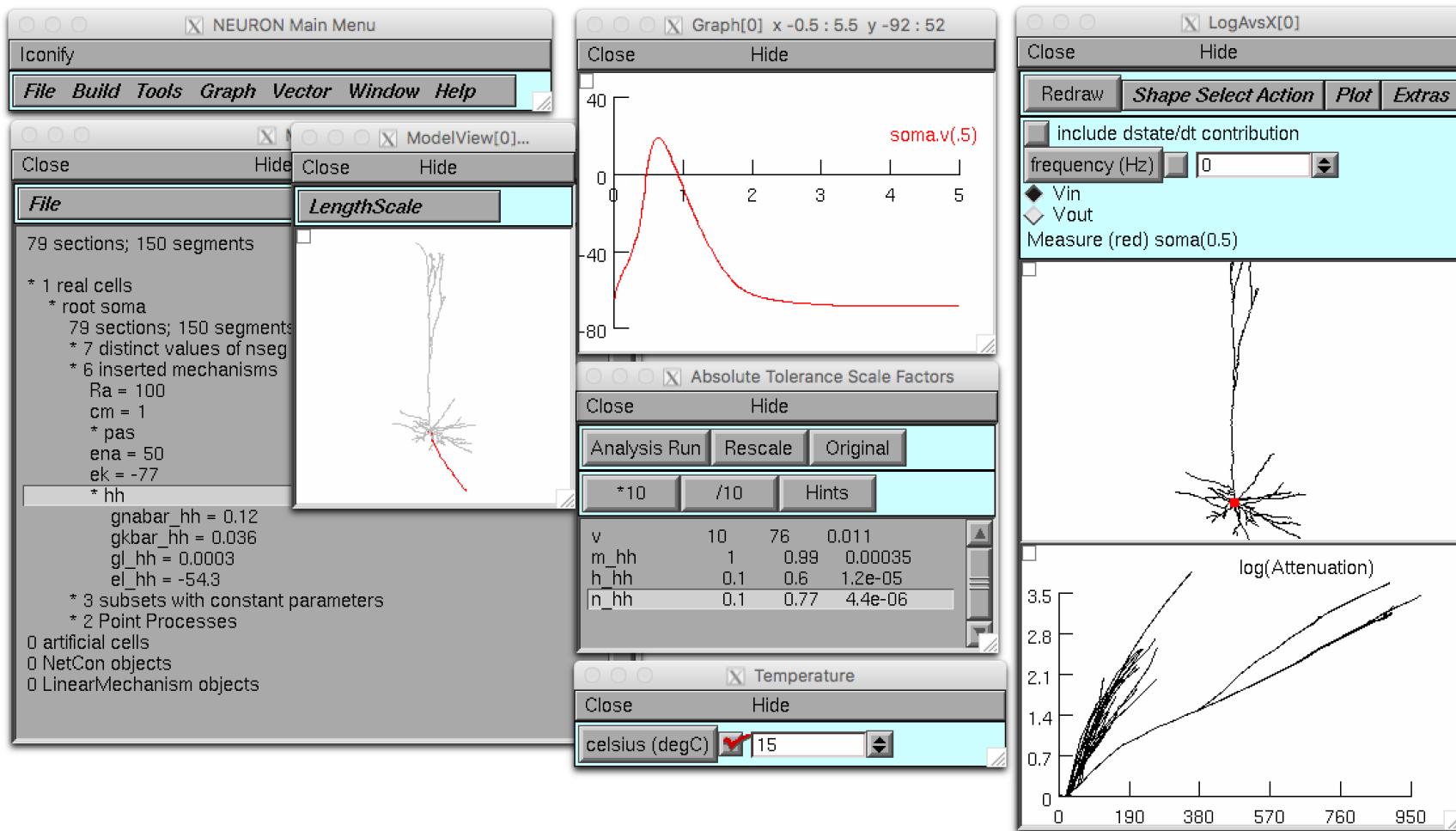


# NEURON

<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 (rxn).
- Stochastic rxn simulations.
- 3D intracellular rxn simulation.

## Performance enhancements

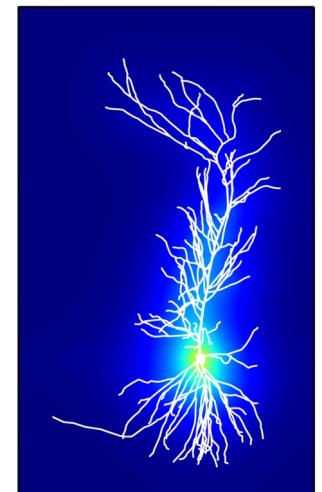
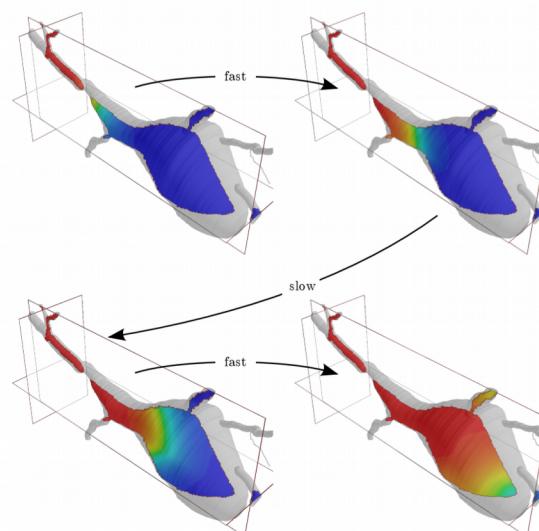
- GPU support.
- Faster reaction-diffusion.

## 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](http://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](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.

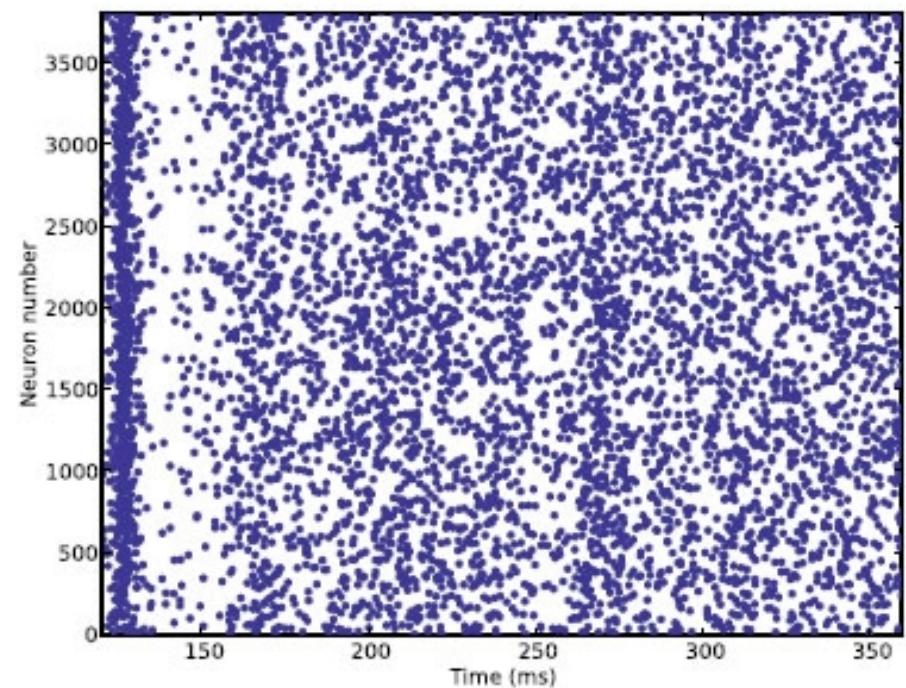
# Brian 2

<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.

