Blowout bifurcation and on-off intermittency in a pulse neural network with two modules

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Let us consider a pulse neural network composed of excitatory neurons and inhibitory neurons written as

$$\dot{\theta}_{E_k}^{(i)} = (1-\cos\theta_{E_k}^{(i)}) + (1+\cos\theta_{E_k}^{(i)}) \times (r_{E_k} + \xi_{E_k}^{(i)}(t) + I_{E_kE_k}(t) - I_{E_kI_k}(t) + \sum_{l\neq k}(I_{E_kE_l}(t) - I_{E_kI_l}(t))), \quad (1)$$

$$\dot{\theta}_{I_k}^{(i)} = (1-\cos\theta_{I_k}^{(i)}) + (1+\cos\theta_{I_k}^{(i)}) \times (r_{I_k} + \xi_{I_k}^{(i)}(t) + I_{I_kE_k}(t) - I_{I_kI_k}(t) + \sum_{l\neq k}(I_{I_kE_l}(t) - I_{I_kI_l}(t))), \quad (2)$$

$$I_{XY}(t) = \frac{g_{XY}}{2N_Y}\sum_{j=1}^{N_Y}\sum_m \frac{1}{\kappa_Y}\exp\left(-\frac{t-t_m^{(j)}}{\kappa_Y}\right), \quad (3)$$

$$\langle \xi_X^{(i)}(t)\xi_Y^{(j)}(t')\rangle = D\delta_{XY}\delta_{ij}\delta(t-t'), \quad (4)$$

where X or $Y = E_k$ or I_k. This network is modeled by the slowly connected class 1 neural network[1]. Note that this network is composed of multiple modules, and the k-th module is composed of excitatory ensemble E_k and inhibitory ensemble I_k. The each neuron is connected to the other neurons with the synaptic coupling written by Eq.(3) where the firing time $t_m^{(j)}$ is defined as the time when the phase $\theta_Y^{(j)}$ of the j-th neuron in the ensemble Y exceeds the value π. The connection strengths in the identical module are set as $g_{E_kE_k} = g_{EE}$, $g_{I_kI_k} = g_{II}$, and $g_{E_kI_k} = g_{I_kE_k} = g_{ext}$, and the connection strengths between different modules are set as $g_{X_kY_l} \equiv \epsilon_{XY}(k \neq l)$.

To examine the dynamics of the network with one module, the analysis with the Fokker-Planck equation is applicable, and various synchronized firings including chaotic ones are observed[2].

For the network with two modules, the blowout bifurcation and the on-off intermittency[3] are observed as shown in Fig.1. The on-off intermittency induces chaotic itinerancy for networks with multiple modules.

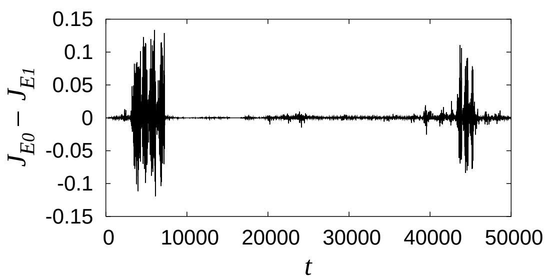

FIG. 1: The time series of the differences of the firing rate J_{E_k} in the limit of $N_{E_k}, N_{I_k} \to \infty$.

The raster plot of the firing times of excitatory neurons in the network with three modules is shown in Fig.2. It is observed that the synchronized clusters are organized and rearranged chaotically.

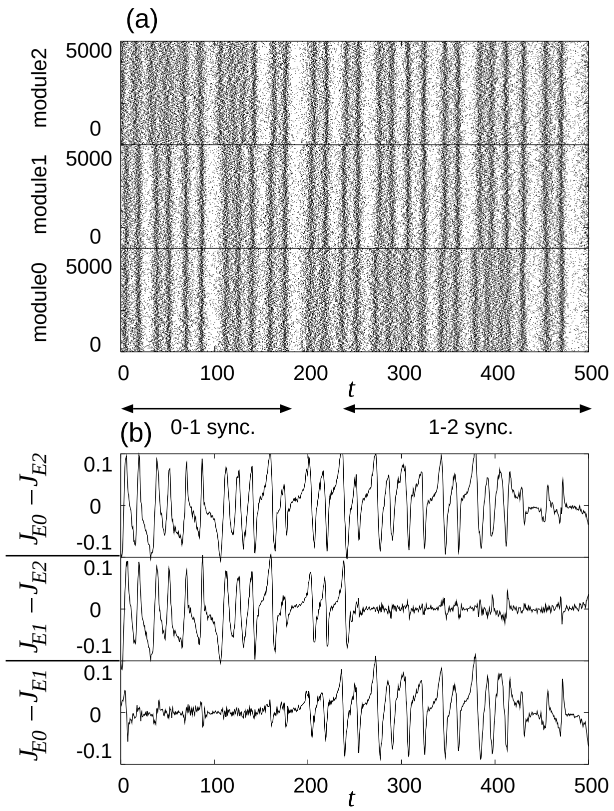

FIG. 2: Chaotic itinerancy observed in the network with three modules where $N_{E_k} = N_{I_k} = 5000$. (a) The raster plot of the firing times of excitatory neurons in each module. (b) The time series of the differences of the firing rate J_{E_k}.

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