An Introduction to Design and Simulation using SNS-Toolbox and SNSTorch

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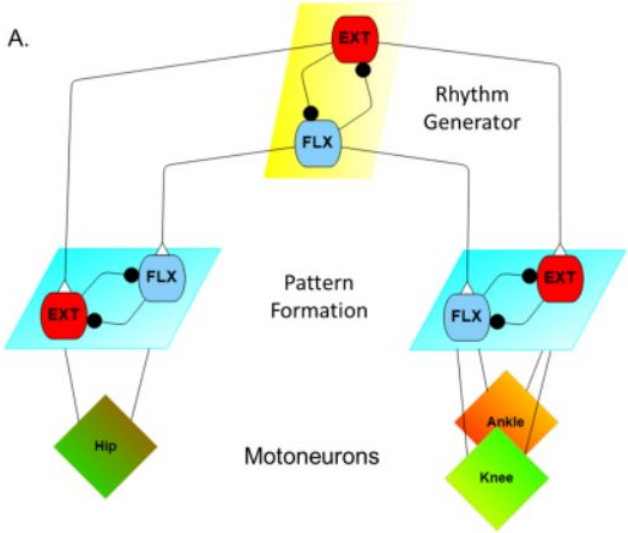
Workshop Schedule

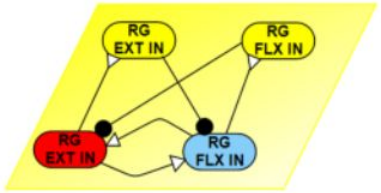
- Background: SNS Networks
- SNS-Toolbox
- SNSTorch

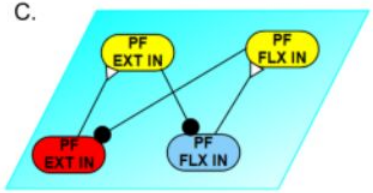
https://tinyurl.com/SNS-NICE-24

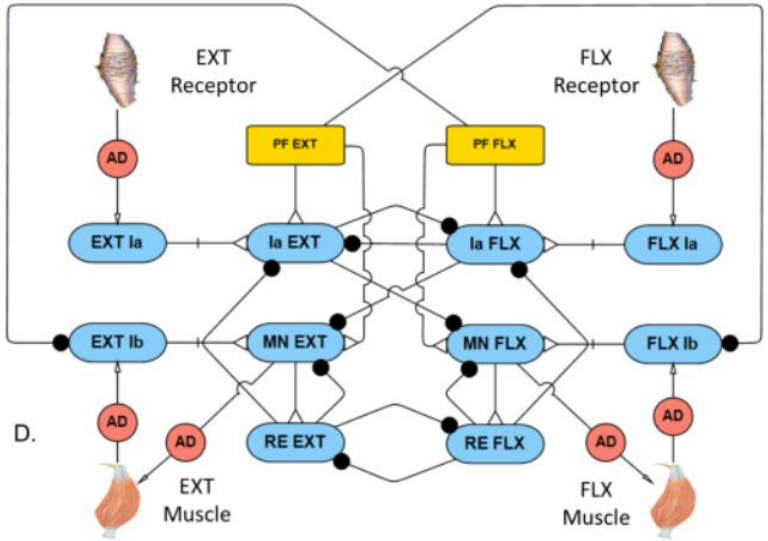
Area of Interest

- Most modeling focusing on the brain function in higher mammals, such as humans/primates
  - Massive networks, neural dynamics with weight-based synapses
- Not all nervous systems use huge amounts of neurons!
  - Fruit Fly ~1 million
  - C. elegans ~100
- Not all neural computation occurs in the brain!
  - In motion specifically, high level commands from the brain are processed by neurons in the spinal cord
- Neural parameters are not homogenous!
- Modeling focus: Motor nervous system across animal body/dynamic scales