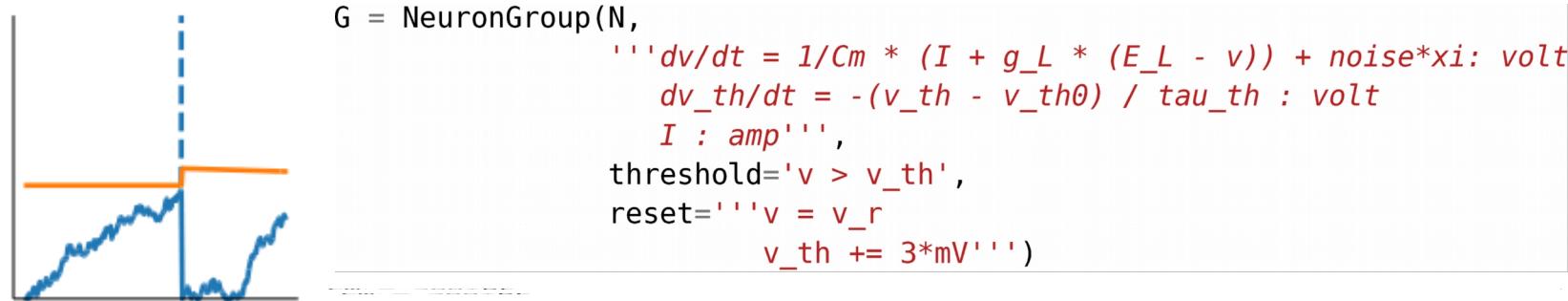
```
from brian2 import *
eqs = '''
dv/dt  = (ge+gi-(v+49*mV))/(20*ms) : volt
dge/dt = -ge/(5*ms)                      : volt
dgi/dt = -gi/(10*ms)                     : volt
'''
P = NeuronGroup(4000, eqs, threshold='v>-50*mV',
                 reset='v=-60*mV')
P.v = -60*mV
Pe = P[:3200]
Pi = P[3200:]
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



### Spike-timing dependent plasticity (STDP)



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](https://doi.org/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](https://doi.org/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>

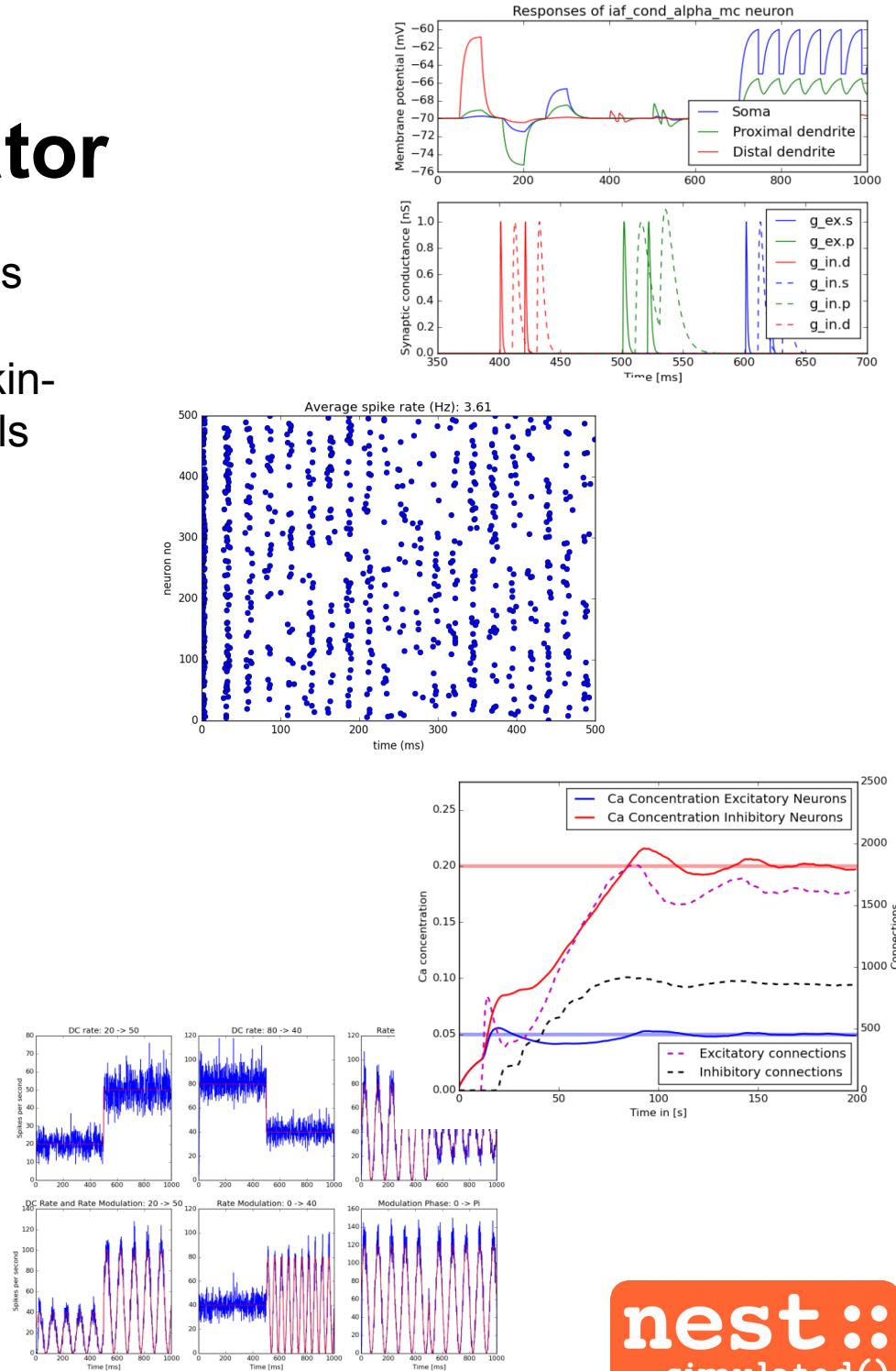
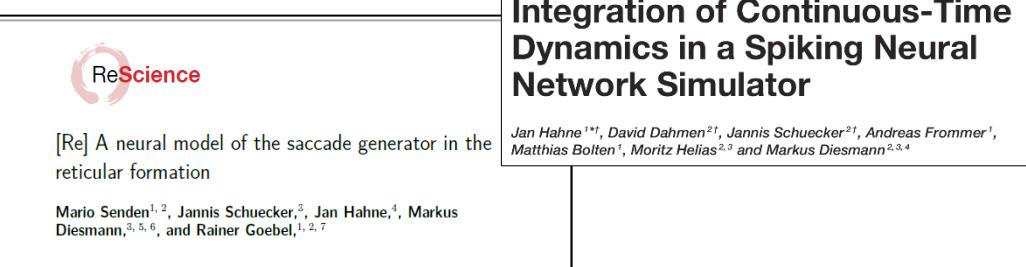
# NEST: The Neural Simulation Tool

<http://www.nest-simulator.org>

NEST is a simulator for spiking neural network models focusing 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 Hodgkin-Huxley-style, few-compartment models
  - binary and rate 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
  - NESTML: Automatic code generation for neuron models
