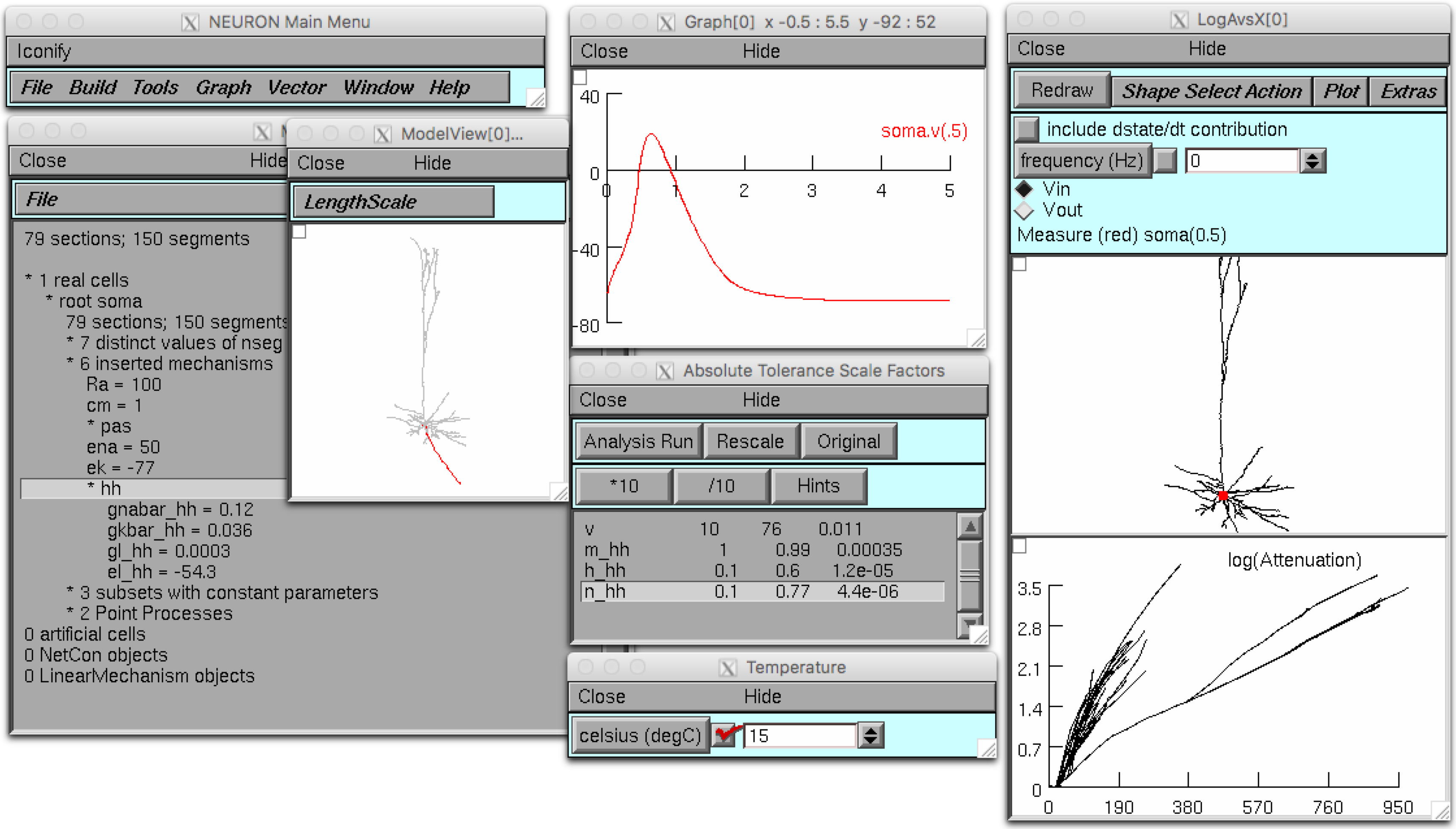
NEURON

http://neuron.yale.edu

NEURON is a tool for *developing*, *simulating*, and *analysing* empirically-based models of neurons and networks of neurons. NEURON supports all classes of spiking models and runs on both desktops and supercomputers.



Powerful GUI tools • Fully Python scriptable • Large networks and single cells • Morphologically and biophysically detailed cells, integrate-and-fire cells, and anything in between • Run on a single core or on 128,000 processors.

Plans and in development

Features

- Standards support: NeuroML, SBML.
- Extracellular reaction-diffusion (rxd).
- Stochastic rxd simulations.
- 3D intracellular rxd simulation.

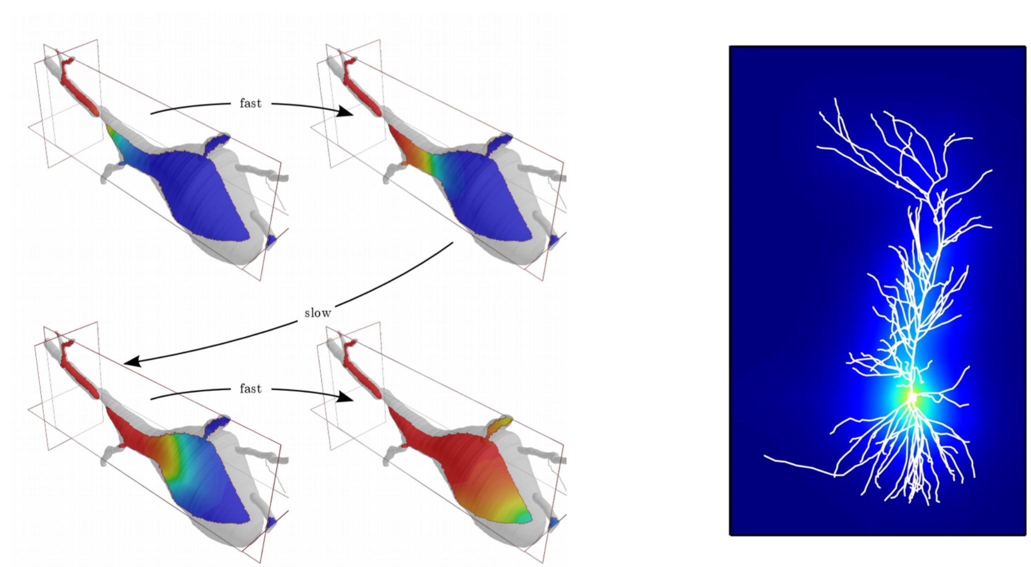
Performance enhancements

- GPU support.
- Faster reaction-diffusion.

Better documentation

- Recently released Python programmer’s reference.

Migliore et al 2014. Olfactory bulb network model. Up to 69,000 cells. modeldb.yale.edu/151681



3D intra- (left) and extracellular (right) reaction-diffusion simulations.