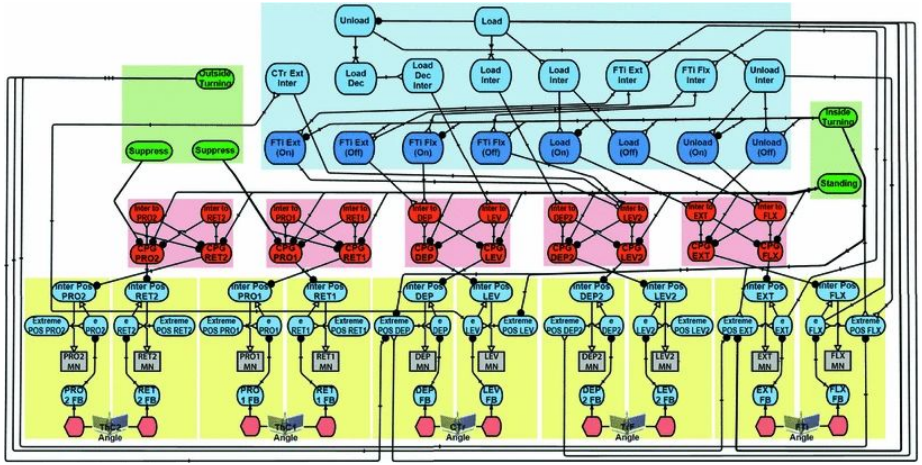




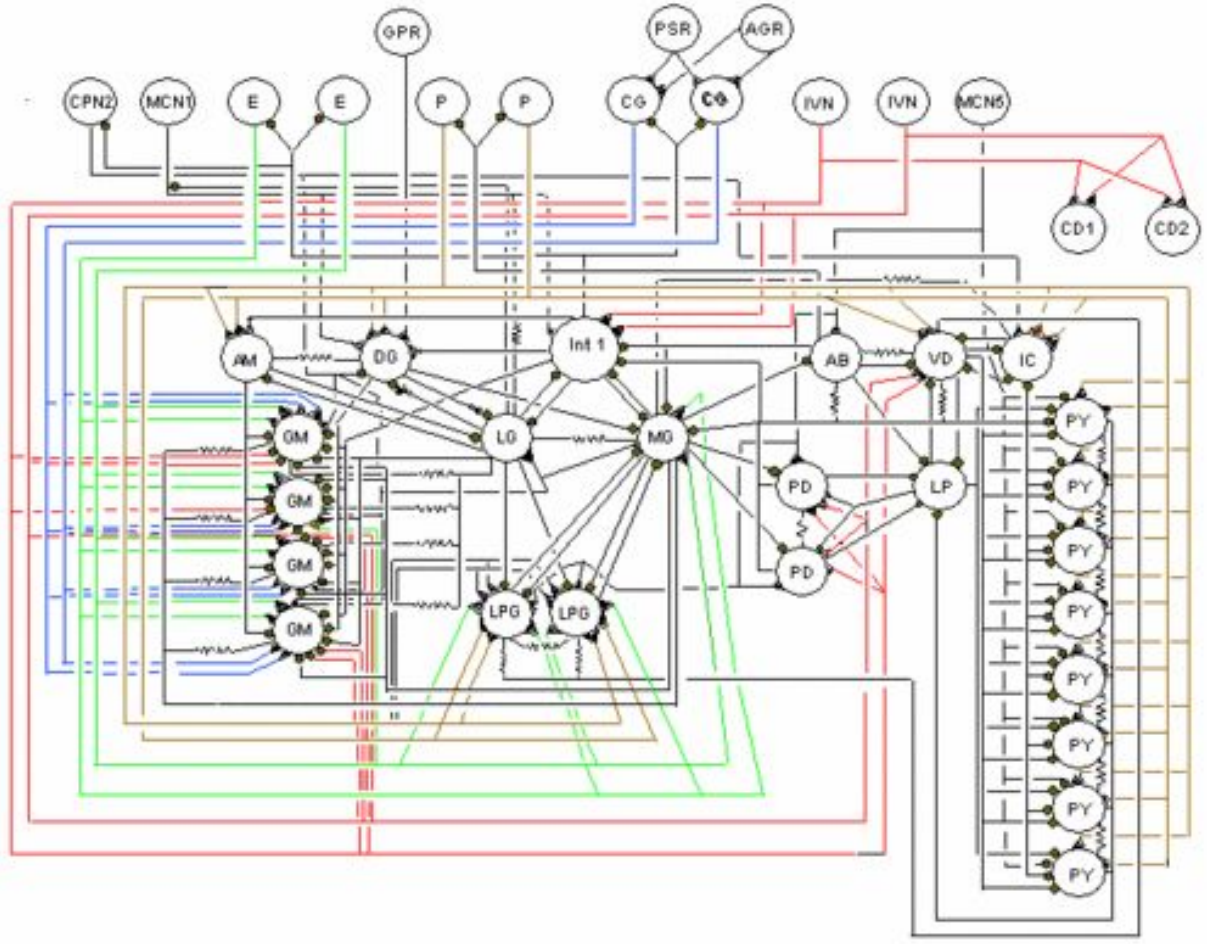




[Deng 2019]



