Exact low-dimensional description for fast neural oscillations with low-firing rates

Pau Clusella[1] and Ernest Montbrió[2]
[1]*Dynamical Systems Biology Lab, Department of Medicine and Life Sciences, Universitat Pompeu Fabra, Barcelona Biomedical Research Park, Barcelona, Spain*
[2]*Neuronal Dynamics Group, Department of Information and Communication Technologies, Universitat Pompeu Fabra, Barcelona, Spain*

Neural mass models (NMMs) are low-dimensional systems aimed to capture the collective dynamics of neural populations. Most NMMs rely on heuristic assumptions or approximation techniques, thereby providing phenomenological descriptions that cannot be traced back to specific single-cell behavior. Nonetheless, an exact mean-field theory for quadratic integrate-and-fire (QIF) neurons has been proposed recently [1], paving a new road to rigorously bridge microscopic neuronal activity and population dynamics.

NMMs developed under this framework assume a deterministic setup where the only source of disorder is a quenched Lorentzian-distributed current heterogeneity. Therefore, collective oscillations emerging from these models correspond to individual neurons behaving as self-sustained oscillators, thus displaying nearly-synchronized firing patterns. This regular behavior is at odds with experimental evidence, which shows that, in fast neural oscillations (40-200 Hz), single neurons fire irregularly at low rates (1-40 Hz). The lack of an exact mean field theory to account for stochastic dynamics and reproduce collective rhythms with irregular neuronal discharges has hitherto been a major challenge in the quest to derive biophysically grounded NMMs from single-cell neuronal models.

In this work, we address this problem by proving that the exact mean-field theory for QIF neurons proposed in [1] also applies for neurons with independent stochastic input currents following a Cauchy distribution. Our analysis follows from recent developments in the Kuramoto model, and the resulting macroscopic model reveals that, in networks of QIF neurons, Lorentzian heterogeneity and Cauchy noise may be used interchangeably at the macroscopic level, yet produce different spiking patterns at the single-unit scale. In particular, we show that networks of identical stochastic units do display irregular synchronization with random-like firing times at frequencies lower than the macroscopic activity. Nonetheless, the collective dynamics remains identical to that obtained using heterogeneity, thus disproving the misconception that the emergence of collective rhythmicity in populations of heterogeneous or stochastic neurons correspond to two different network mechanisms.

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[1] Montbrió, E., Pazó, D. & Roxin, A. Macroscopic Description for Networks of Spiking Neurons. *Phys. Rev. X.* **5**, 021028 (2015,6), https://link.aps.org/doi/10.1103/PhysRevX.5.021028