More NEURON Resources

API documentation (both Python and HOC):
https://neuron.yale.edu/neuron/static/py_doc/index.html

ModelDB (over 575 NEURON models):
http://modeldb.yale.edu

NEURON forum (over 14,000 posts):
https://neuron.yale.edu/phpBB/

Tutorials:
http://neuron.yale.edu/neuron/docs

NEURON courses:
Week-long NEURON course every summer.
Day-long NEURON course before each Society for Neuroscience conference.

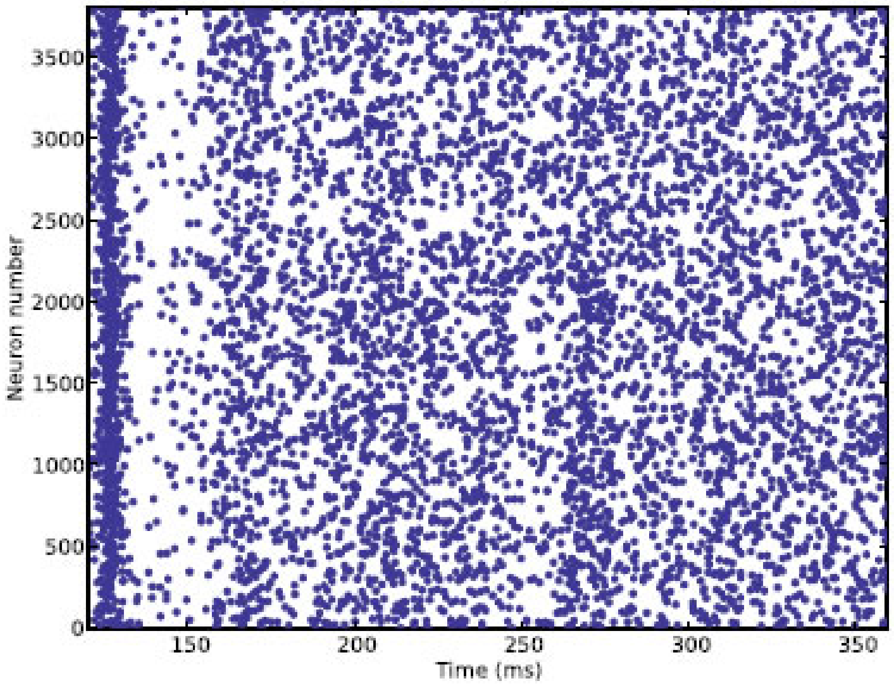
Brian 2

http://briansimulator.org

Brian 2 is a free, open source simulator for spiking neural networks. It is designed to be easy to learn and use, highly flexible and easily extensible.

Brian 2 allows for concise but complete descriptions of neural and synaptic models, based on mathematical equations and physical units.

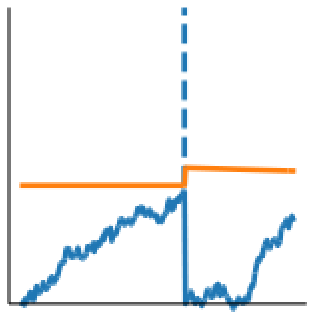
```
from brian2 import *
eqs = '''
dv/dt  = (ge+gi-(v+49*mV))/(20*ms) : volt
dge/dt = -ge/(5*ms)                : volt
dgi/dt = -gi/(10*ms)               : volt
'''
P = NeuronGroup(4000, eqs, threshold='v>-50*mV',
                reset='v=-60*mV')
P.v = -60*mV
Pe = P[:3200]
Pi = P[3200:]
Ce = Synapses(Pe, P, on_pre='ge+=1.62*mV')
Ce.connect(p=0.02)
Ci = Synapses(Pi, P, on_pre='gi-=9*mV')
Ci.connect(p=0.02)
M = SpikeMonitor(P)
run(1*second)
plot(M.t/ms, M.i, '.')
show()
```



The user-provided model descriptions are transformed into executable code in a low-level language (e.g. C++). This *code generation* approach permits to benefit from the flexibility and ease-of-use of a high-level language with the execution speed of a low-level language.

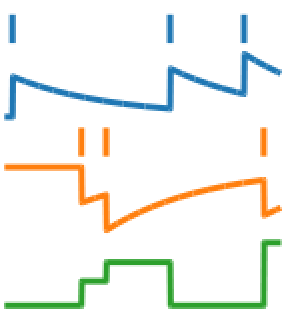
General formalism allows to define a wide range of neural and synaptic models

Noisy adaptive integrate-and-fire neuron



```
G = NeuronGroup(N,
                '''dv/dt = 1/Cm * (I + g_L * (E_L - v)) + noise*xi: volt
                   dv_th/dt = -(v_th - v_th0) / tau_th : volt
                   I : amp''',
                threshold='v > v_th',
                reset='''v = v_r
                      v_th += 3*mV''')
```

Spike-timing dependent plasticity (STDP)



```
S = Synapses(source, target,'''w : 1
                          dapre/dt = -apre / taupre : 1 (event-driven)
                          dapost/dt = -apost / taupost : 1 (event-driven)''',
             on_pre='''ge += w
                    apre += Apre
                    w = clip(w + apost, 0, gmax)''',
             on_post='''apost += Apost
                     w = clip(w + apre, 0, gmax)''')
```

Simulations can be executed on a variety of targets

"runtime mode" – generated code is executed directly from the Python main loop
→ generated code can be numpy or C++ code

"standalone mode" – generated code is written to disk and executed separately
→ C++ code, with optional support for multiple processor cores via OpenMP
→ with *Brian2GeNN*: C++ code for the *GeNN* simulator, compiling into CUDA code for the GPU

Resources for Brian 2

Brian documentation (including examples and tutorials)
http://brian2.readthedocs.io

Mailing lists
https://groups.google.com/group/briansupport
https://groups.google.com/group/brian-development

Publications
Goodman DF and Brette R (2009). The Brian simulator. *Frontiers Neurosci*
doi: 10.3389/neuro.01.026.2009
Stimberg M, Goodman DFM, Benichoux V, Brette R (2014). Equation-oriented specification of neural models for simulations. *Frontiers Neuroinf*
doi: 10.3389/fninf.2014.00006

Related software packages
Brian2GeNN (code generation for GPUs via the GeNN simulator)
http://brian2genn.readthedocs.io
Brian2tools (tools for visualization and model export)
http://brian2tools.readthedocs.io

NEST: The Neural Simulation Tool

http://www.nest-simulator.org

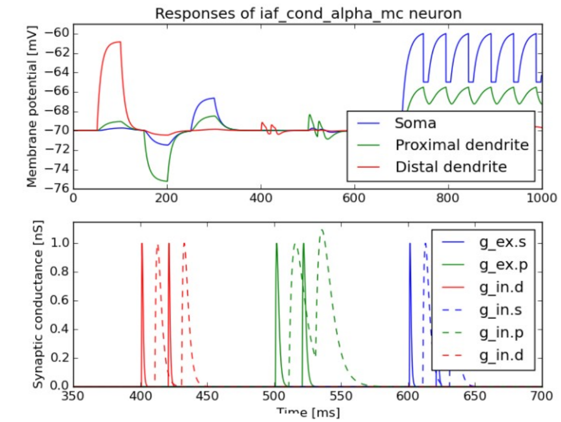
NEST is a simulator for spiking neural network models focussing on the dynamics, size and structure of neural systems rather than on the exact morphology of individual neurons. NEST is ideal for networks of spiking neurons of any size, from individual neurons to whole-brain models.