  - NESTIO: Efficient data recording to binary file formats
  - Dry-run mode: Efficient performance analysis on supercomputers
  - Exascale readiness
  - Optimized network construction speeds for highly parallel simulations of complex networks
- Regular publications on NEST simulation technology

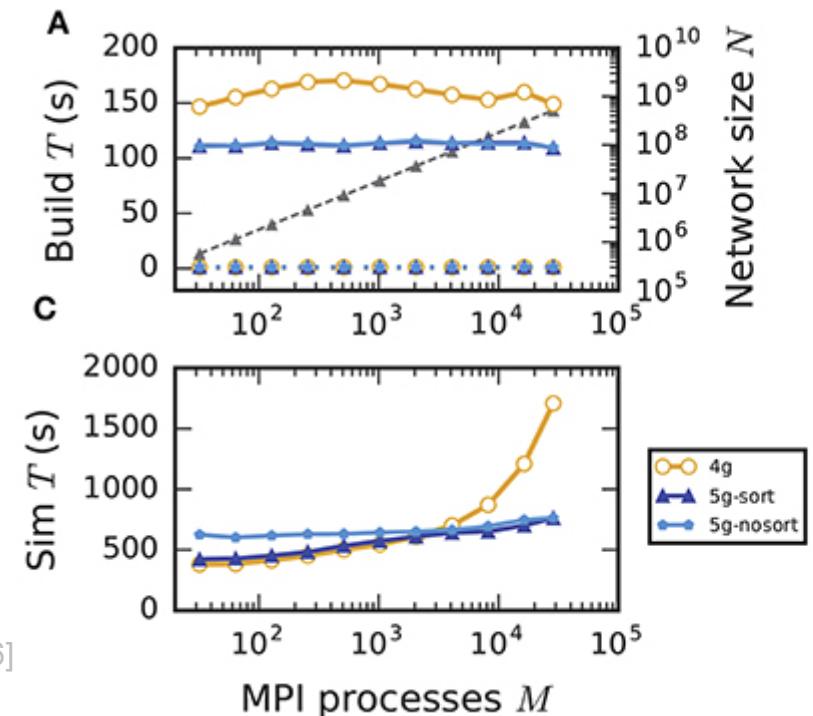
Extremely Scalable Spiking Neuronal Network Simulation Code: From Laptops to Exascale Computers

Jakob Jordan<sup>1\*</sup>, Tammo Ippen<sup>1,2</sup>, Moritz Helias<sup>1,3</sup>, Itaru Kitayama<sup>4</sup>, Mitsuhsisa Sato<sup>4</sup>, Jun Igashira<sup>5</sup>, Markus Diesmann<sup>1,3,6</sup> and Susanne Kunkel<sup>7,8</sup>



shows how to make memory consumption of compute nodes independent of network size

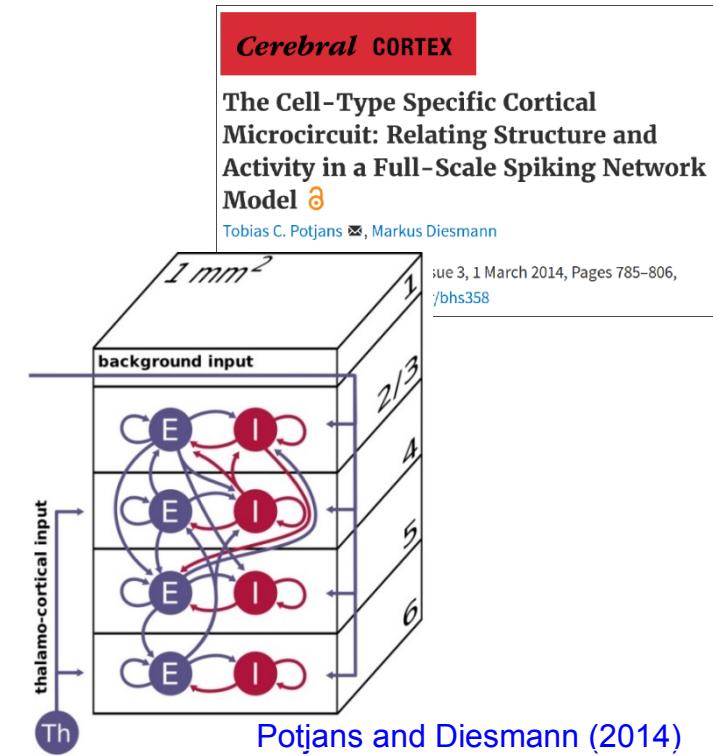
The GitHub interface shows the repository 'nest / nest-simulator'. It has 21 stars and 111 forks. There are 147 issues and 24 pull requests. A search bar shows 'is:pr is:open'. The pull requests list includes several items related to installation, kernel, and infrastructure, with details like PR creation date, assignees, and labels.