[Szczecinski 2014]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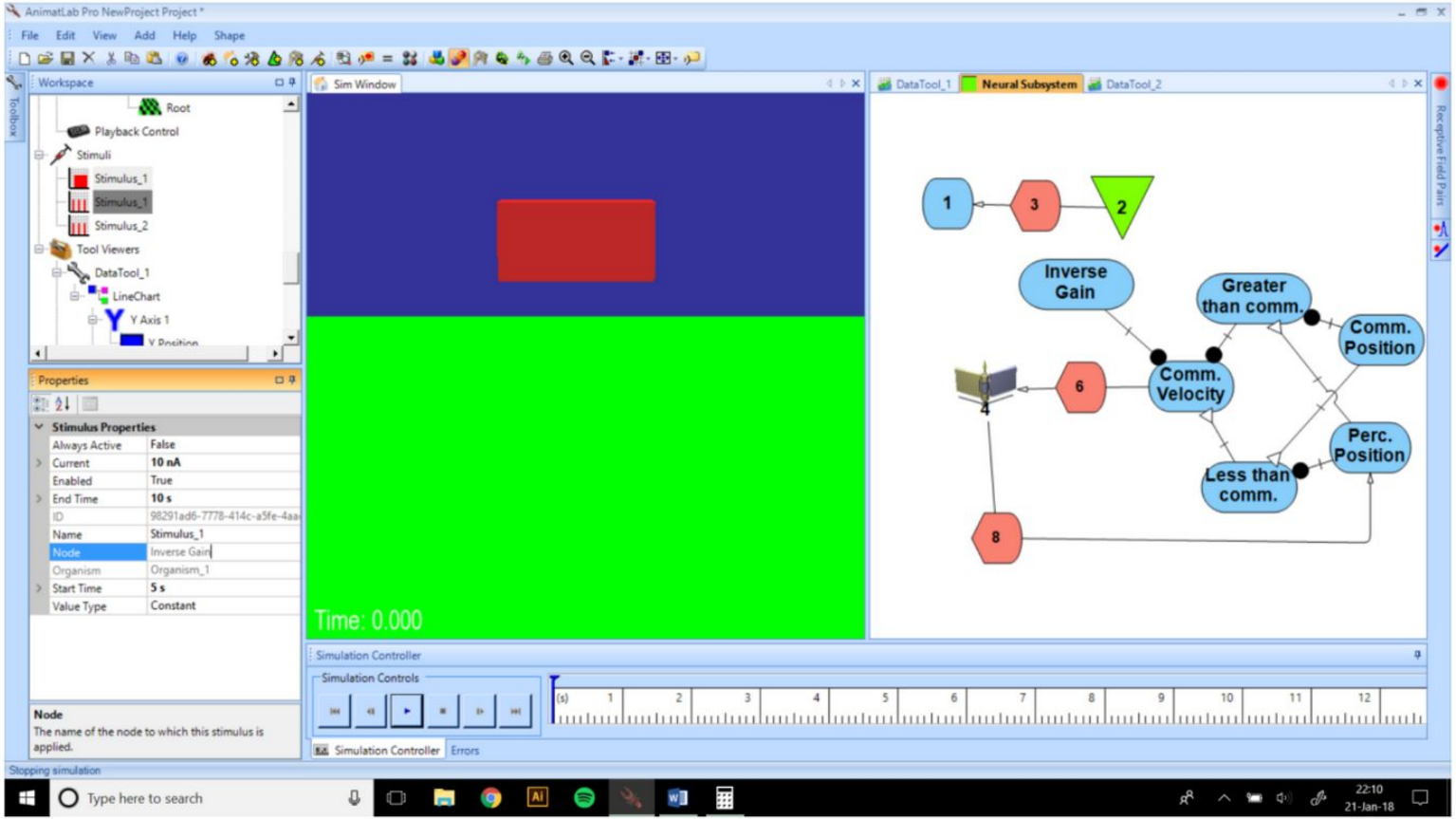
The Case for Beyond Weights

- In large neural networks, a rich set of dynamics just from neurons
- In smaller systems, the computational properties of synapses can play a greater role in behavior
- Particularly the case for heavily recurrent “hairball” networks.

What is a Synthetic Nervous System (SNS)?

- A SNS is a dynamical, mathematical model of parts of an animal's nervous system which can be applied to control a robot. [Szczecinski 2017]
- SNS networks are dynamic. Subcomponents (neurons) have states (membrane potentials, firing rates) which are dependent on time.
- All behavior comes from the interaction of mathematical equations, not simplified descriptive rules.
- By constraining SNS networks to using biologically-plausible dynamics, SNS experiments can propose neurobiological hypotheses [Mangan 2023, Webb 2002].

AnimatLab



[Cofer 2010], Screenshot courtesy of Dr. Nicholas Szczecinski

Neural Simulator Feature Comparison

Software	AnimatLab	NRP	Nengo	SnnTorch	SpykeTorch	BindsNET	Brian2	NEURON	NEST	ANNArchy
GUI Required	X	X								
Real-Time Capable	X		X	X	X	X				X
Chemical Synapses	X	X*	X*				X	X		X
Electrical Synapses	X	X*	X*				X	X	X	X
Non-Spiking and Spiking	X	X	X				X	X		X
GPU Support		X*	X*	X	X	X	X	X†	X†	X†
Cross Platform		X	X	X	X	X	X	X	X	