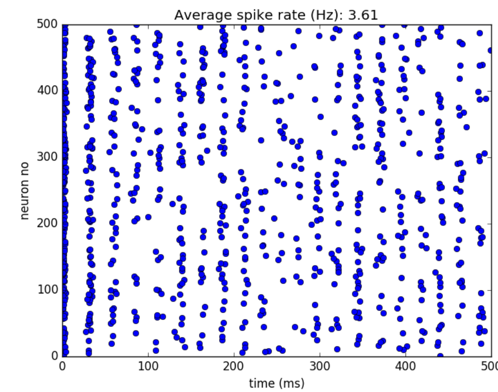
NEST: A powerful simulator

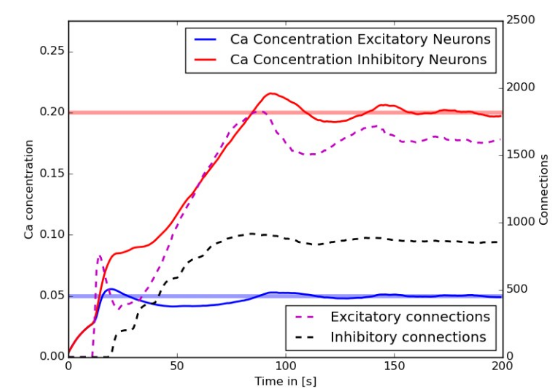
- Focused on networks of spiking point neurons
- Supports
    - Many neuron models including Hogdkin-Huxley style and few-compartment models
    - Synaptic plasticity including neuromodulatory signals
    - Structural plasticity
    - Gap junctions
    - Spatially structured networks

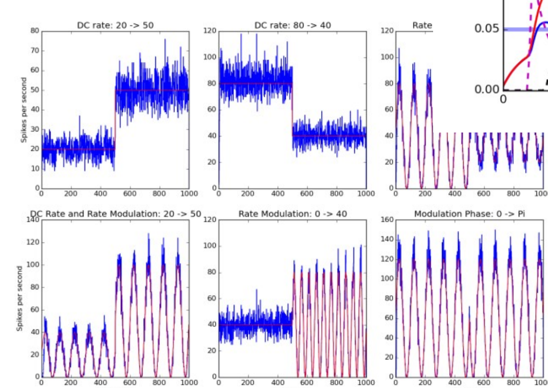
  •Python interface

  •Scales from laptops to supercomputers
- Active user and developer community
- Systematic quality control by continuous integration testing and code review
- Based on over 20 years of experience



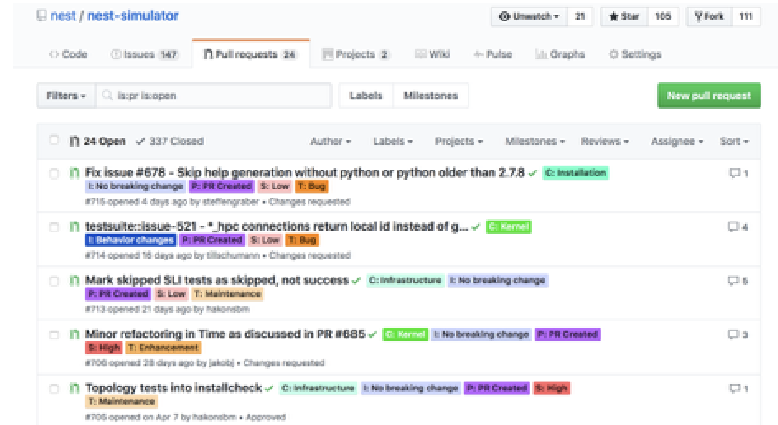


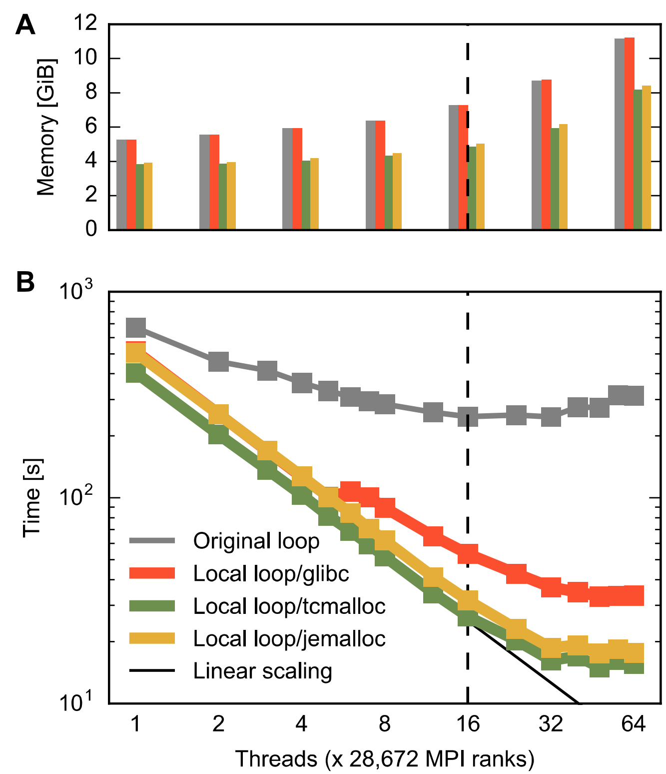




NEST Development

- Active developer community on Github
- Regular open developer video conferences
- Focus on improving performance and usability
- Some current projects
    - Support for rate models
    - NESTML: Automatic code generation for neuron models
    - NESTIO: Efficient data recording to binary file formats
    - Dry-run mode: Efficient performance analysis on supercomputers
    - Improved network construction speeds for highly threaded simulations
- Regular publications on NEST simulation technology





Ippen et al (2017)

