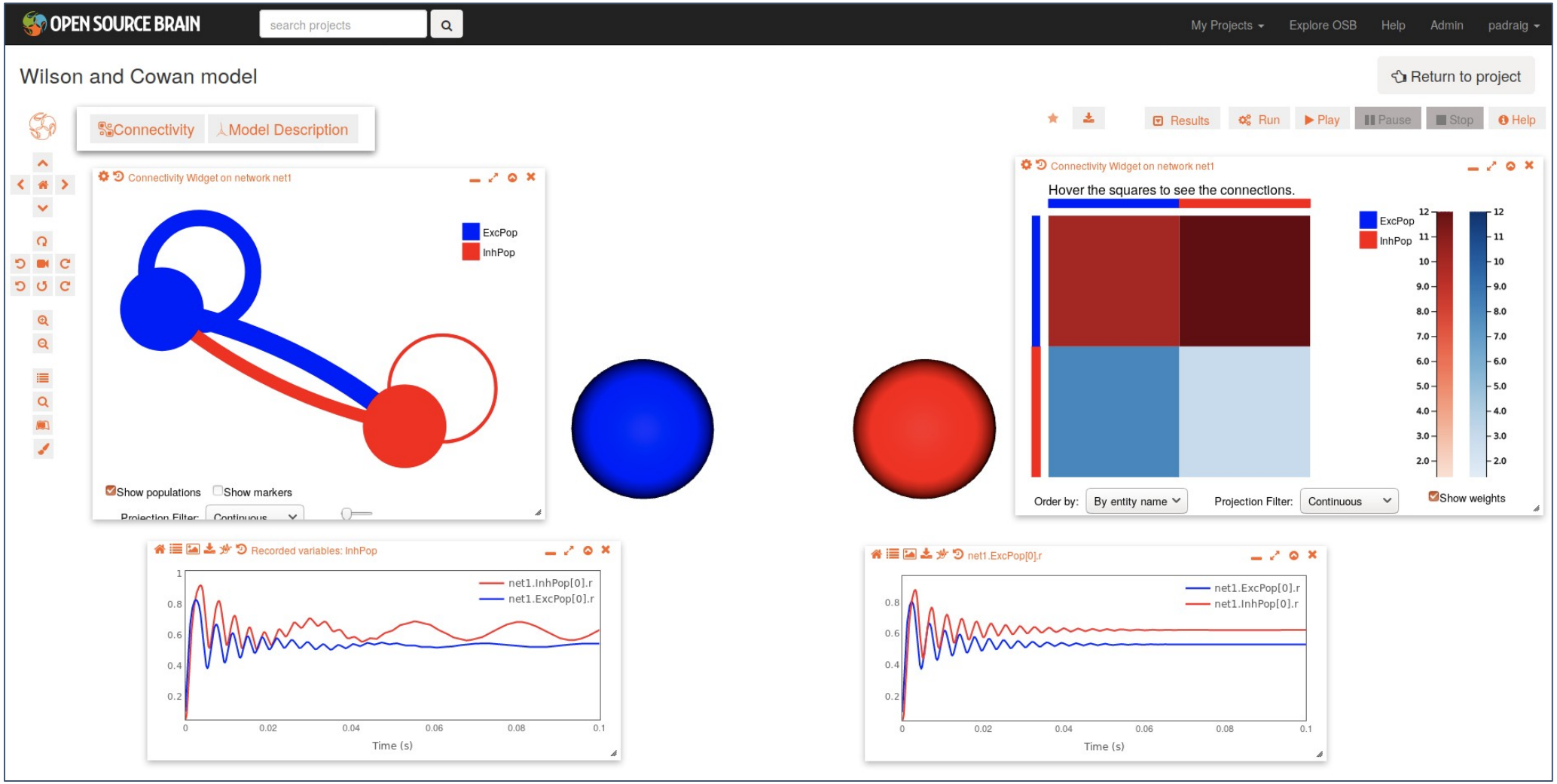




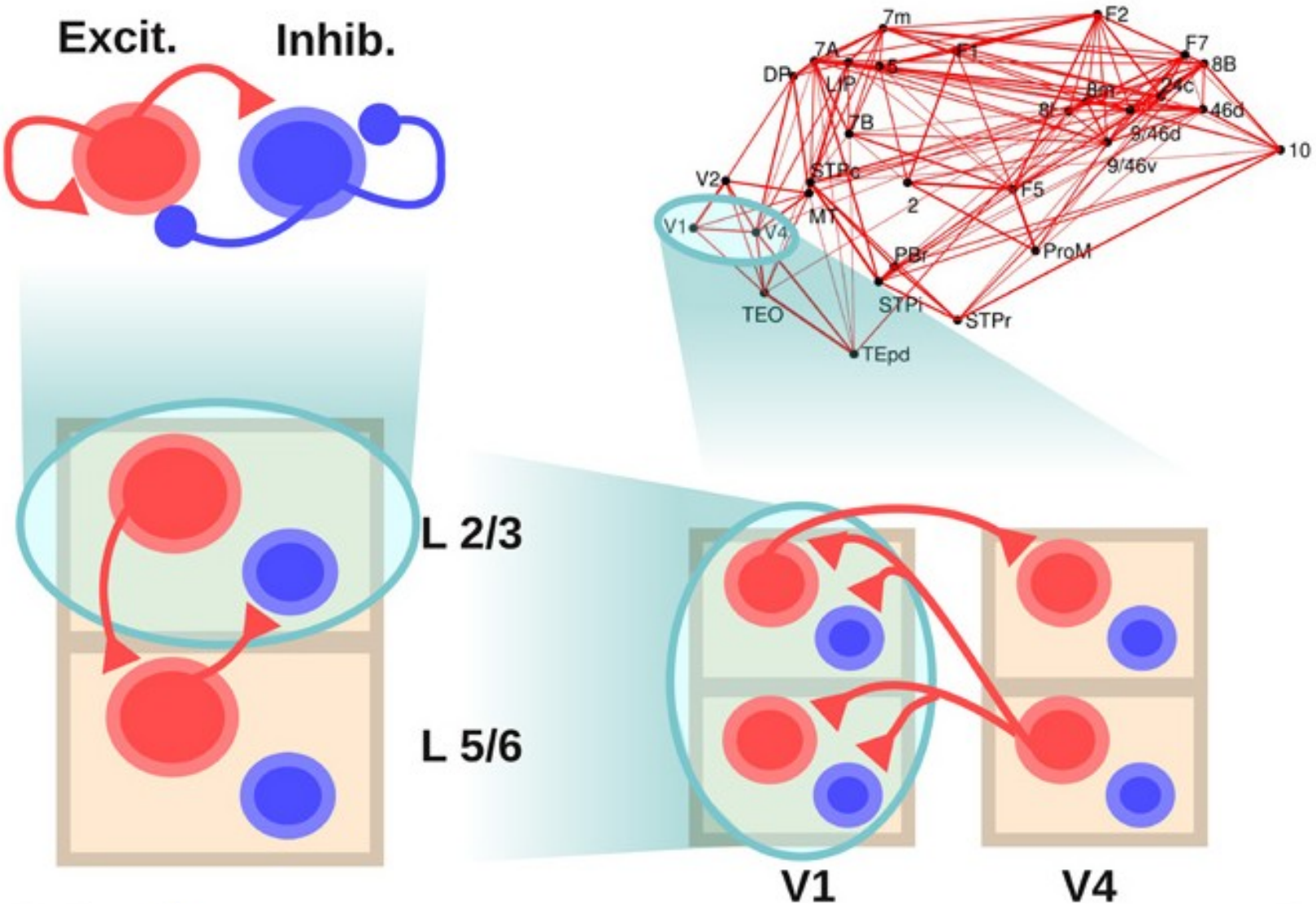

```
-wee 10. -wei 9. -wie 5. -wii 3 -ze 3 -zi 4. -ie1 0 -ii1 0 -w 0.25
```

OPEN SOURCE BRAIN [NeuroML]

Wilson and Cowan – Excitatory and Inhibitory populations