[Cofer 2010, Capolei 2019, Bekolay 2014, Eshraghian 2023, Mozafari 2019, Hazan 2018, Goodman 2008, Hines 1997, Gewaltig 2007, Vitay 2015]

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Chemical Synapses	X	X*	X*				X	X		X	X
Electrical Synapses	X	X*	X*				X	X	X	X	X
Non-Spiking and Spiking	X	X	X				X	X		X	X
GPU Support		X*	X*	X	X	X	X	X†	X†	X†	X
Cross Platform		X	X	X	X	X	X	X	X		X

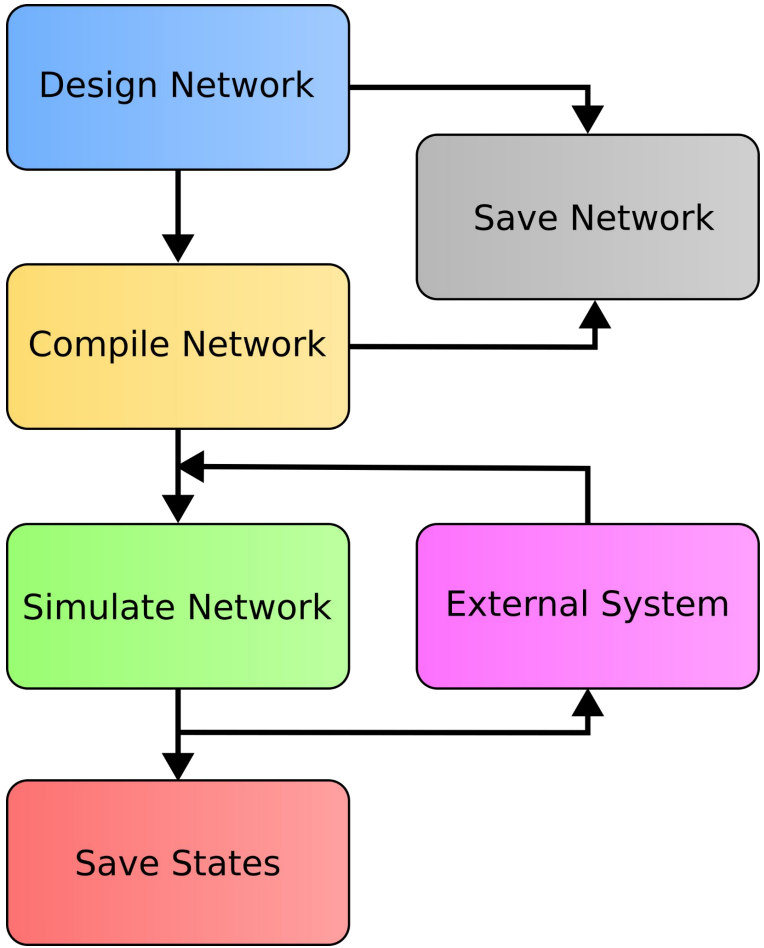
[Cofer 2010, Capolei 2019, Bekolay 2014, Eshraghian 2023, Mozafari 2019, Hazan 2018, Goodman 2008, Hines 1997, Gewaltig 2007, Vitay 2015, Nourse 2023]

Two Companion Software Packages

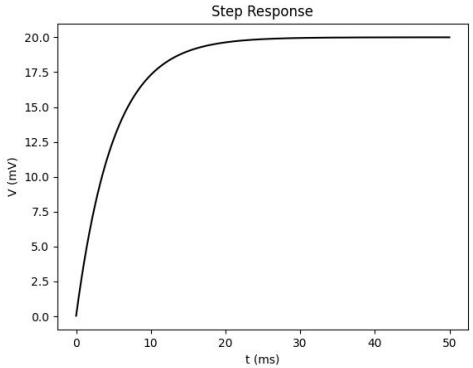
- SNS-Toolbox
  - 10^0-10^4 neurons
  - All neural/synaptic dynamics implemented
  - `pip install sns-toolbox`
- SNSTorch (alpha)
  - Larger networks
  - Still in early development, not all neural/synaptic dynamics implemented currently
  - `pip install snstorch`