Jordan et al. (2018)

# Publicly available large-scale NEST models

- Microcircuit model of 1 mm<sup>2</sup> of early sensory cortex with full density of neurons and synapses (Potjans and Diesman, 2014)
  - ~ 80,000 LIF neurons, ~ 0.3 billion synapses
  - Reproduces asynchronous irregular spiking and layer- and population-specific firing rates
  - Building block for many further studies
  - SLI, PyNEST, PyNN versions available (NEST and PyNN releases; Open Source Brain)
  - used in 17 peer-reviewed studies, cited in 62 peer-reviewed publications
- Multi-area model of all vision-related areas of macaque cortex (Schmidt et al., 2018)
  - 32 areas in one hemisphere, each represented mm<sup>2</sup> microcircuit
  - ~ 4 million LIF neurons, ~ 24 billion synapses
  - Reproduces resting-state spiking activity and functional connectivity
  - PyNEST version with data integration process available (GitHub)



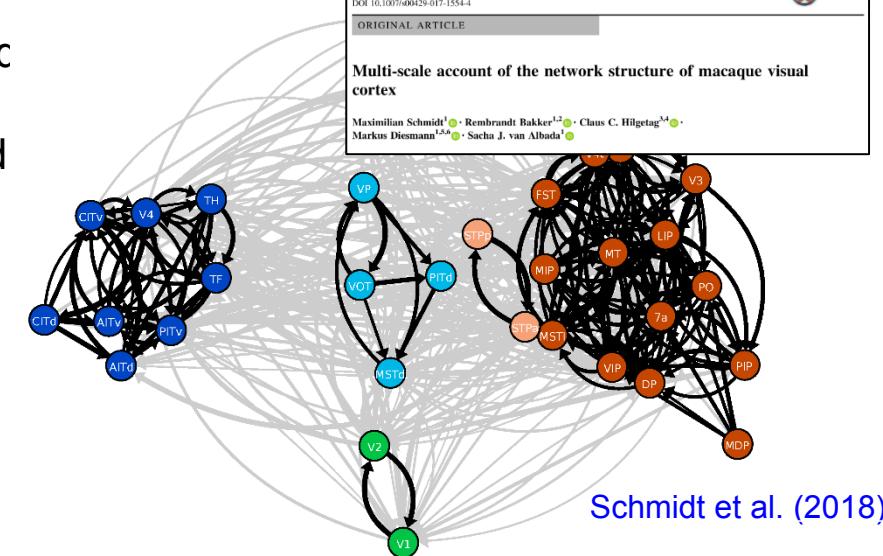
Cerebral CORTEX

The Cell-Type Specific Cortical Microcircuit: Relating Structure and Activity in a Full-Scale Spiking Network Model

Tobias C. Potjans , Markus Diesmann

issue 3, 1 March 2014, Pages 785–806,  
[/bhs358](https://doi.org/10.1007/s00429-017-1554-4)

Potjans and Diesmann (2014)



Brain Struct Funct

DOI 10.1007/s00429-017-1554-4

ORIGINAL ARTICLE

Multi-scale account of the network structure of macaque visual cortex

Maximilian Schmidt<sup>1</sup> , Rembrandt Bakker<sup>1,2</sup> , Claus C. Hilgetag<sup>3,4</sup> , Markus Diesmann<sup>1,5,6</sup> , Sacha J. van Albada<sup>1</sup>

Schmidt et al. (2018)

# 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](http://mail.nest-initiative.org/cgi-bin/mailman/listinfo/nest_user)

## NEST Initiative

<http://www.nest-initiative.org>

## Annual NEST Conference



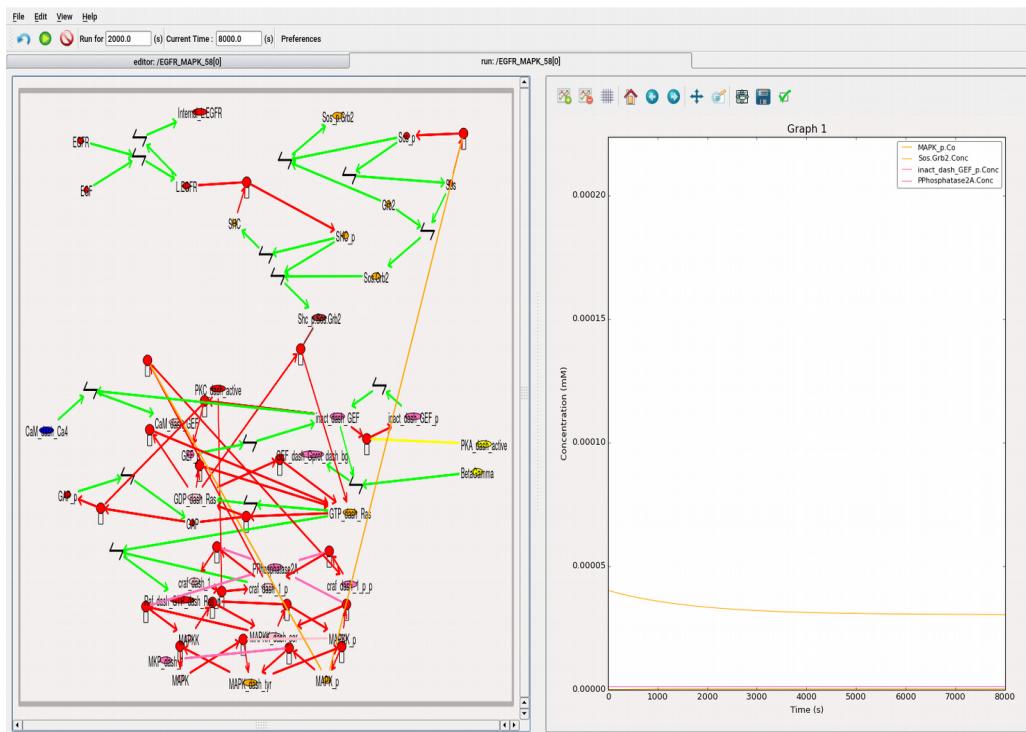
# MOOSE

## 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

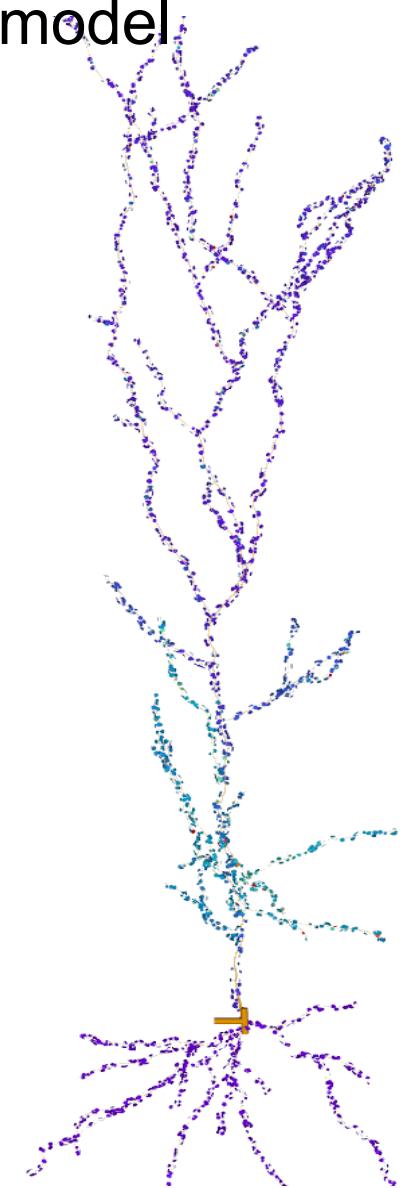


GUI for building and running chemical models.