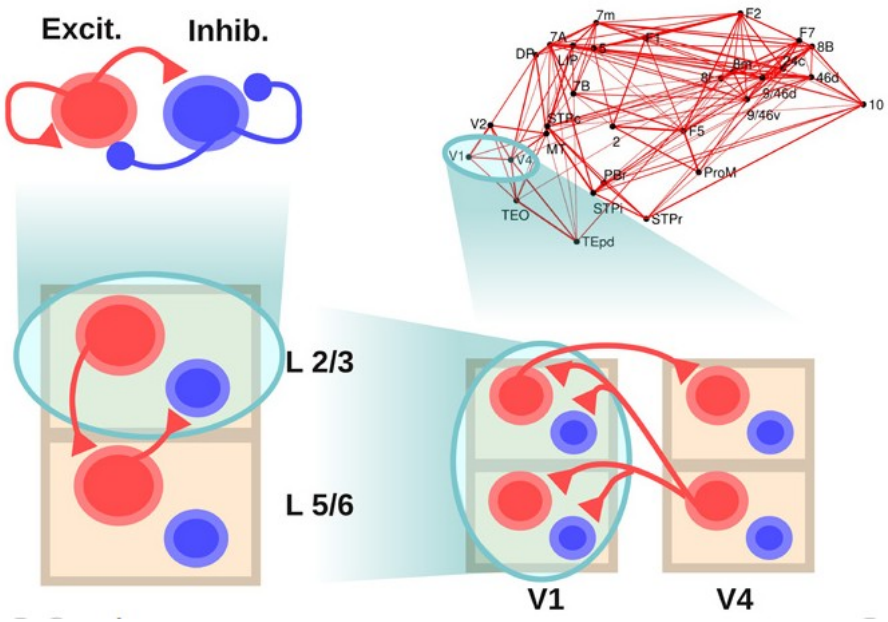


OPEN SOURCE BRAIN [NeuroML]



JF Mejias, JD Murray, H Kennedy, and X-J Wang, Feedforward and Feedback Frequency-Dependent Interactions in a Large-Scale Laminar Network of the Primate Cortex. Science Advances, 2016

OPEN SOURCE BRAIN [NeuroML]



