Noise induced phase transition in cortical neural field: the role of finite-size fluctuations

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Mean-field models [1] of neural population dynamics are central to theoretical neuroscience. However, cortical columns consist of a finite number of neurons ($N \sim 10^2 - 10^4$), requiring realistic models to account for finite-size fluctuations [2, 3]. This endogenous noise can induce transitions and coherence, phenomena well-studied in isolated or coupled populations but less understood in spatially extended systems. We investigate a two-dimensional cortical field, where each lattice node is a population composed of N excitatory spiking neurons. Each neuron has a membrane potential V integrating with leakage the input current due to both the pre-synaptic barrage of spikes it receives, and the inhibitory potassium flow determining the adaptation phenomenon of spike frequency [4, 5]. Populations are interconnected with a probability that decays exponentially with distance. For optimal population sizes (N), finite-size fluctuations coupled with spatial interactions generate coherent oscillations absent in the “thermodynamic” limit ($N \to \infty$, see Figure). We characterise this novel noise-induced phase transition using standard tools from non-equilibrium statistical physics and explore the system’s dynamics in the bifurcation diagram of local excitability versus adaptation strength. Our findings depend primarily on global and local connectivity parameters, rather than single-neuron details; therefore, we expect them to be general and ubiquitous. Lastly, based on these results we address the transition from sleep, dominated by slow global waves, to the asynchronous state characteristic of wakefulness, using our cortical field model offering insights into this fundamental problem in neuroscience, challenging the current understanding [6,7].

Figure 1: Varying N, the number of neurons in the nodes of the lattice, we report the time dependent firing rate of each unit $v_i(t)$ in the top row and the spatial average $\langle v(t) \rangle$in the bottom row.

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