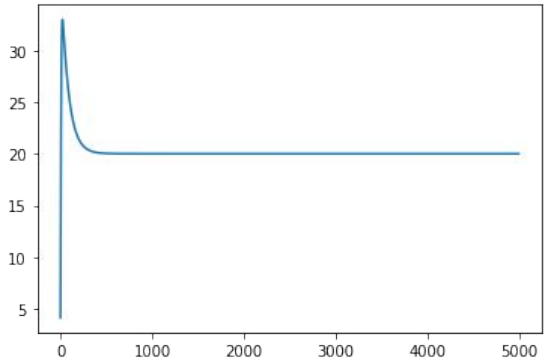
SNS-Toolbox

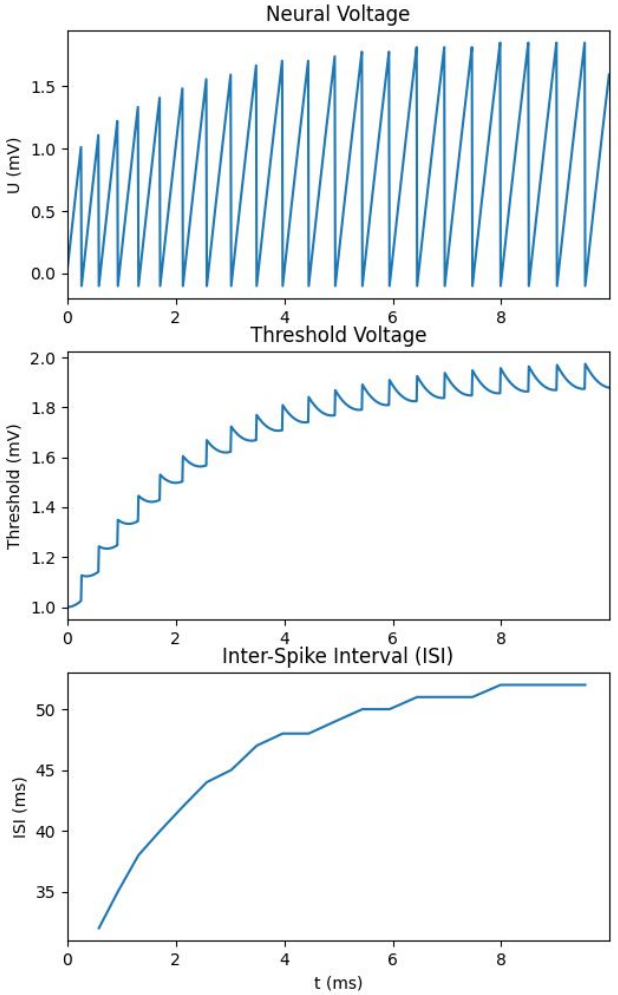
- Open-source Python package
- Users can design and simulate SNS networks
- Networks can run on CPU or GPU, and can interact with other systems
  - Biomechanical simulators
  - Robotic systems