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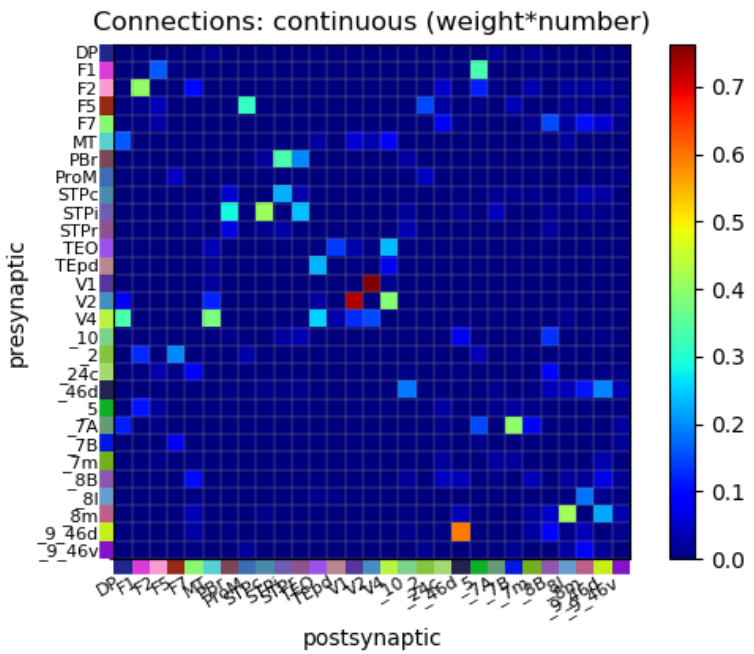