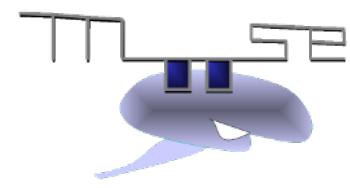
```
1 import moose
2 import rdesigneur as rd
3 rdes = rd.rdesigneur()
4     stimList = [['soma', '1', '.', 'inject', '(t>0.1 && t<0.2) * 2e-8']],
5     plotList = [['soma', '1', '.', 'Vm', 'Soma membrane potential']]
6 )
7 rdes.buildModel()
8 moose.reinit()
9 moose.start( 0.3 )
10
11 rdes.display()
```

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

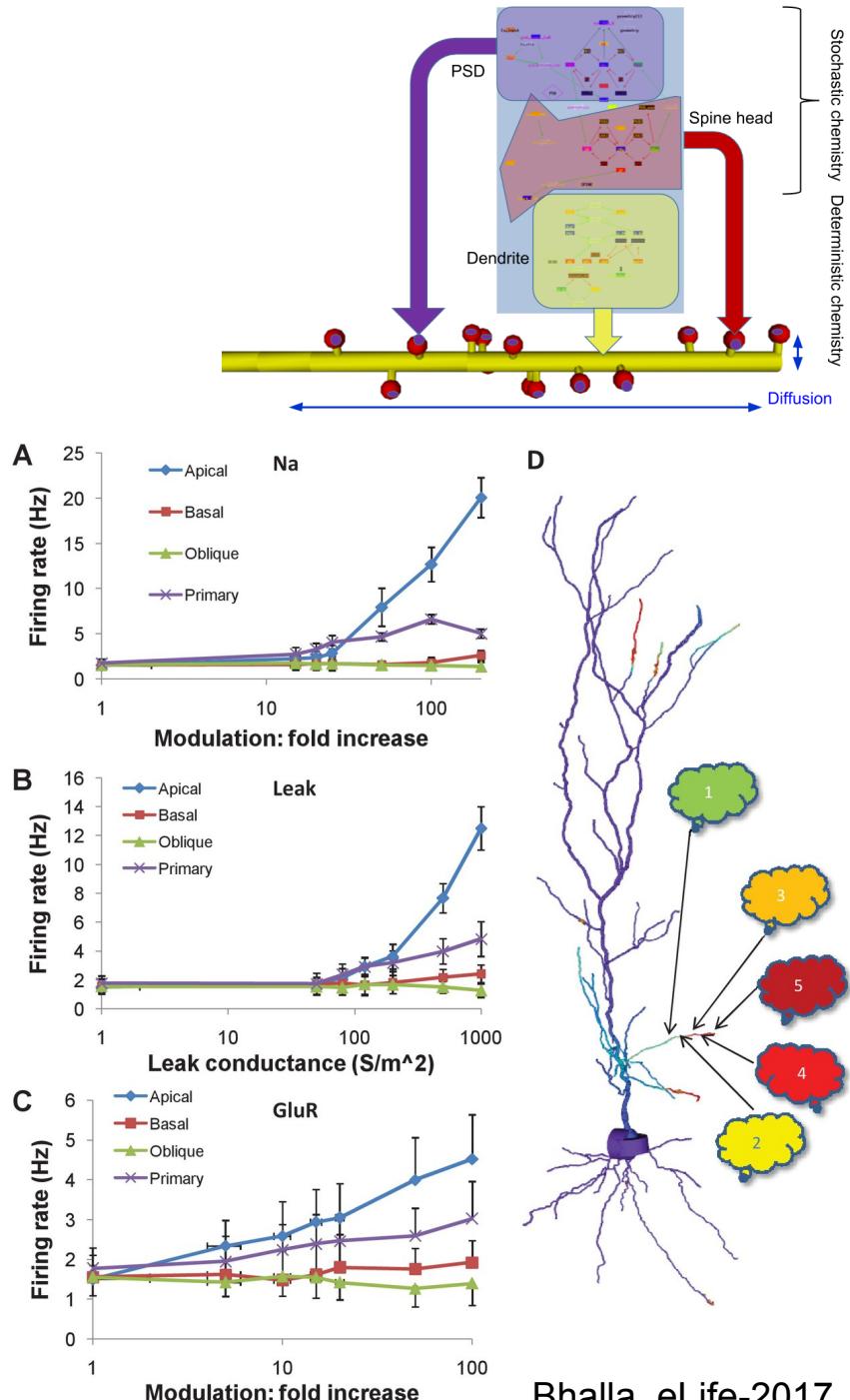
- Fast (written in C++) and easy to use (Python scriptable). **Rdesigneur** library to integrate chemical and electrical models easily.
- Chemical model formats support: SBML, NeuroML(v-1.8) and genesis format. Neuron morphology: SWC format.
- GUI for building chemical models.
