

Master project description

Paris-Saclay Institute of Neuroscience (NeuroPSI)

Title : Which Information Is Lost by Mesoscopic Reduction?

A Matched Benchmark of Adaptive Conductance-Based Spiking Networks, Moment Closures, and Learned Vector Fields

Description :

A Master-Equation based approach (Elboustani & Destexhe, 2009) derived a relatively general mean-field model that can apply to a wide range of complex and nonlinear neuronal models, such as the Adaptive Exponential (AdEx) model with conductance-based synapses. This was the basis for whole-brain models that can predict the large-scale consequences of changes at the level of synaptic receptors (Sacha et al., 2025), an approach which necessarily require to integrate complex biophysical models.

However, besides the ability of the mean-field to predict outcomes at the large scale, there are approximations in the derivation of this mesoscopic model, and the limits (and errors) due to these approximations are unclear. For a matched conductance-based adaptive AdEx circuit, what is the principal source of mesoscopic prediction error: neglect of finite-size covariances, an inaccurate analytical closure or vector field, or an insufficient macroscopic state representation? How does the answer depend on dynamical regime and observable?

To answer these questions, we will consider different mean-field models and determine the least complex mesoscopic representation that preserves specified properties of a reference spiking neural network (SNN), and to diagnose why a reduction fails when it does. The SNN is therefore a controlled reference model, not a claim of biological ground truth.

This project asks which information must be retained when a conductance-based adaptive spiking neural network is reduced to a mesoscopic model. A matched RS-FS AdEx network will provide controlled reference simulations across stationary, transient, asynchronous, synchronized, and adaptation-dependent regimes. Its dynamics will first be compared with first- and second-order adaptive mean fields. A learned vector field constrained to use the same macroscopic variables will then separate two possible failures: inaccurate analytical equations versus an insufficient state representation. If the state is demonstrably adequate, a constrained hybrid correction may be tested; it is not a mandatory component. Evaluation will combine population statistics, finite-size moments, response dynamics, robustness, extrapolation, dynamical fidelity, and computational cost. Rather than seeking a universal winner, the project will produce a validity map linking model complexity, observable, and dynamical regime. A modular extension will test one violated assumption at a time, such as sparse connectivity, neuronal heterogeneity, or laminar organization. Negative results remain informative by identifying when a simpler mechanistic reduction is sufficient.

(For more details about the project, see [GitHub](#) and contact [Yannaël](#))

Expected outputs :

A documented and tested repository for the reference SNN, first-order mean field, and second-order mean field; with a task-conditioned benchmark with shared inputs, observables, temporal coarse-graining, and evaluation procedures

Keywords : Adaptive Exponential Integrate-and-Fire (AdEx); mesoscopic model; moment closure; finite-size fluctuations; learned vector field; universal differential equation; model reduction; dynamical systems.

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