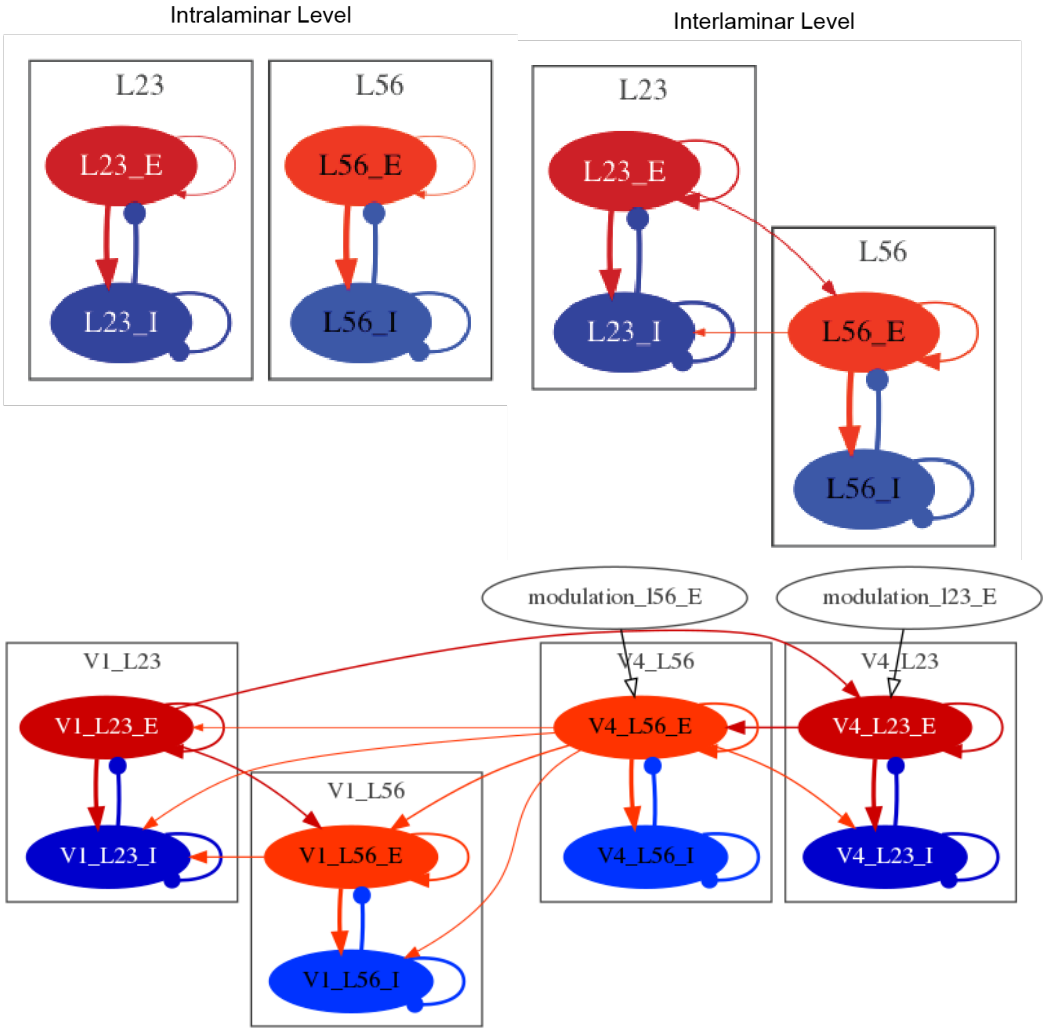
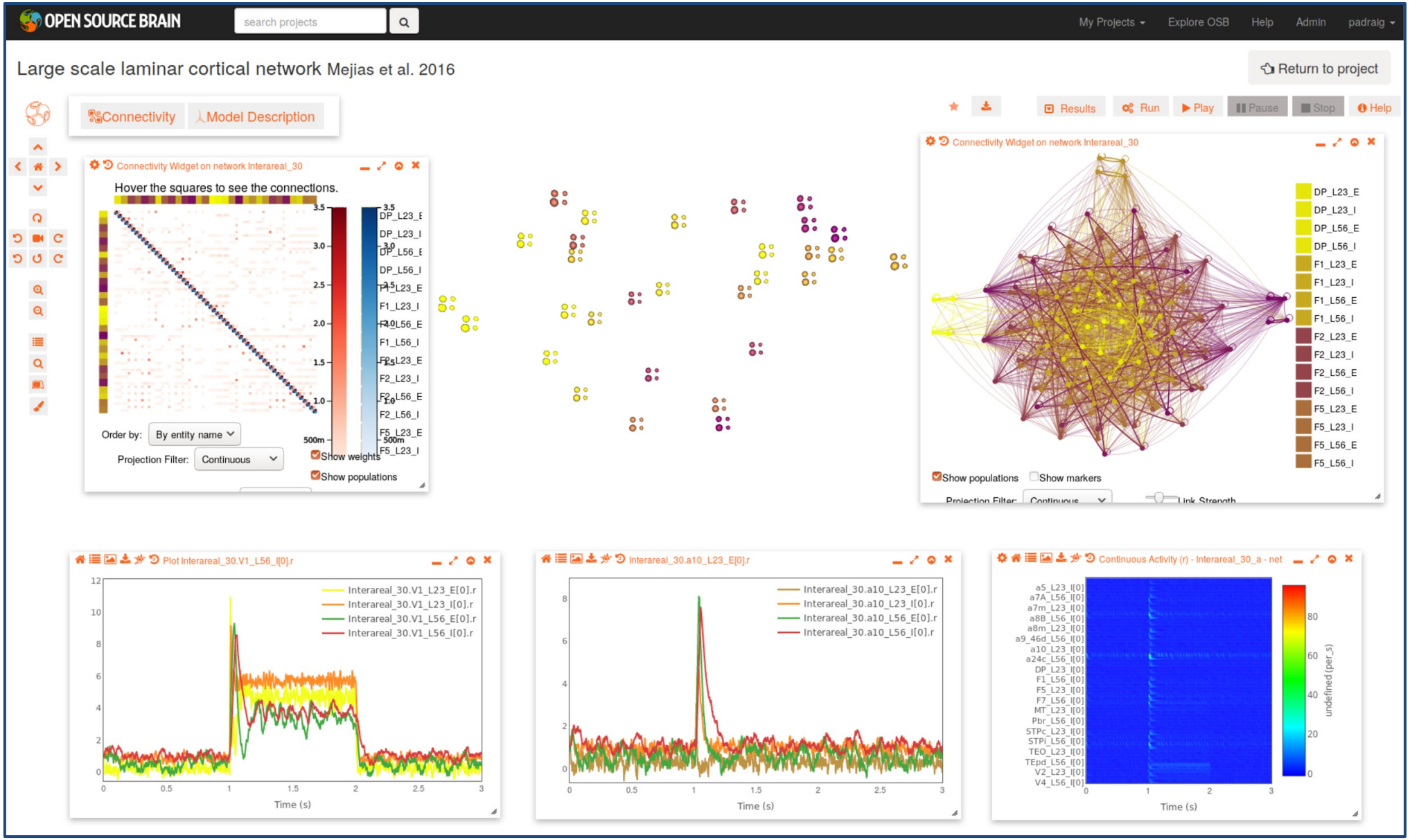