More NEST Resources

Simulator homepage

http://www.nest-simulator.org

Github repository

http://github.com/nest/nest-simulator

NEST User mailing list

http://mail.nest-initiative.org/cgi-bin/mailman/listinfo/nest_user

NEST Initiative

http://www.nest-initiative.org

Annual NEST User Workshop

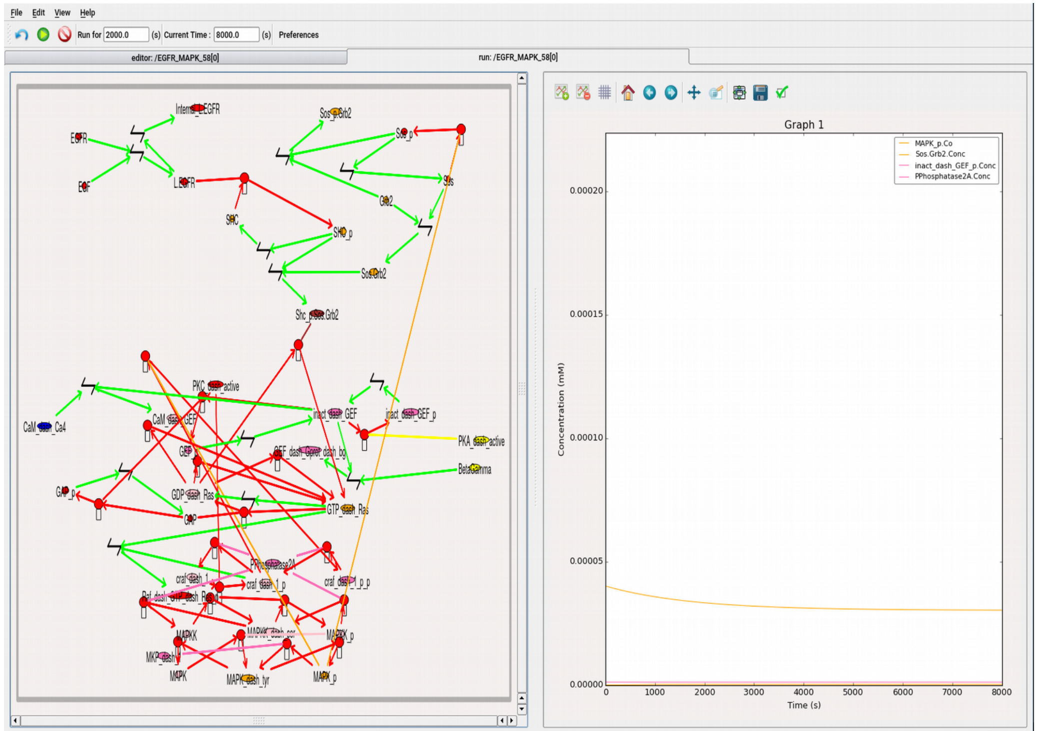
MOOSE

Multiscale Object Oriented Simulation Environment

https://github.com/BhallaLab/moose

MOOSE is designed to simulate neural systems ranging from biochemical signaling to complex models of single neurons, circuits, and large networks. MOOSE can operate at many levels of detail, from stochastic chemical computations, to multicompartment single-neuron models, to spiking neuron network models.

Example: multiscale model



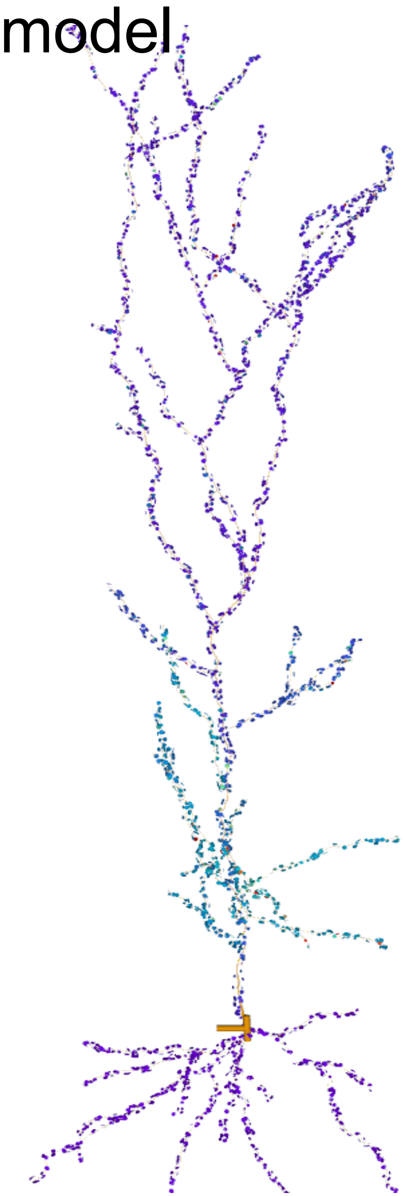
GUI for building and running chemical models.

```
import moose
import rdesigneur as rd
rdes = rd.rdesigneur(
    stimList = [['soma', '1', '.', 'inject', '(t>0.1 && t<0.2) * 2e-8' ]],
    plotList = [['soma', '1', '.', 'Vm', 'Soma membrane potential']]
)
rdes.buildModel()
moose.reinit()
moose.start( 0.3 )

rdes.display()
```

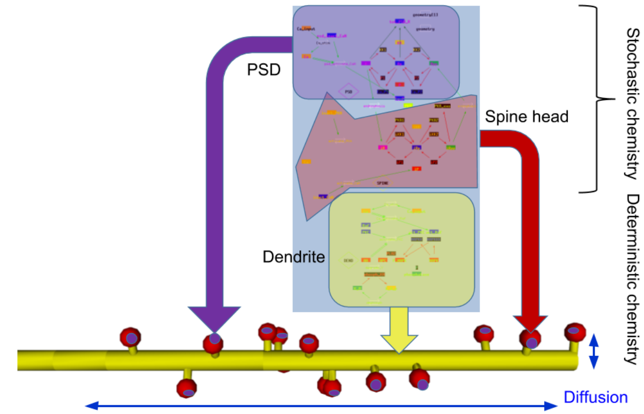
Fully **Python scriptable**. **rdesigneur** interface to integrate chemical and electrical model.

- Morphology from Hippocampal CA1 pyramidal neuron
  - NeuroMorpho.org
- More than 3000 compartments, ion channels in each.
- Roughly 5000 spines with user defined distribution.
- Full reaction set in each spine and morpho compartment
- Background synaptic input at 0.1 Hz
- Patterned synaptic input on groups of spines → Ca influx
- Ca → signaling, signaling → channel modulation



3d visualizer for neural activity (Linux Only).