- User [documentation](#)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

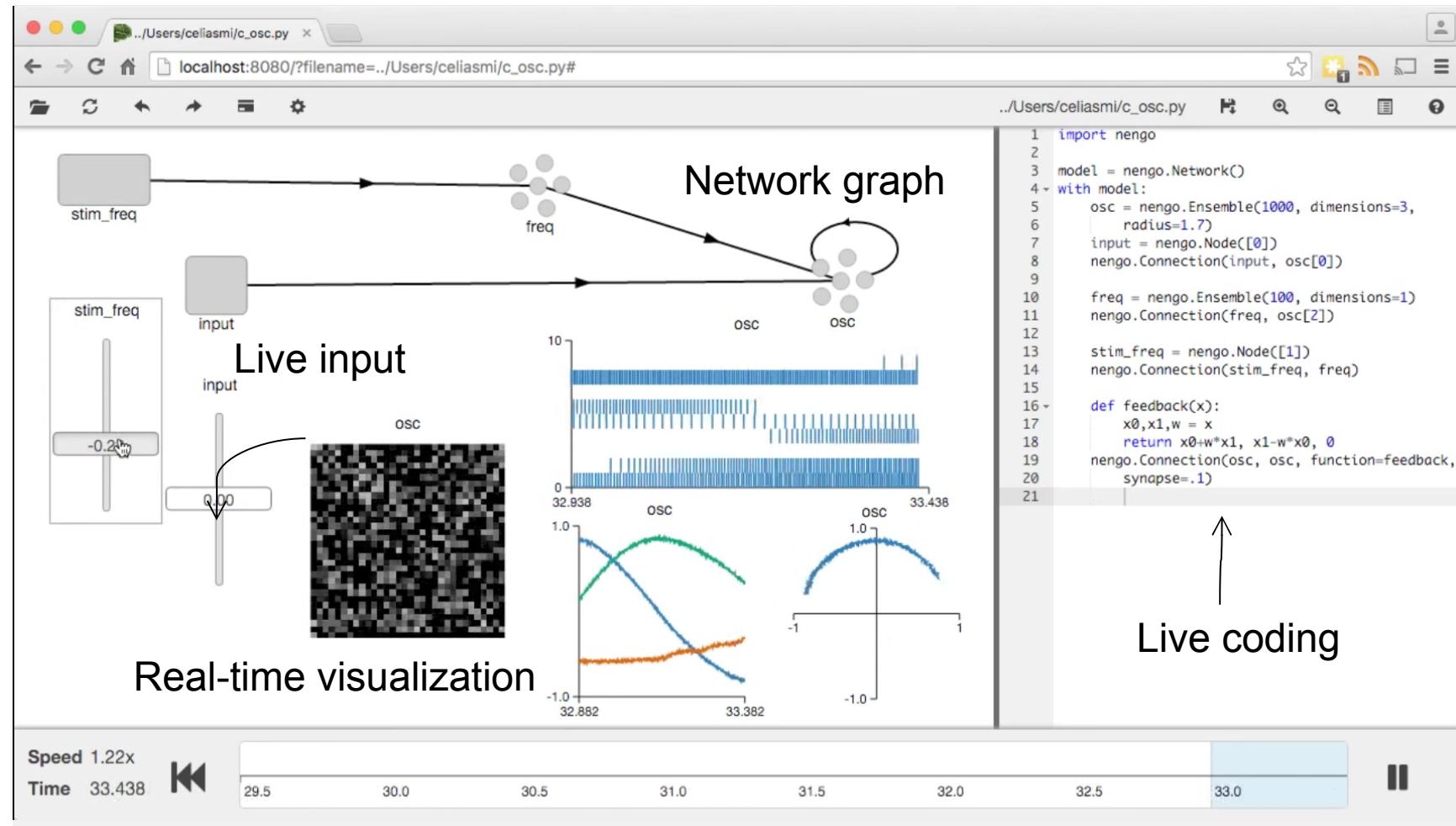
- Enhanced GPU and openMP support for various solvers.



# 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.



**Documentation** -- Usage and API documentation is at:

<https://pythonhosted.org/nengo/>

**Getting Help** -- Nengo forum at:

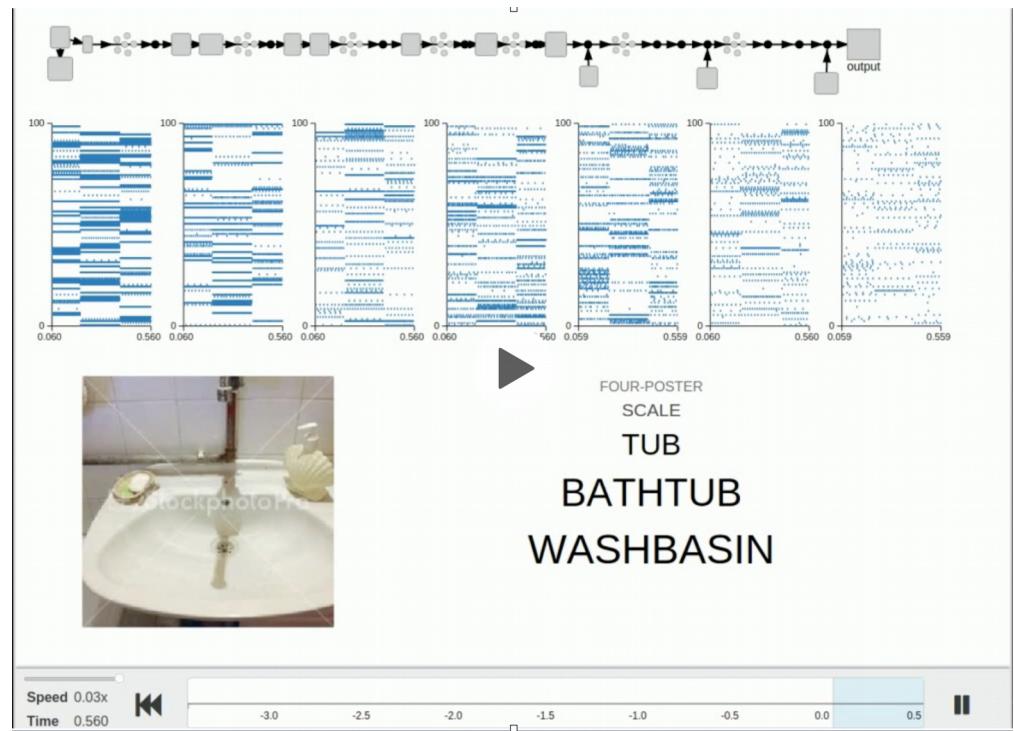
<https://forum.nengo.ai>

## **Application Highlights**

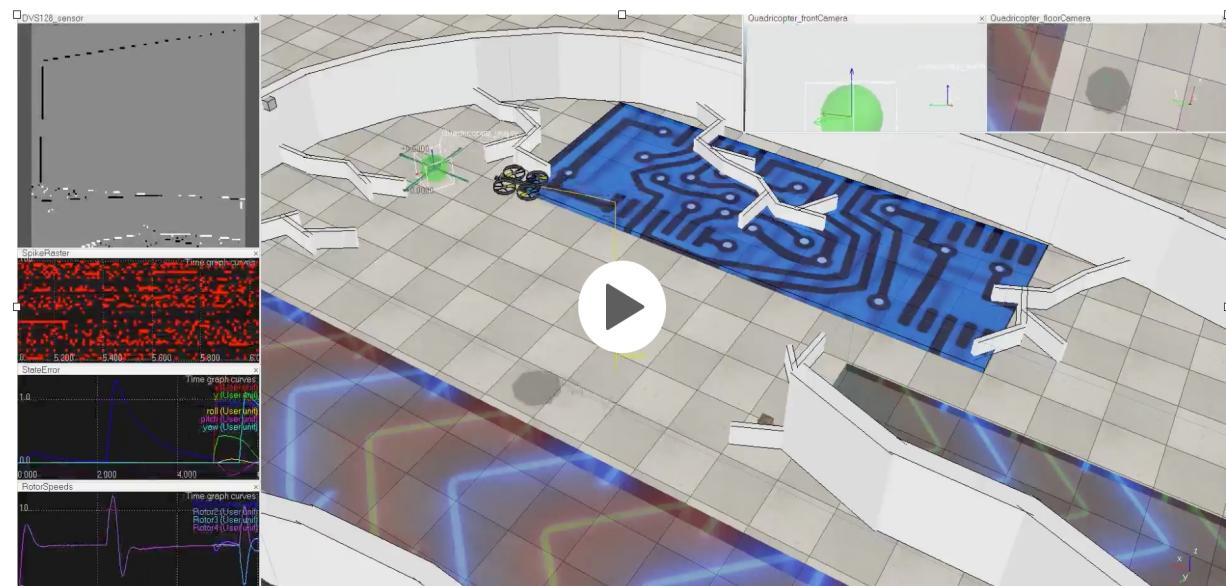
- Used to develop large-scale spiking deep networks
- Integration with robot simulators & platforms
- 6 DOF nonlinear adaptive control on neuromorphic hardware for 30x power savings
- Spun large-scale neuro-cognitive model published in *Science*

## **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



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



**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](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](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

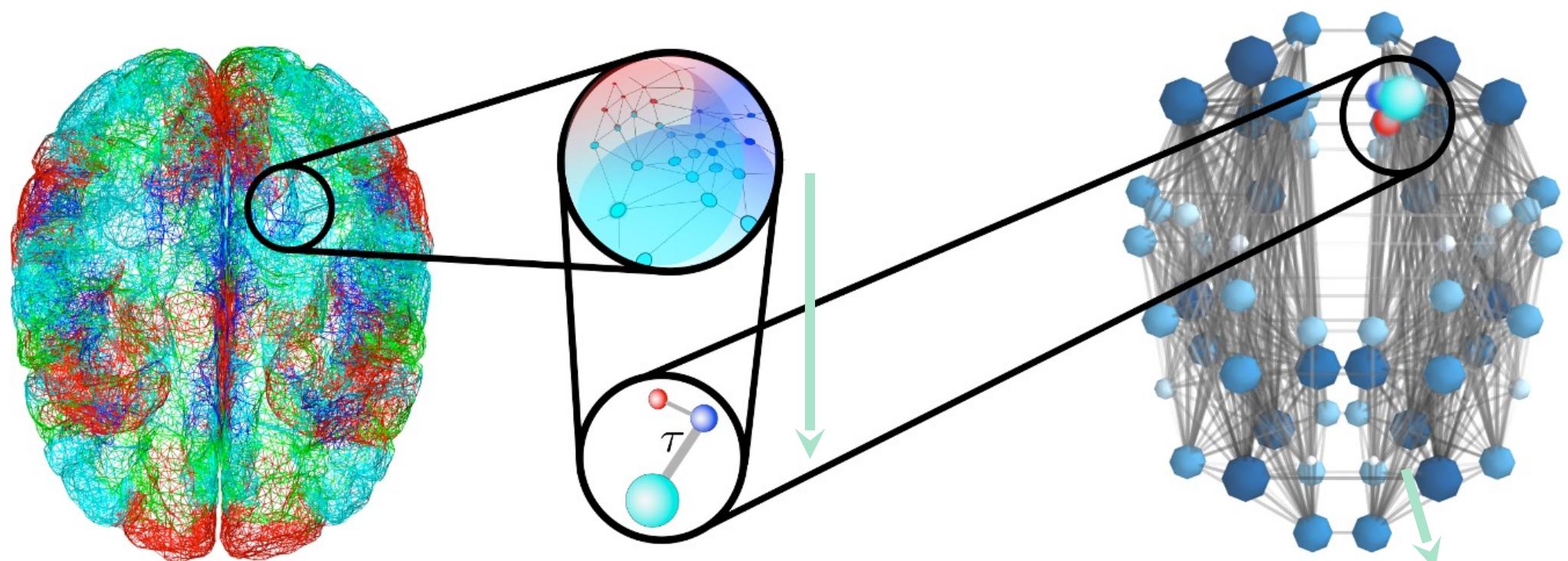
<https://nengo.github.io/contributing.html>

# The Virtual Brain

<http://www.thevirtualbrain.org>

The Virtual Brain (TVB) is a neuroinformatics platform for full brain network simulations using biologically realistic connectivity. It enables 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



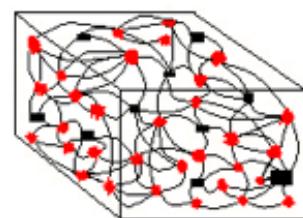
# Microscopic unit of modeling: neuronal population

## Local dynamics

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

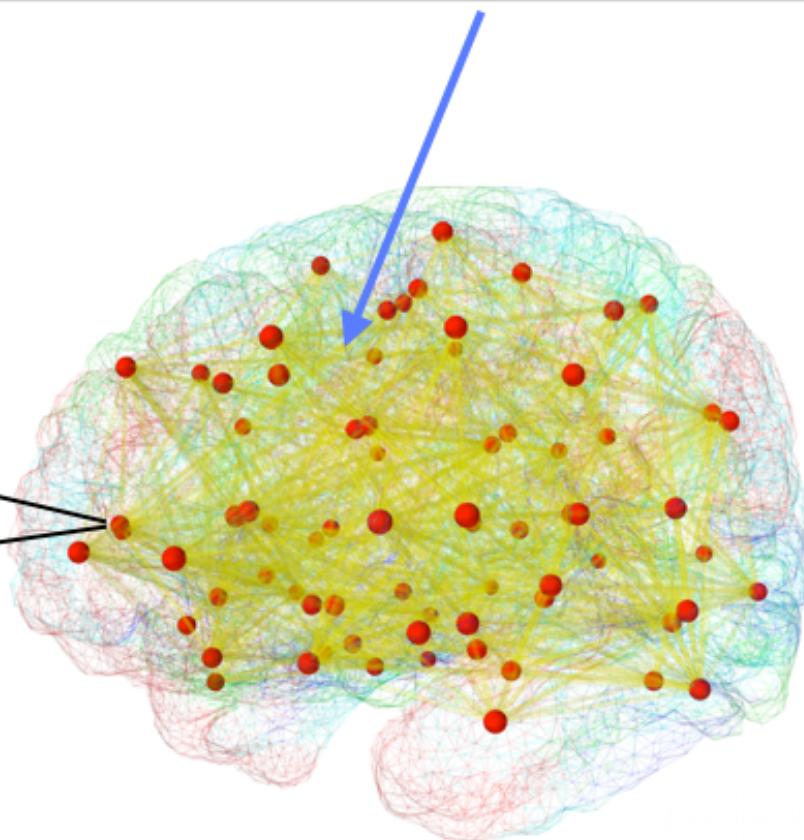
Field potential

1mm



Neuronal population

## Global dynamics



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

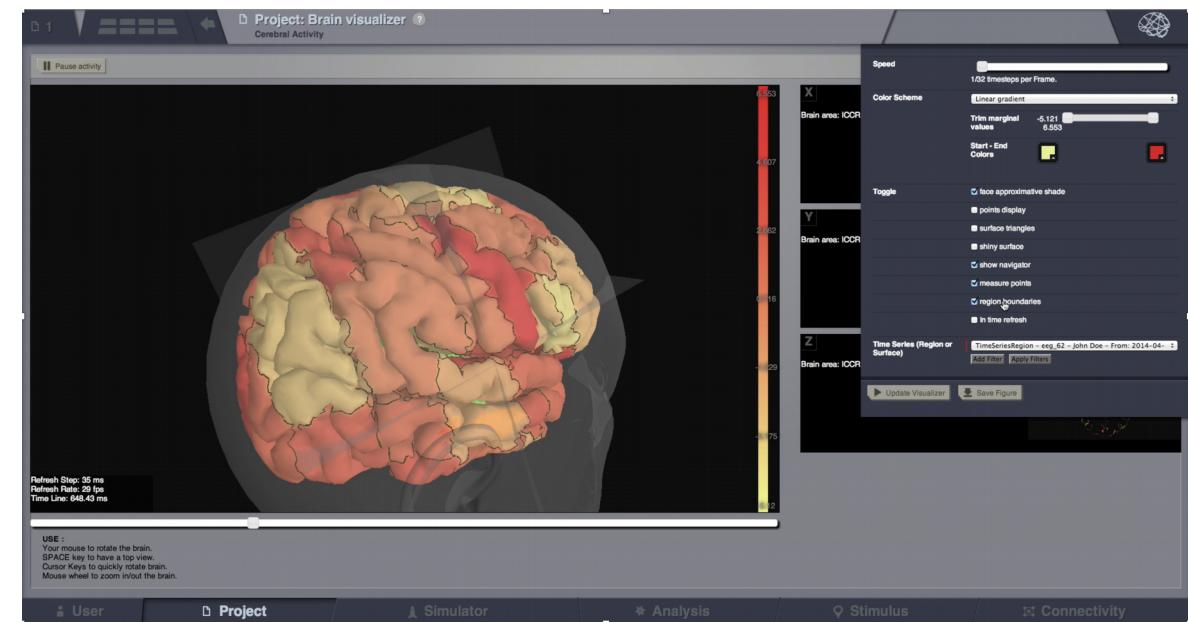