Jessica Dafflon, Kings College
Google Summer of Code 2018


OPEN SOURCE BRAIN
search projects
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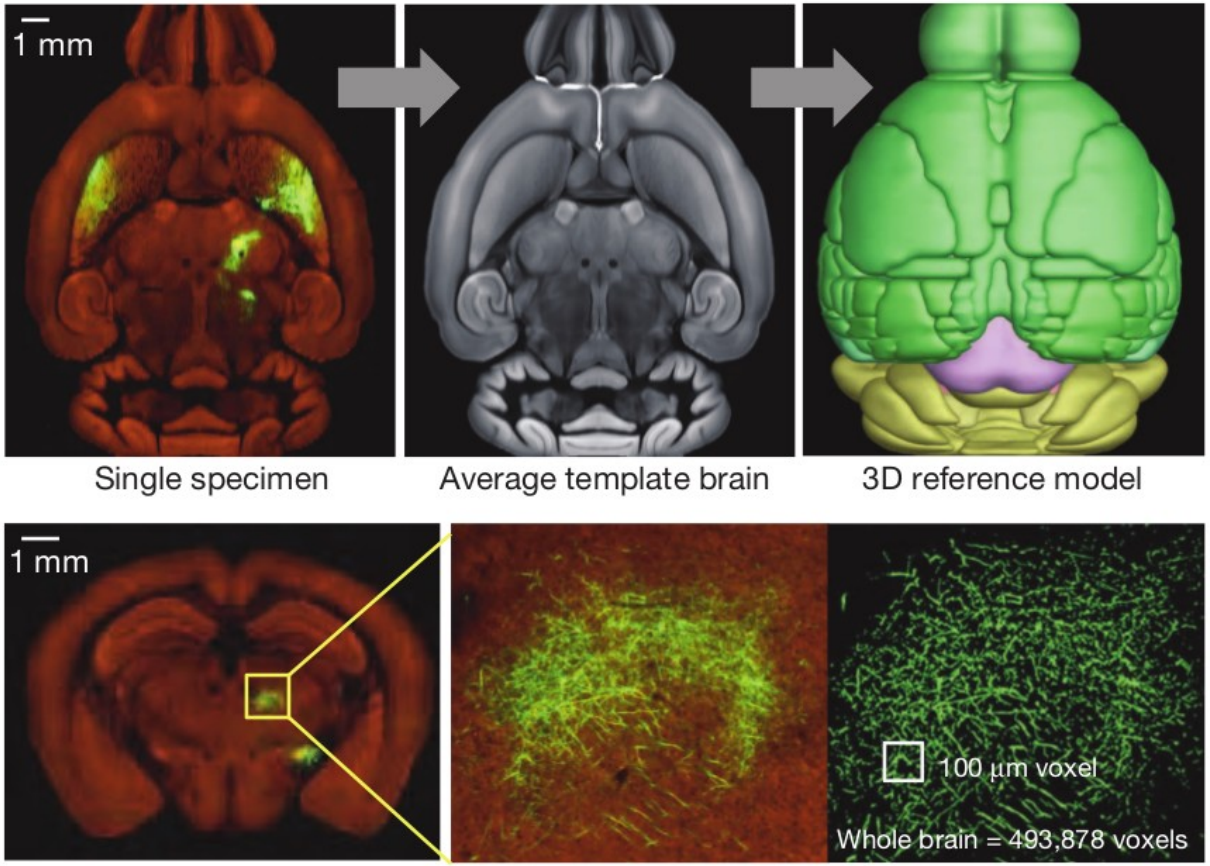
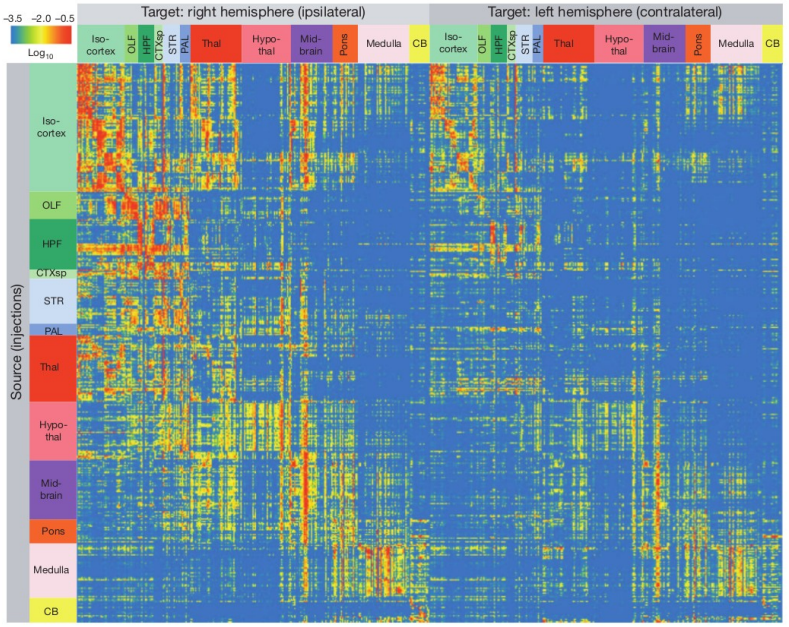
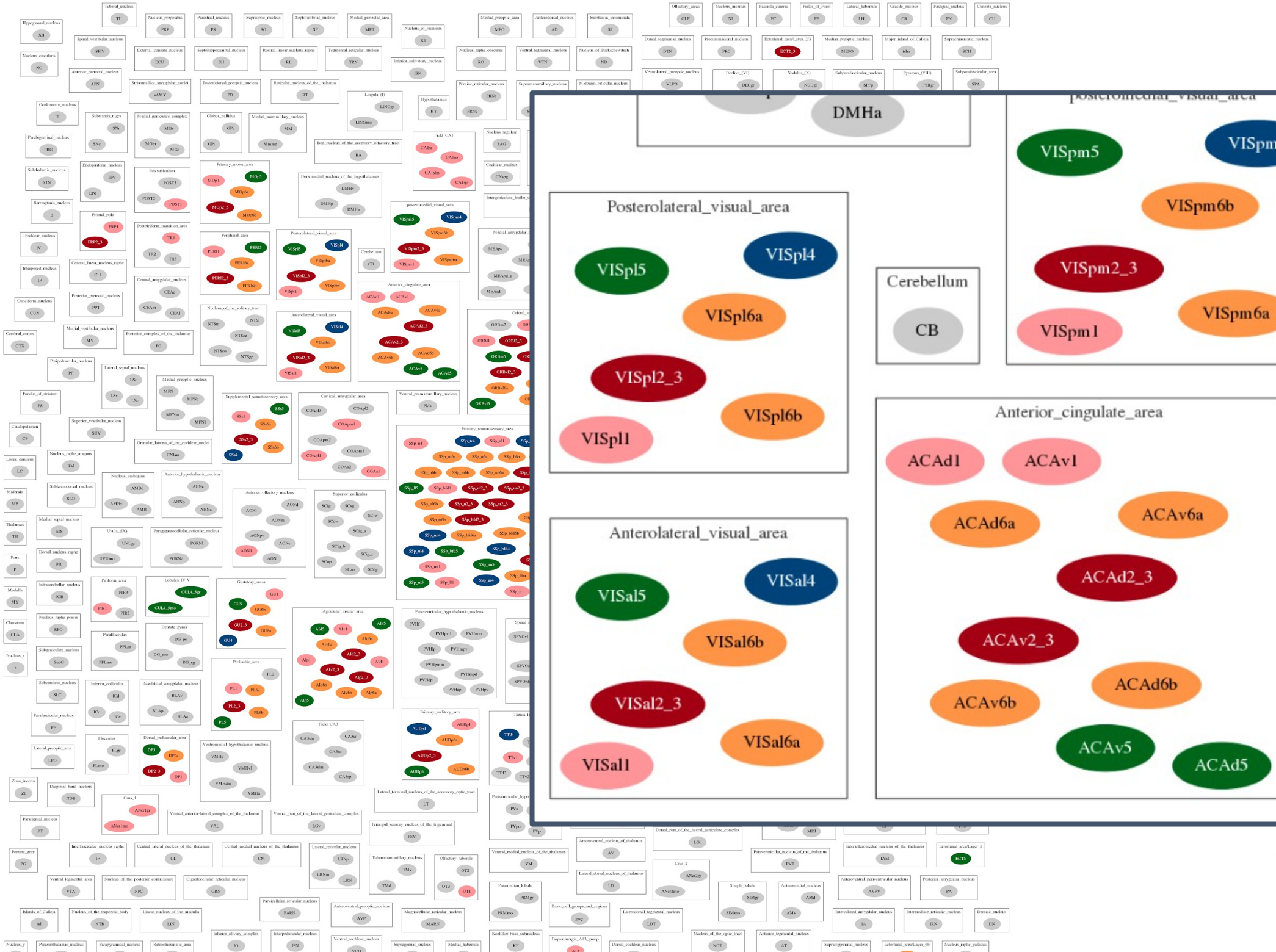
Help
Admin
padraig
Large scale laminar cortical network Mejias et al. 2016
Return to project
Connectivity
Model Description
Results
Run
Play
Pause
Stop
Help
Connectivity Widget on network Interareal_30
Hover the squares to see the connections.
Order by:
By entity name
Projection Filter:
Continuous
Show weights
Show populations
Show markers
Link Strength
DP_L23_E
DP_L23_I
DP_L56_E
DP_L56_I
F1_L23_E
F1_L23_I
F1_L56_E
F1_L56_I