Features and Plans



Features

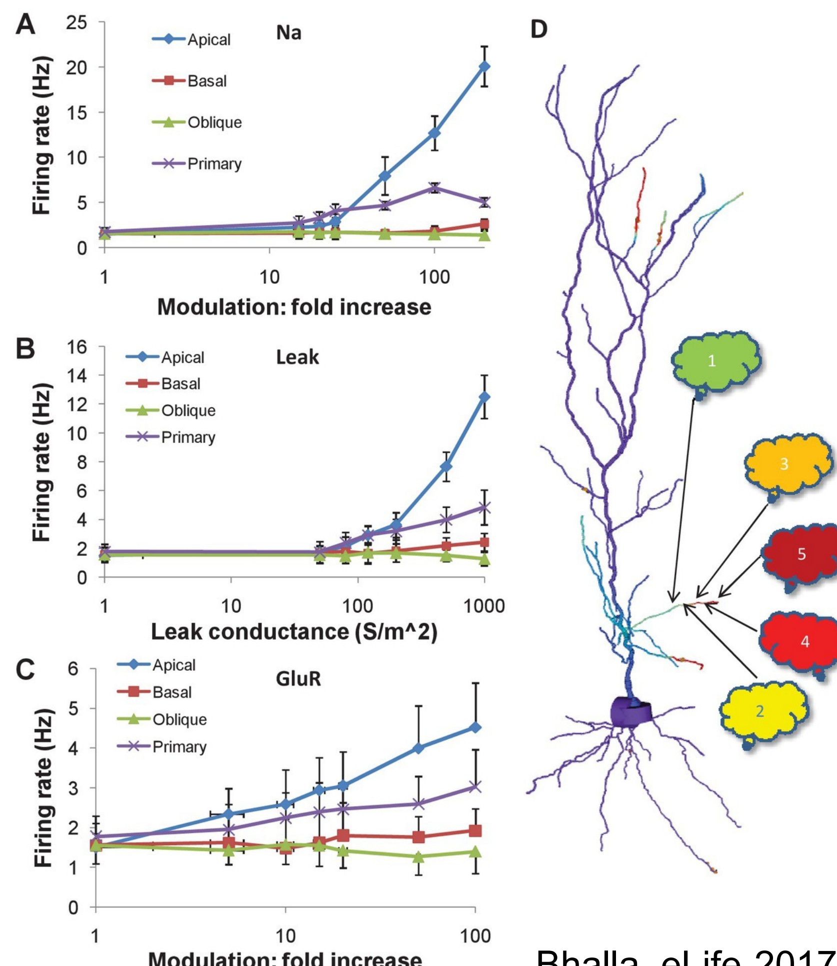
- Fast (written in C++) and easy to use (Python scriptable). **Rdesigneur** library to integrate chemical and electrical models easily.
- Chemical model formats support: SBML, NeuroML(v-1.8) and genesis format. Neuron morphology: SWC format.
- GUI for building chemical models.
- User documentation and many examples
- Linux (via OBS) and MacOSX (via Homebrew).

In development

- Hsolve being ported to GPU (alpha). Credit: GSoC-2015,2017).
- Multithreaded chemical solvers Gsolve/Ksolve/Dsolve (beta). Speed improves roughly linearly with number of cores.
- Major upgrade of documentation.
- Activity-driven morphology change

Future Plans

- Enhanced GPU and openMP support for various solvers.

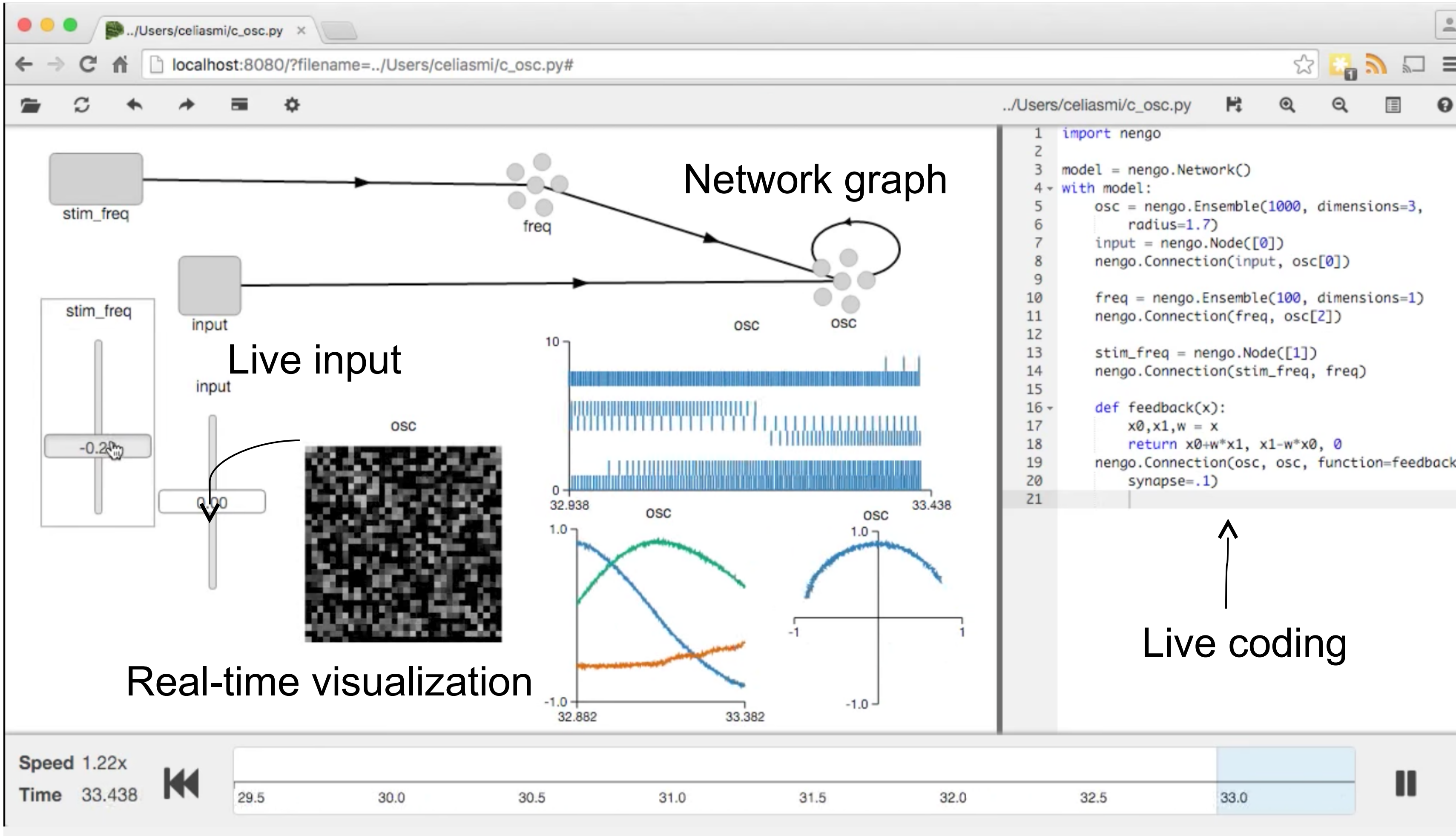


Bhalla, eLife-2017

Nengo 2.0

http://nengo.github.io

Nengo is a graphical and scripting based software package for simulating large-scale spiking and non-spiking neural systems. It supports CPUs, GPUs (single and multi), MPI, and neuromorphic chips.