Neural Dynamics

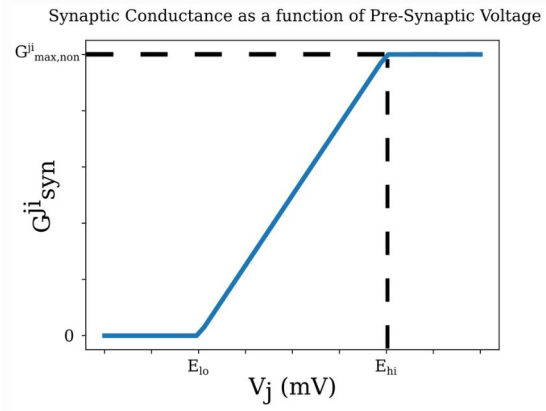


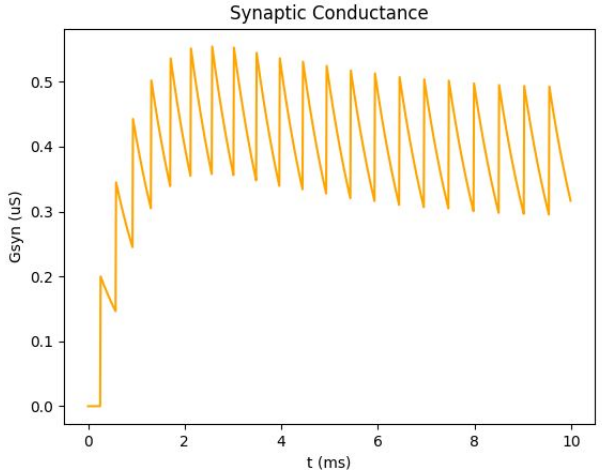




Synaptic Dynamics

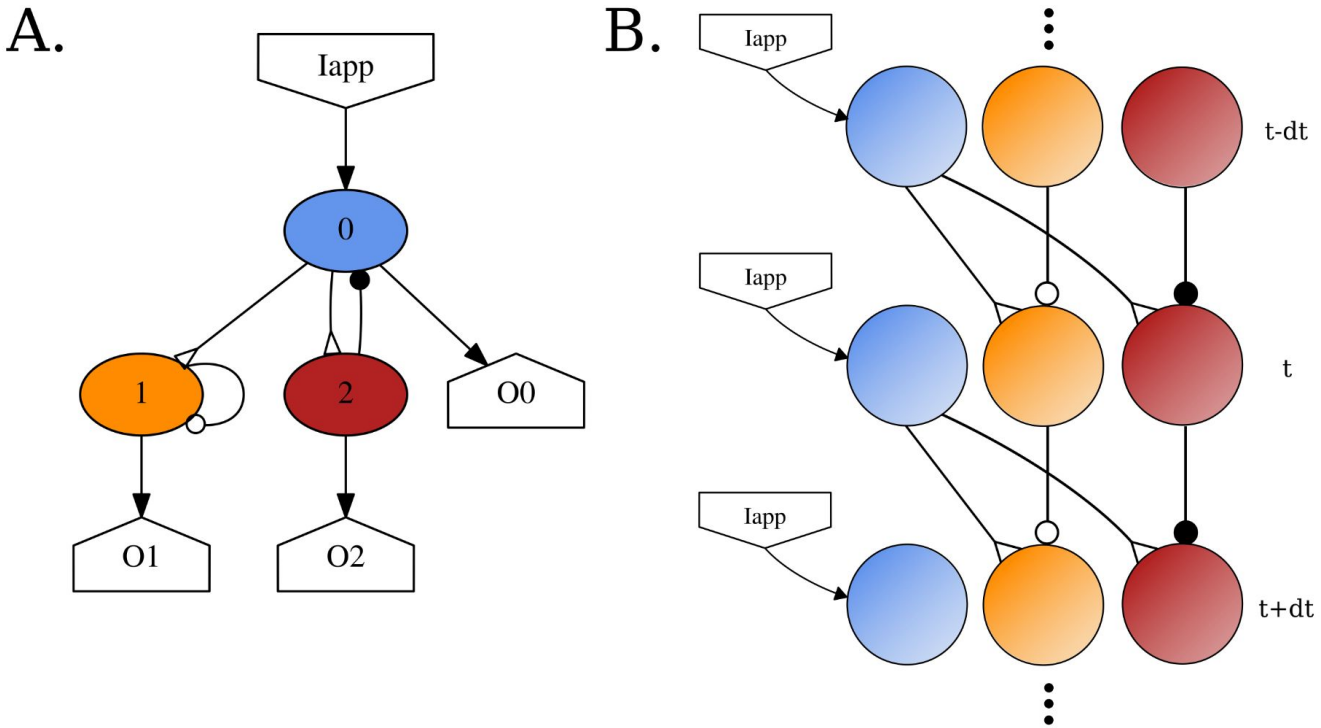
$$I_{syn}^{ji} = G_{syn}^{ji}\left(V_j\right) \cdot \left(E_{syn}^{ji} - V_i\right)$$