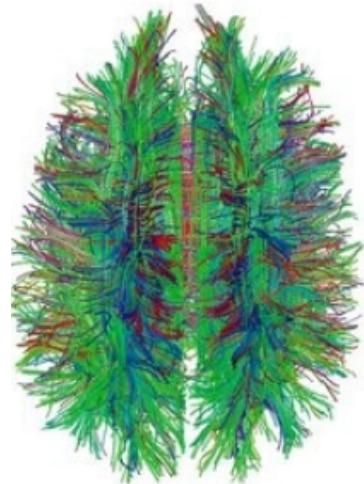
Sanz Leon et al Front Neuroinformatics 2013;  
Neuroimage 2015

THE VIRTUAL BRAIN.

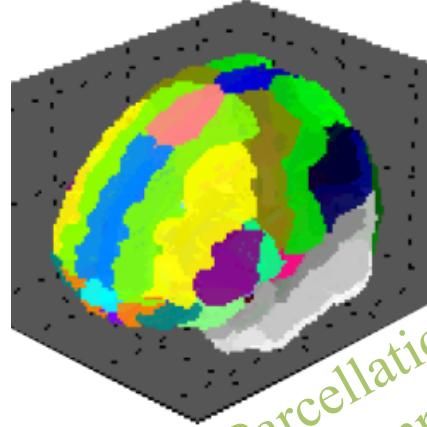


# The Virtual Brain (TVB) platform release in 2012

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

THE VIRTUAL BRAIN

# www.thevirtualbrain.org

The Virtual Brain: Delivering practical results. For novel clinical applications.

**Fork me on GitHub!**

**THE SCIENCE.**  
**FOR CLINICS.**  
**ONE APP.**  
**OUR MILESTONES.**  
**YOUR TEAM.**

**Delivering practical results.  
For novel clinical applications.**

**APP 1.1.3 GET IT HERE!**

**NEWSWIRE**

Coming up: June 7, 2014  
Workshop: TVB:Node#1, Hamburg, Germany : Practical brain network modeling with many hands-on sessions

**NODE#1 HAMBURG**  
PRACTICAL BRAIN NETWORK MODELING

April 1, 2014  
Release of The Virtual Brain  
1.1.2 - Not an April Fools' but for real: The biggest release ever with over 130 enhanced features and extensions! More and improved visualizers, beautiful 3D surfaces with an importer for the common OBJ format, hemisphere separation for surfaces, support for proxy metatimestamp in time series and much more - available for download for all supported platforms

March 10, 2014  
The TVB website and the registration/download server is now based on a new publishing platform called "Zwei". This allows for more user-friendly features in the future, faster updates and more efficient administration.

February 25, 2014  
The Virtual Brain offers 5 exciting student projects for the **Google Summer of Code 2014** - participants get a chance to work on a well-kept codebase and contribute to better therapies for