Interactive simulation timeline

Documentation -- Usage and API documentation is at:

https://pythonhosted.org/nengo/

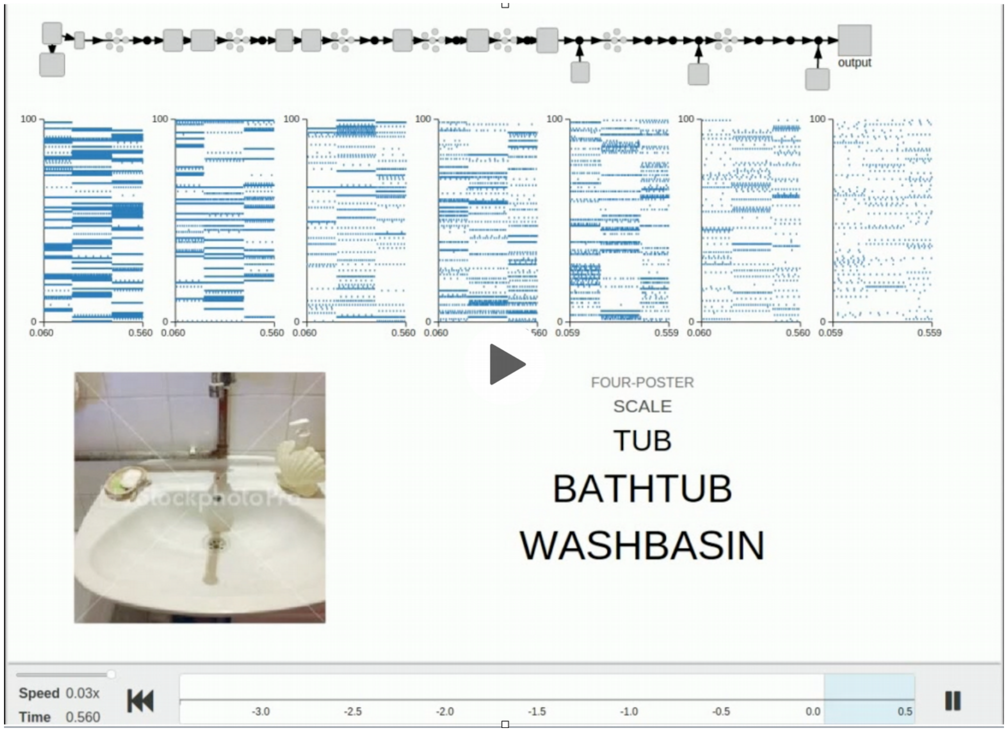
Getting Help -- Nengo forum at:

https://forum.nengo.ai

Screen cap from https://youtu.be/UVeIPKnQAL4

Application Highlights

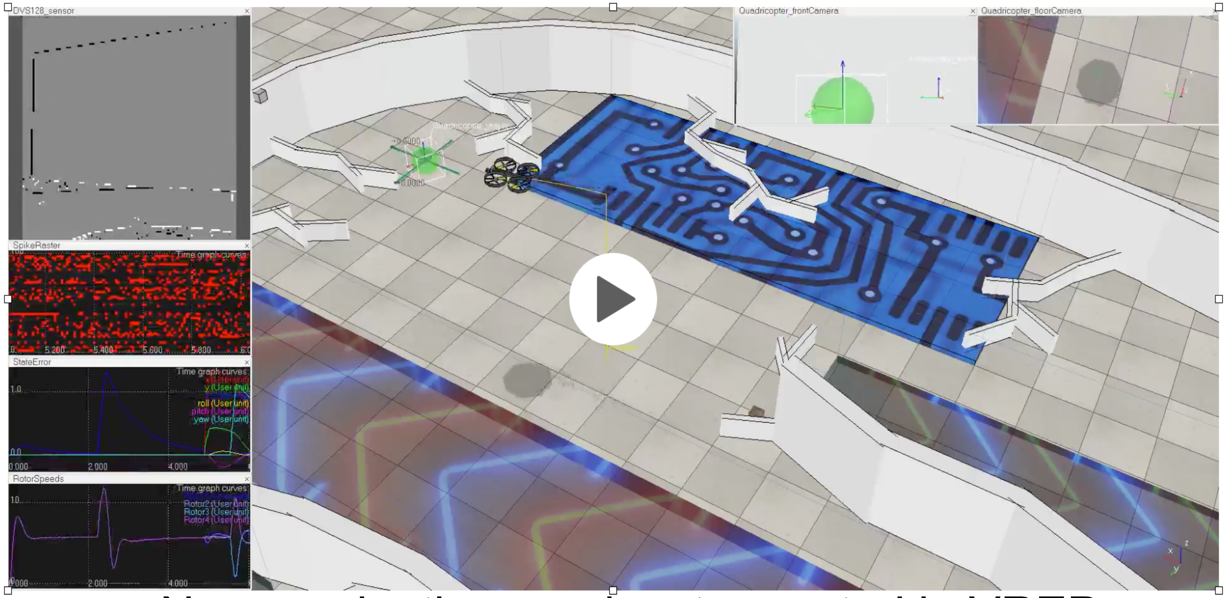
- Used to develop large-scale spiking deep networks
- Integration with robot simulators & platforms
- 6 DOF nonlinear adaptive control on neuromorphic hardware for 30x power savings
- Spaun large-scale neuro-cognitive model published in *Science*



Spiking ImageNet in Nengo
https://youtu.be/7R5F4mNURGc

Strengths

- *Scalability*: simulate millions of neurons efficiently
- *Integration*: combine deep learning, spiking, recurrent, and NEF networks
- *Learning*: on-line, spike-based, off-line, batch processing, STDP, RL, customizable



Nengo adaptive quadcopter control in VREP
https://youtu.be/KBwBX7bzohA

More Nengo Resources

In Development

- More complete NEURON integration
- Fully featured Semantic Pointer Architecture (SPA) library for cognitive modeling
- Additional tools for TensorFlow integration (Nengo DL)
- Additional backends for FPGAs, neuromorphic ASICs, etc.