F2_L23_E
F2_L23_I
F2_L56_E
F2_L56_I
F5_L23_E
F5_L23_I
F5_L56_E
F5_L56_I
Plot Interareal_30.V1_L56_I[0].r
Interareal_30.V1_L23_E[0].r
Interareal_30.V1_L23_I[0].r
Interareal_30.V1_L56_E[0].r
Interareal_30.V1_L56_I[0].r
Time (s)
Interareal_30.a10_L23_E[0].r
Interareal_30.a10_L23_I[0].r
Interareal_30.a10_L56_E[0].r
Interareal_30.a10_L56_I[0].r
Time (s)
Continuous Activity (r) - Interareal_30_a - net
a5_L23_I[0]
a7A_L56_I[0]
a7m_L23_I[0]
a8B_L56_I[0]
a8m_L23_I[0]
a9_46d_L56_I[0]
a10_L23_I[0]
a24c_L56_I[0]
DP_L23_I[0]
F1_L56_I[0]
F5_L23_I[0]
F7_L56_I[0]
MT_L23_I[0]
Pbr_L56_I[0]
STPc_L23_I[0]
STPi_L56_I[0]
TEO_L23_I[0]
TEpd_L56_I[0]
V2_L23_I[0]
V4_L56_I[0]
undefined (per_s)
Time (s)