**BALANCING COMPLEXITY AND UTILITY**

**TRANSFORMING CLINICAL THERAPY FOR BRAIN DISEASES**

**WHAT?** The Virtual Brain will deliver the first open simulation of the human brain based on individual large-scale connectivity. Within the next 5 years, running on comparably tame hardware and right in your browser!

**WHY?** To explore to what degree manipulations of brain connectivity can be exploited for clinical purposes in epilepsy and stroke.

**HOW?** By employing novel concepts from neuroscience, effectively reducing the complexity of the brain simulation while still keeping it sufficiently realistic.

**MORE ...**

**MORE ...**

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

# Download: Windows, Mac, Linux

The Virtual Brain

**GET ACCESS TO YOUR DOWNLOAD PACKAGE**

The various software packages for TVB are free to download once you've registered with us, including your email address. Please choose below whether you've done so before or if you would like to register for the first time.

**PROPER CITATION**

When using The Virtual Brain for scientific publications, please cite it as follows:

Paula Sanz Leon, Stuart A. Knock, M. Marmaduke Woodman, Lia Domide, Jochen Mersmann, Anthony R. McIntosh, Viktor Jirsa (2013) The Virtual Brain: a simulator of primate brain network dynamics. *Frontiers in Neuroinformatics* 7:10. doi: 10.3389/fninf.2013.00010

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Your contact in Europe:  
**Dr. Viktor Jirsa**  
Director of Research: Centre National de la Recherche Scientifique (CNRS), Aix-Marseille Université  
Head: Theoretical Neuroscience Group (TNG)  
viktor.jirsa@univmed.fr

Your technical contact:  
**TVB Support**  
tvb.admin@thevirtualbrain.org

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