Online Tutorials & Examples (in addition to documentation)

- Covering NEF and SPA methods in Nengo GUI

https://github.com/nengo/nengo_gui/tree/master/nengo_gui/examples/tutorial

- >40 Jupyter notebook examples covering core Nengo usage

https://pythonhosted.org/nengo/examples.html

- To accompany the book How to Build a Brain (2013)

https://github.com/nengo/nengo_gui/tree/master/nengo_gui/examples/hbb_tutorials

Additional resources

- Annual Nengo Summer School

http://nengo.ca/summerschool

- Information for current or prospective developers can be found at

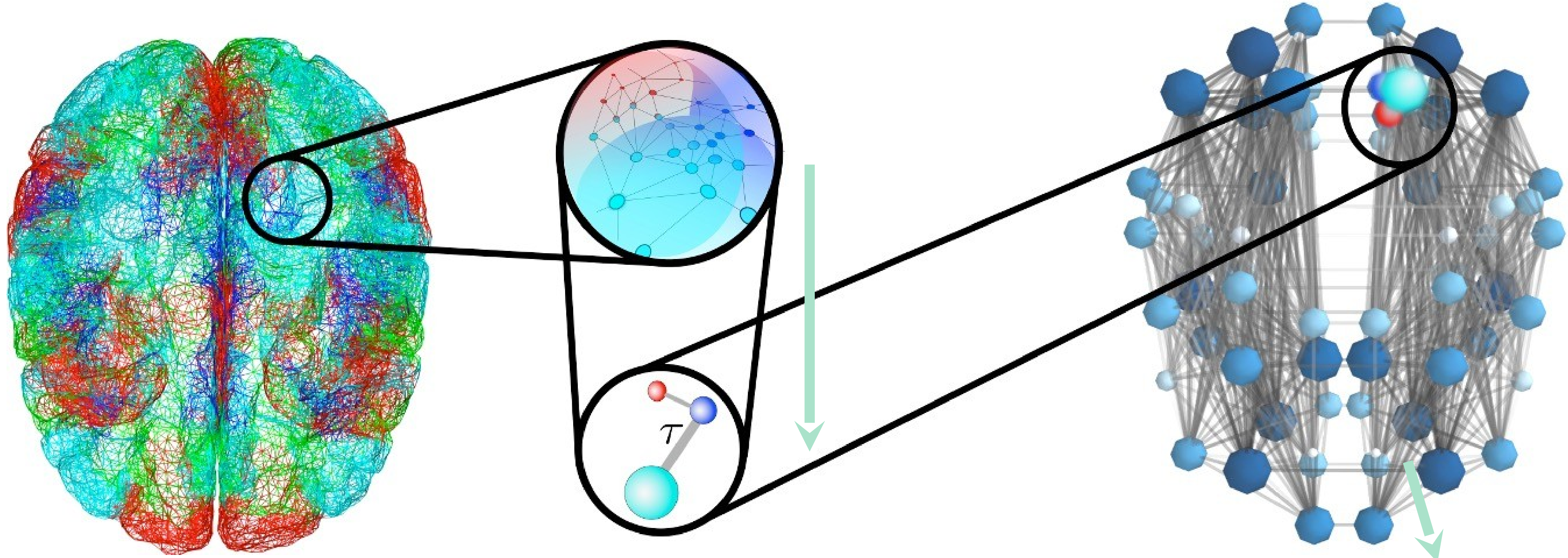
https://nengo.github.io/contributing.html

The Virtual Brain

http://www.thevirtualbrain.org

The Virtual Brain (TVB) is a neuroinformatics platform for full brain network simulations using biologically realistic connectivity. Itenables the model-based inference of neurophysiological mechanisms across different brain scales that underlie the generation of macroscopic neuroimaging signals including functional MRI (fMRI), EEG and MEG.

Large-scale brain networks



Network node:
Mean field modeling

Connectome:
connectivity & time delays

Human Brain Project

THEVIRTUALBRAIN.

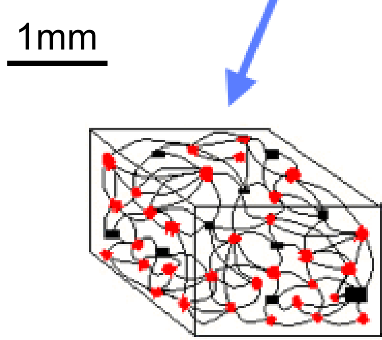
Microscopic unit of modeling: neuronal population

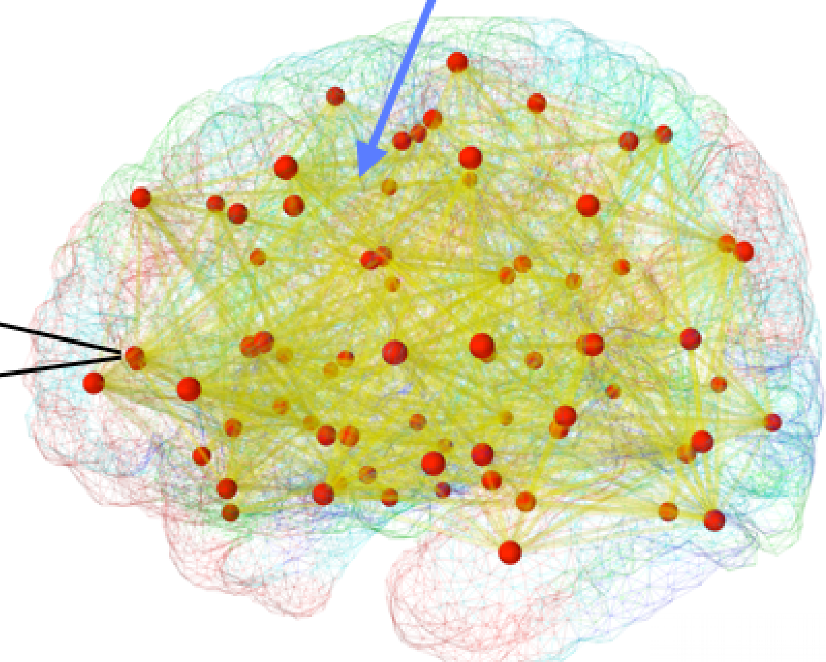
Local dynamics

Global dynamics

$$\psi(x,t) = N(\psi(x,t)) + \int_{local} g(x-x')S(\psi(x',t))dx' + \int_{global} G(x,x')S(\psi(x',t-\frac{|x-x'|}{v}))dx' + \text{noise}$$

Field potential





Neuronal population

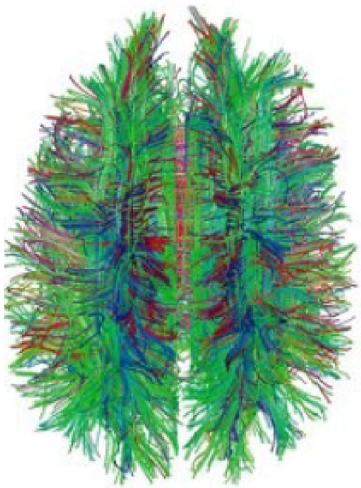
Jirsa et al IEEE 2002
Ghosh et al. PLoS CB 2008
Deco, Jirsa, McIntosh Nat Rev Neurosci 2011
Deco, Jirsa Journ Neurosci 2012
Deco, Jirsa, McIntosh TINS 2013
Ritter et al Brain Connectivity 2013

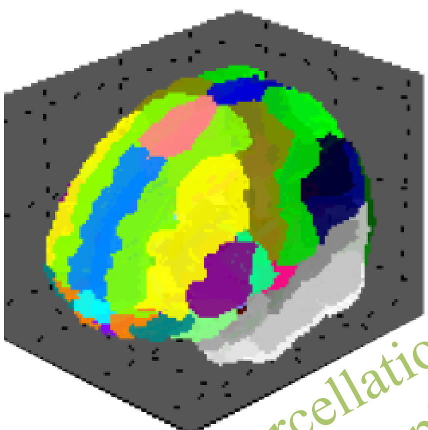
Sanz Leon et al Front NeuroInformatics 2013; Neuroimage 2015

THEVIRTUALBRAIN.