A mesoscale connectome of the mouse brain, Oh et al.
Nature 2014


DMHa
Posterolateral_visual_area
VISpl5
VISpl4
VISpl6a
VISpl2_3
VISpl6b
VISpl1
Cerebellum
CB
VISpm5
VISpm6b
VISpm2_3
VISpm6a
VISpm1
Anterolateral_visual_area
VISal5
VISal4
VISal6b
VISal2_3
VISal6a
VISal1
Anterior_cingulate_area
ACAd1
ACAv1
ACAd6a
ACAv6a
ACAd2_3
ACAv2_3
ACAd6b
ACAv6b
ACAv5
ACAd5

MouseLight Neuron Browser

hhmi janelia Research Campus

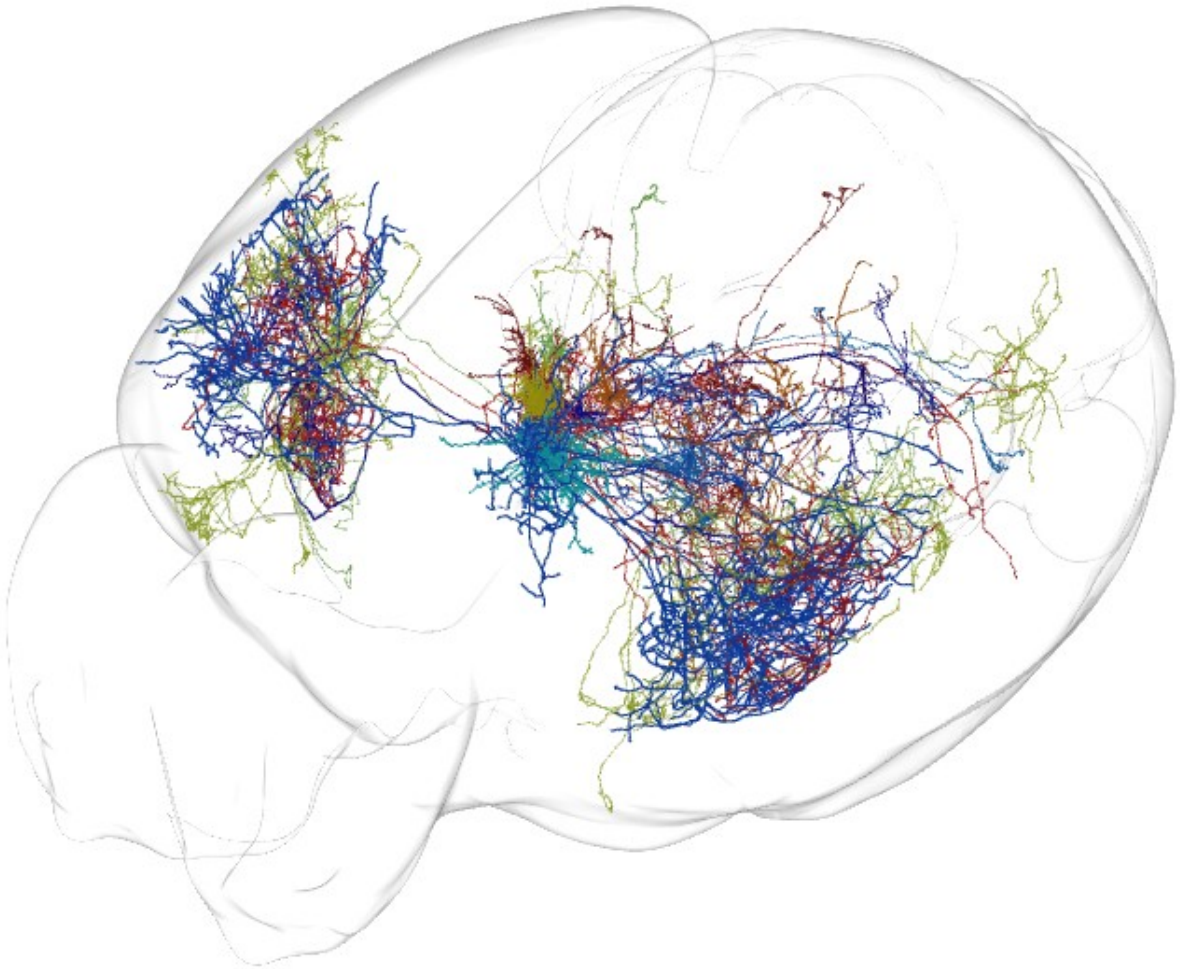
Tutorial Video

Reset

Matched 29 of 502 neurons

Neurons

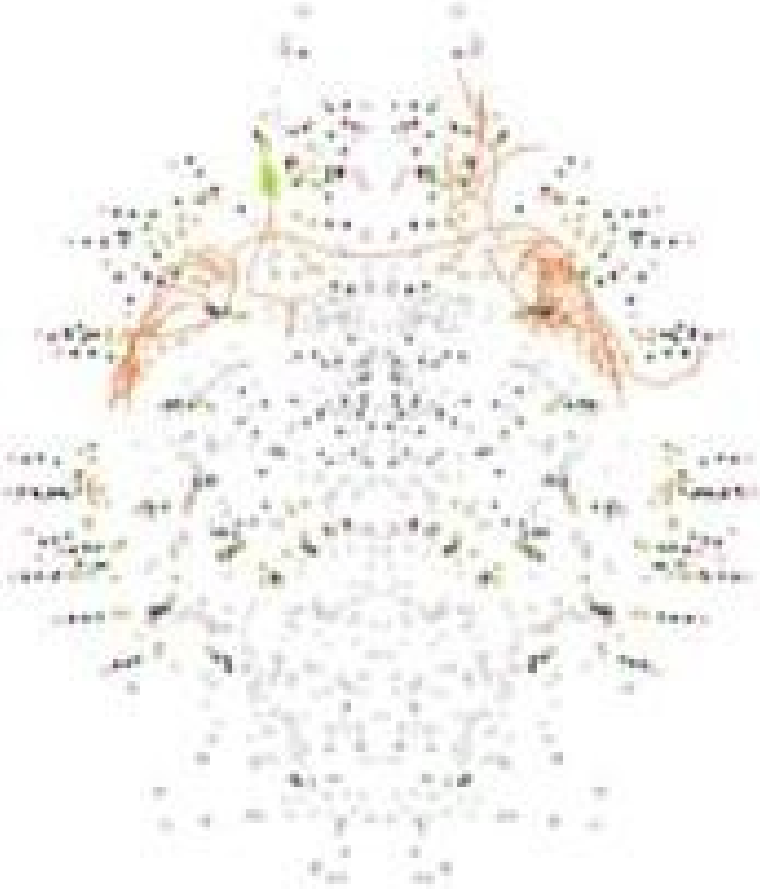
Fetching neuron tracings (37 remaining)



OPEN SOURCE BRAIN

[NeuroML]

