Cost-Efficient Dynamical States Self-Organized by Balanced Excitation/Inhibition in Local Neuronal Networks

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We studied the relationship between firing rate and the dynamical modes in local neuronal networks with a balance of excitation and inhibition. We investigated the dynamical mode of coordinating individual activities to satisfy cost-efficiency trade-off, regarding sparse individual firing required by low energy consumption and collective oscillations for efficient information processing. Low-rate firing can be implemented through a dynamical excitatory-inhibitory balance, which also induces strong fluctuation of spikes and weak cross-correlations of individual activities. Highly coherent firing of individual neurons can be achieved by aggregating different groups of neurons into clusters at different time instants. We adopt a biologically realistic network model of excitatory and inhibitory neurons in which synaptic decay times play a crucial role. In our simulations, low-rate population firing, critical neuronal avalanches and collective oscillations can emerge altogether in the realistic parameter region of synaptic decay times, which is robust when the synaptic efficacies are large enough in the balanced state. With high-rate input of external currents, their coexistence region shrinks but the coexistence maintains. We found that (i) Neuronal avalanches are the cost-efficient dynamical modes to coordinate sparse irregular individual activities into coherent collective oscillations for information processing; (ii) The dynamics can provide maximal information capacity with the minimal firing rate (metabolic cost) in the biological parameter regime. Our results suggest that the cost-efficient dynamical states can be employed as a building block for efficient information processing with low energy cost.