The Virtual Brain (TVB) platform release in 2012

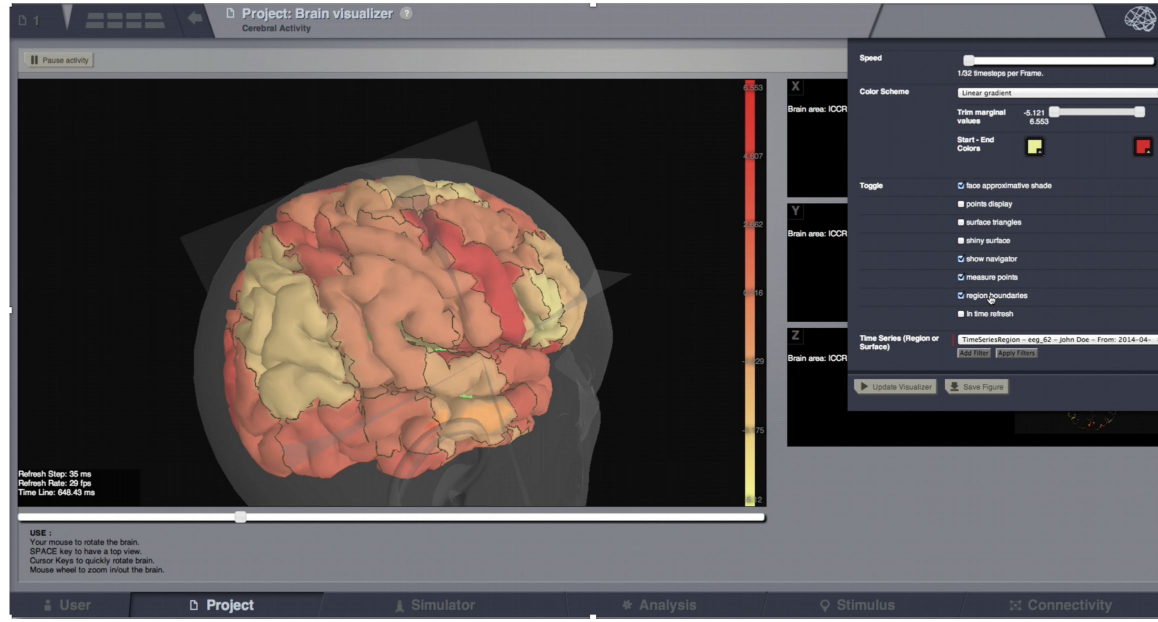
DTI/ Tractography





Parcellation Template

Jirsa et al IEEE 2002
Ghosh et al. PLoS CB 2008
Deco, Jirsa, McIntosh Nat Rev Neurosci 2011
Deco, Jirsa Journ Neurosci 2012
Deco, Jirsa, McIntosh TINS 2013
Ritter et al Brain Connectivity 2013

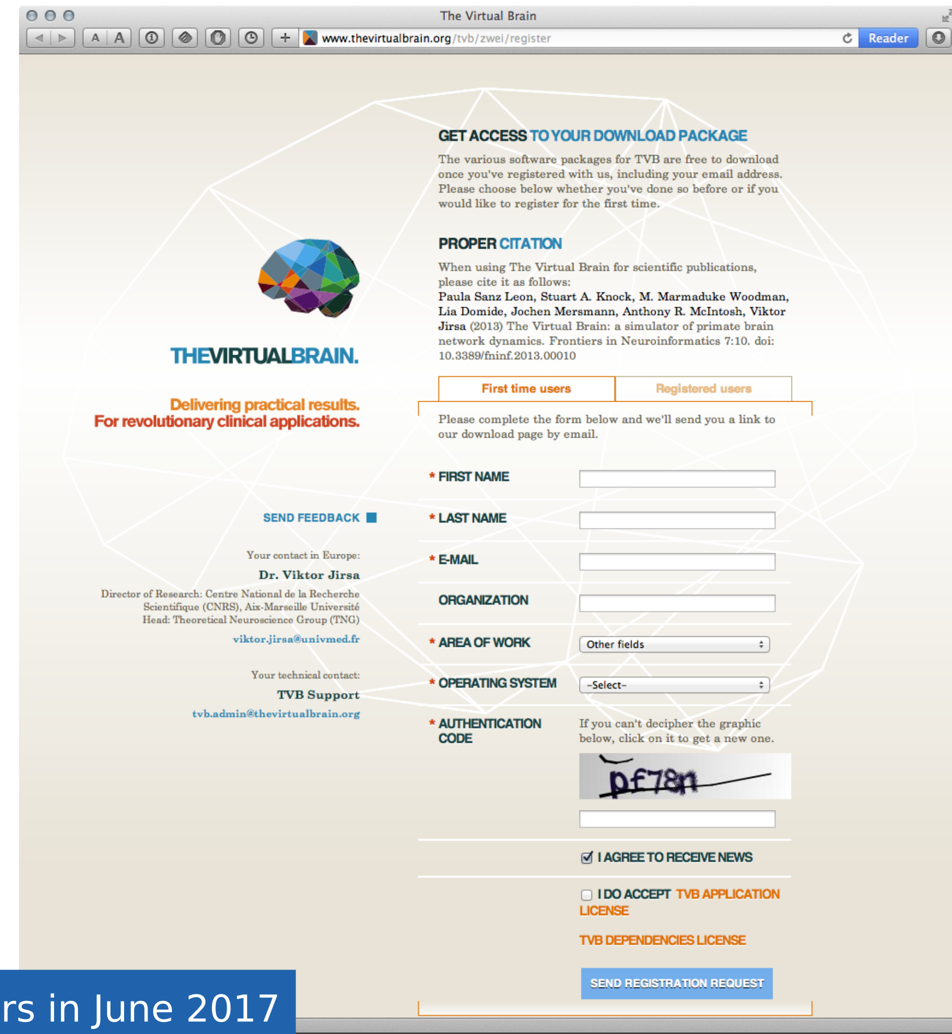


Sanz Leon et al Front NeuroInformatics 2013; Neuroimage 2015

THEVIRTUALBRAIN.

www.thevirtualbrain.org

Download: Windows, Mac, Linux



6369 registered users in June 2017
http://www.thevirtualbrain.org