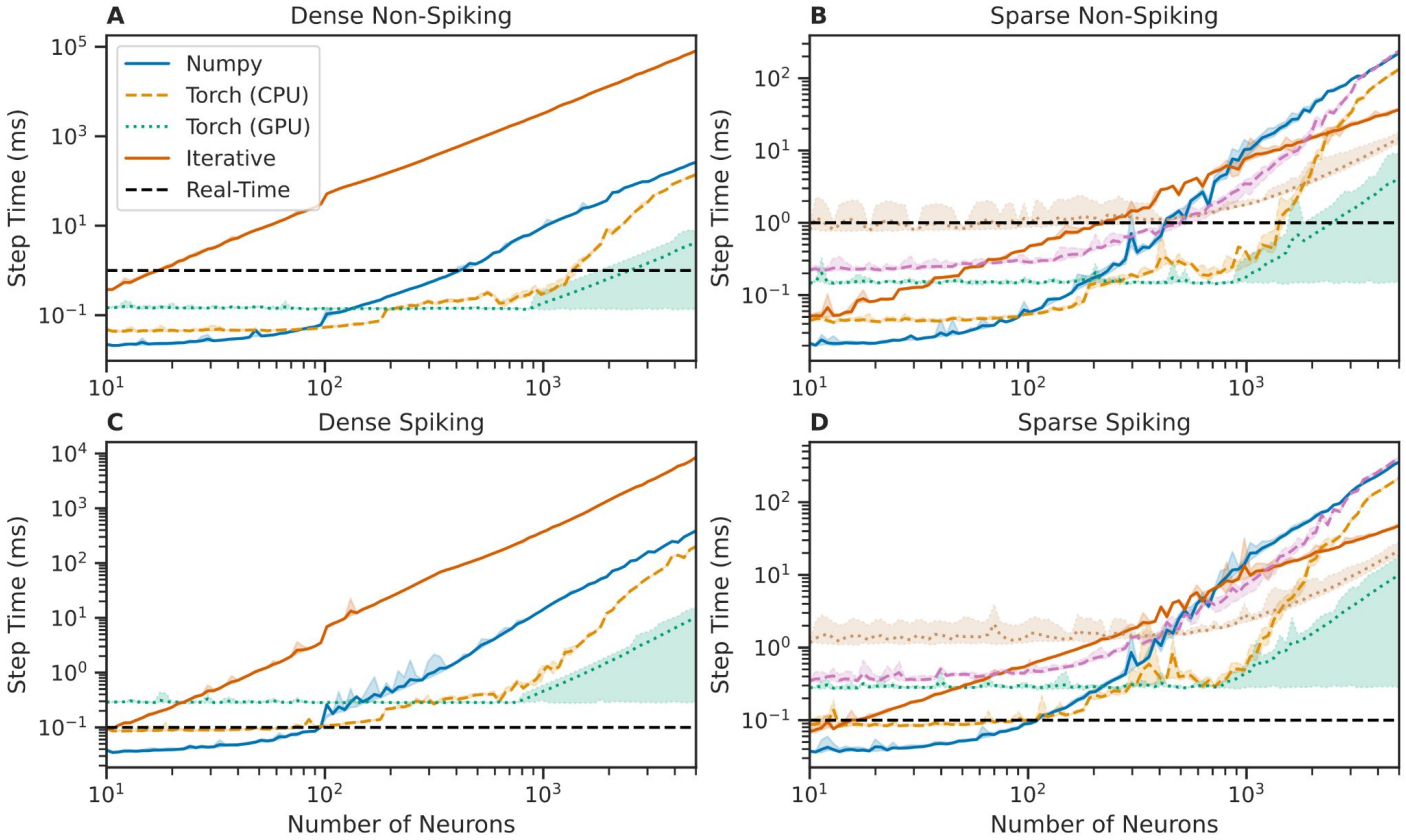


$$I_{syn}^{ji} = G_{syn,electrical} \cdot \left(V_j - V_i\right)$$

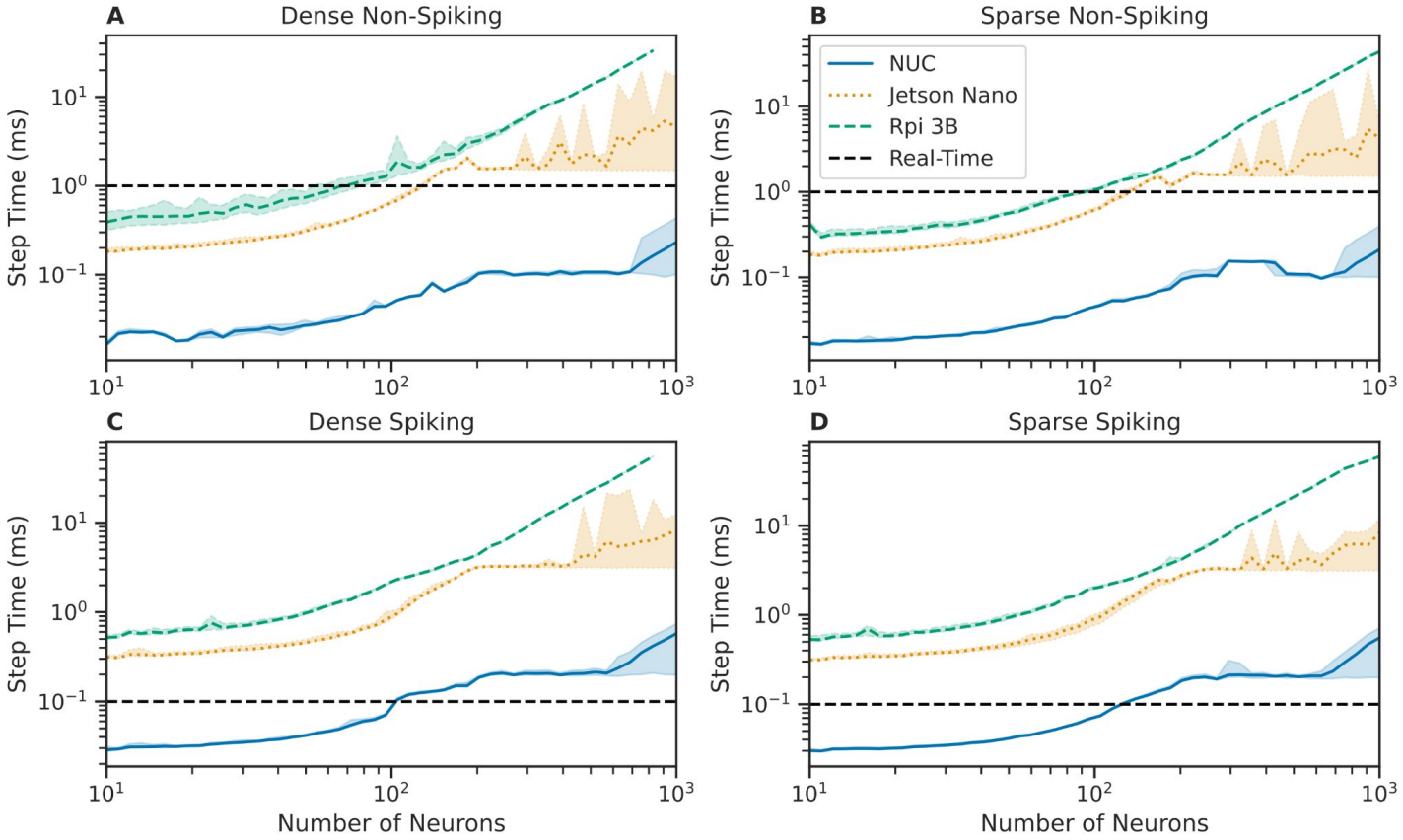
Simulation Representation



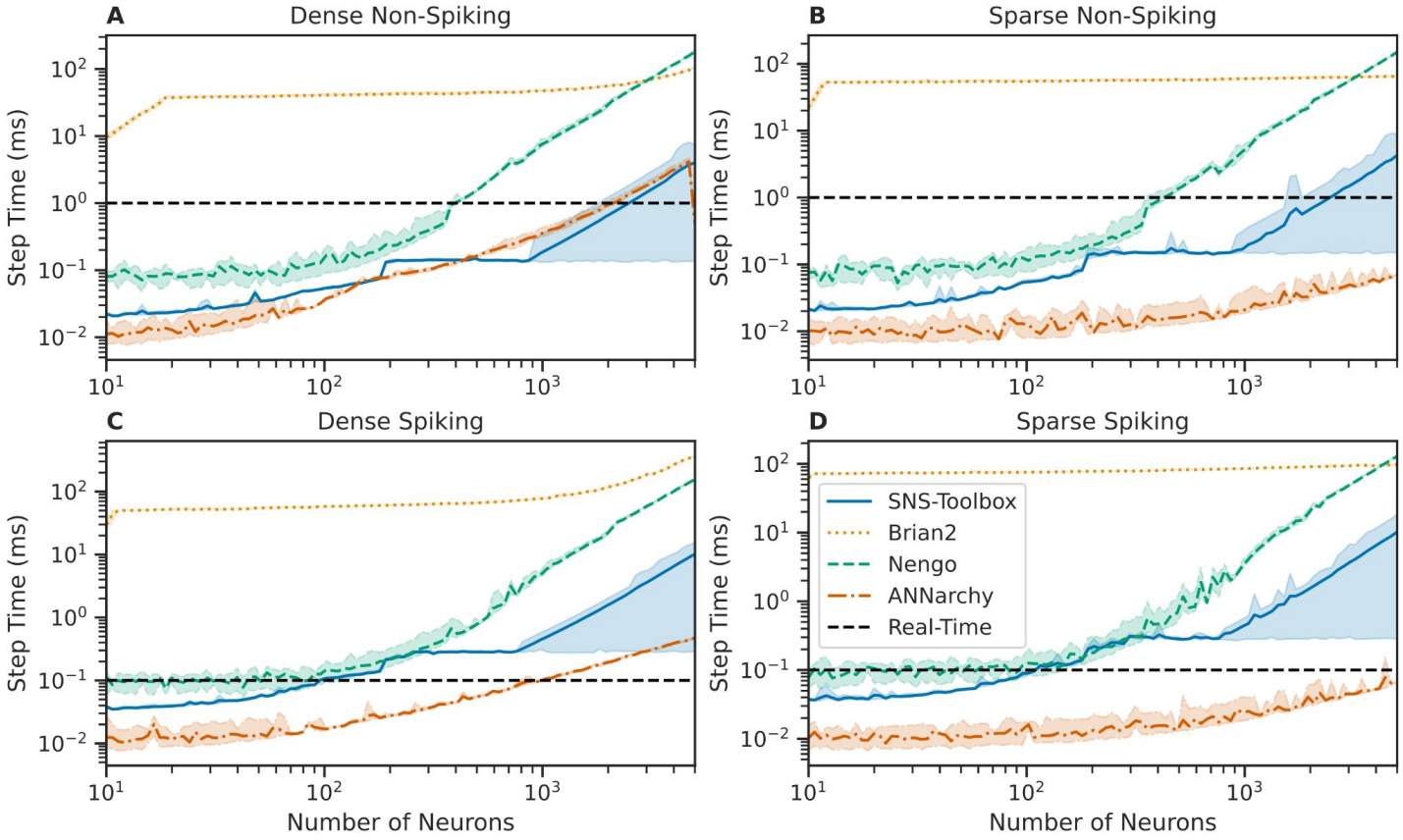
SNS-Toolbox: Backend Performance



SNS-Toolbox: Hardware Performance



SNS-Toolbox: Software Performance Comparison



SNSTorch: SNS-Toolbox for Larger Networks

- Pytorch-based layer implementation
- Still early in development, currently available in alpha release
- Current support:
  - Nonspiking Neurons
  - Elementwise, Convolutional, and Linear Chemical Synapses

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