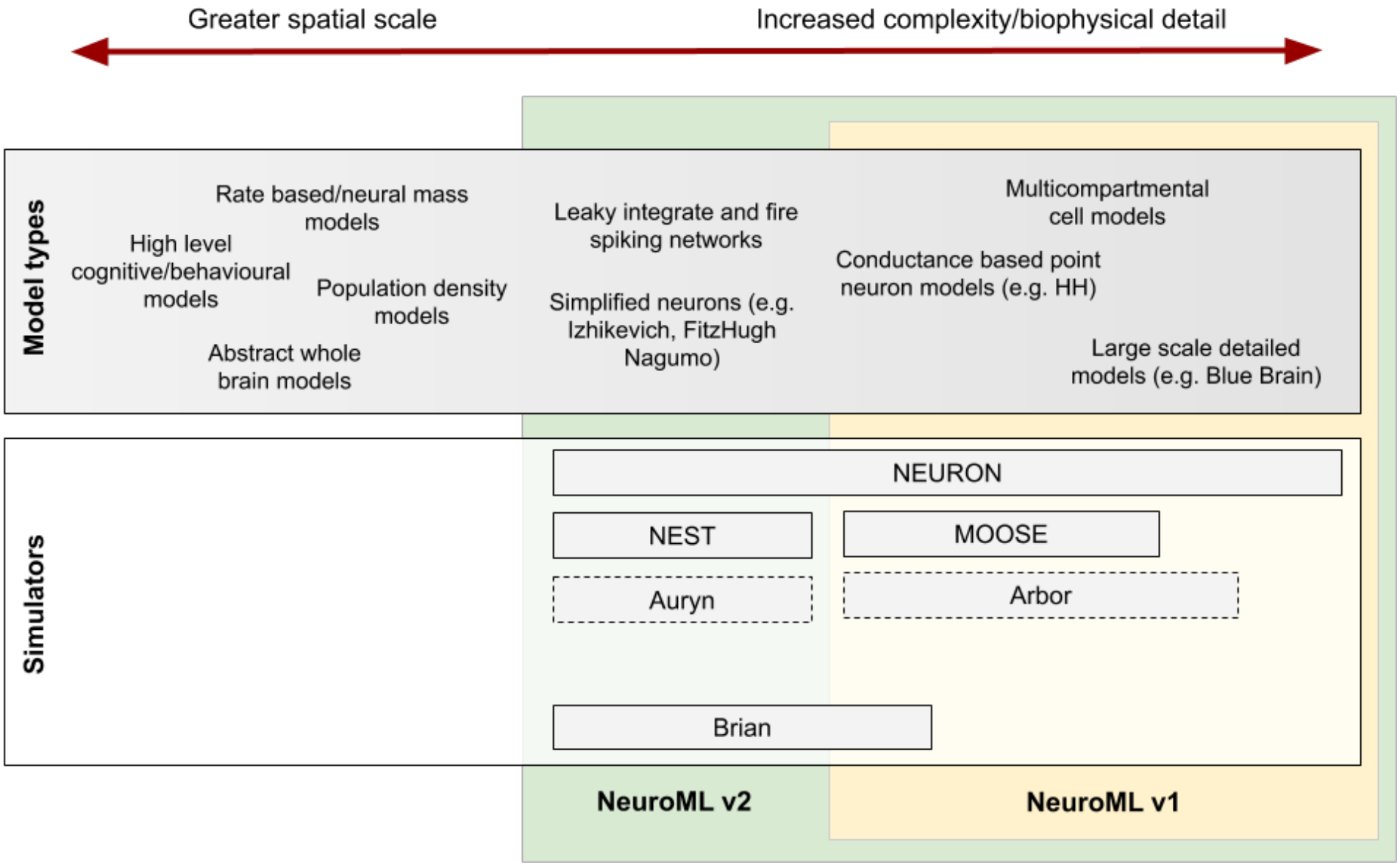
wellcome



Greater spatial scale ← → Increased complexity/biophysical detail

Model types

- High level cognitive/behavioural models
- Rate based/neural mass models
- Population density models
- Abstract whole brain models
- Leaky integrate and fire spiking networks
- Simplified neurons (e.g. Izhikevich, FitzHugh Nagumo)
- Conductance based point neuron models (e.g. HH)
- Multicompartmental cell models
- Large scale detailed models (e.g. Blue Brain)



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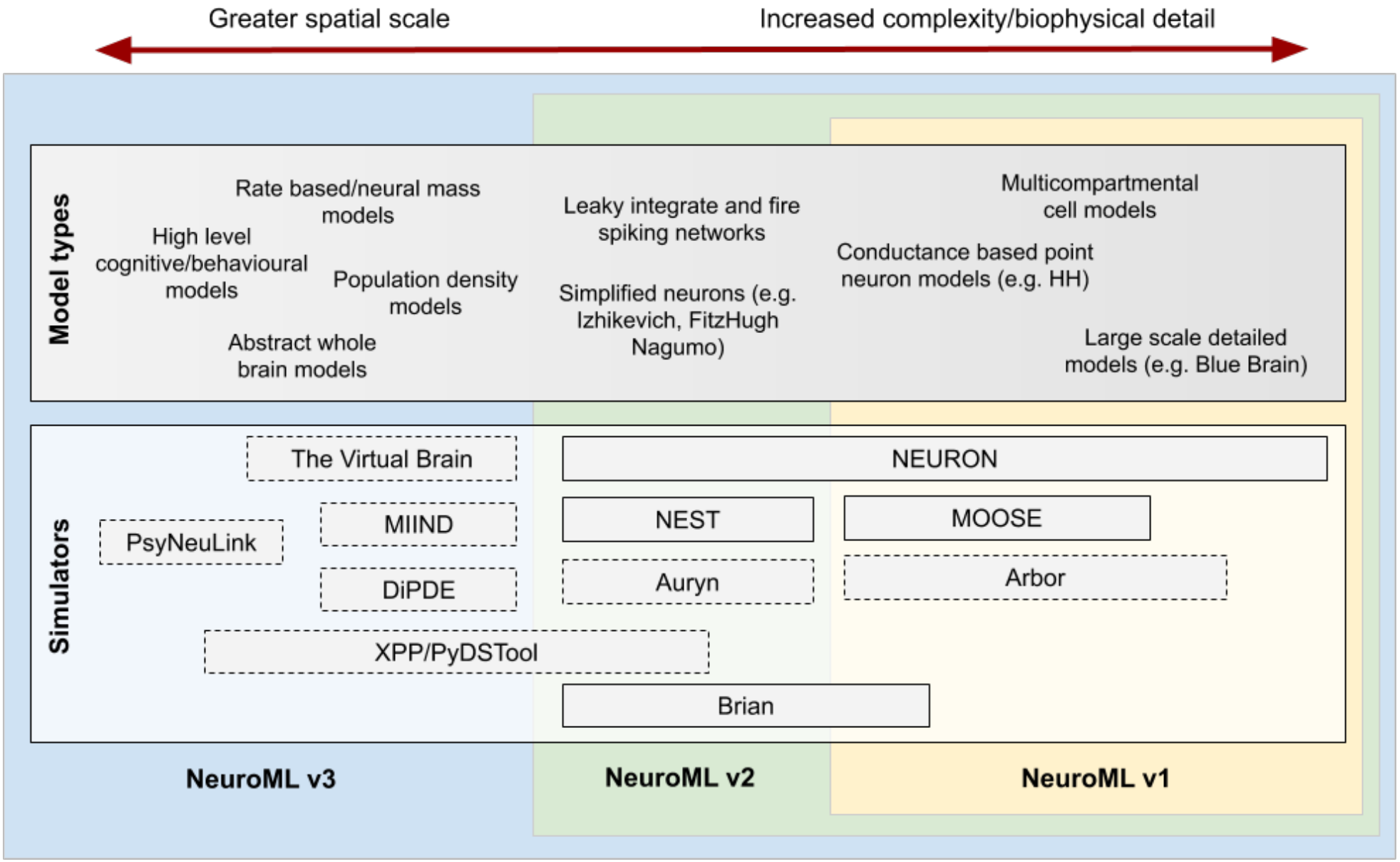

OPEN SOURCE BRAIN [NeuroML]

INCF SIG on Standardised Representations of Network Structures

> This SIG deals with the various tools and formats for creating and sharing representations of biological neuronal networks, and will work towards ensuring these are as interoperable and usable as possible for computational neuroscientists.

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Andrew Davison
Stephen Larson
Avrama Blackwell

Members of the NeuroML community

OpenWorm project

MetaCell

Coordinating initiatives

Funding sources