Noise effects in a cortical model

Maria Marinaro, Silvia Scarpetta
Dipartimento di Fisica"E. R. Caianiello", Salerno University, Baronissi (SA) IT
INFM Sezione di Salerno (SA) IT, and IIASS Vietri sul mare (SA) Italy

We analyze effects of noise on the dynamics of a excitatory-inhibitory (EI) cortical model with finite range connections. The non-homogeneous model is described simply by Cowan-Wilson-like equations with the inclusion of a noise term. Effects of noise are studied in the collective Stochastic Resonance framework, both analytically and with numerical simulations, and the results are compared with experimental observations of Segev et al PRE 2001 and PRL 2002 in in-vitro cortical networks. The Inter-Event-Intervals (IEI) and the PSD of the networks activity are computed, and compared with experimental results of Segev et al.

I. SUMMARY

We consider an intrinsic white noise term in a spiking rate cortical model and analyze effects of noise on the spontaneous activity of the nonlinear system, in order to account for the experimental results of Segev et al. in in-vitro cortical networks [1,2]. Since the connectivity formation of the cultured system we want to model has grown randomly and spontaneously, we can reasonably assume that strength of each connection is a function only of the type of pre-synaptic and post-synaptic neurons (Excitatory or Inhibitory), and of the distance between them, plus some random quenched fluctuations. Recent estimation of connectivity in in-vitro rat cortical networks has shown arborization of the neurons of $1.2 \pm 0.5 mm^2$ [5]. Therefore, in our model each excitatory unit interact with other nearby excitatory and inhibitory units with a connection strength that decrease with distance. Inhibitory-to-excitatory connections are more localized, with each inhibitory unit connected to only one excitatory unit. In a (cultured) interacting neurons system noise can be due to several reasons, like thermal fluctuation, ion channel stochastic activities, and many others. Using linear analytical results as a guide line, we perform simulations of the nonlinear stochastic model. In a proper range of parameters (depending from eigenvalues of the connections matrices) the linear analysis predicts that noise induces a collective synchronous oscillatory behavior in the neurons activity. Without noise the system doesn't shows oscillations (it fires randomly in a uncorrelated manner). This collective oscillatory behavior induced by noise corresponds to a broad peak in the power-spectrum of the neurons activity near the characteristic frequency ω_0 (the value ω_0 also depends from the eigenvalues of the connection matrices). Analytical predictions are confirmed by the nonlinear numerical simulations. In the proper regime, collective oscillations are induced by noise. The activity $u_i(t)$ looks synchronous and aperiodic on long time scale, being decorrelated over long time scale by the noise. This spontaneous aperiodic synchronous activity mimic the spontaneous aperiodic synchronous bursting activity observed under 0.5 mM Ca (and 2.0 mM Ca) concentration in [2]. We compute the Inter-Event-Interval (IEI) between two successive synchronous high activity events. A peak of all u_i with intensity above a threshold is defined as a synchronized bursting event. From the sequence t_n, specifying the location of the nth event, we compute the IEI histogram shown in fig. 1. Notably, the IEI is in a good agreement with the experimental one observed at 0.5 mM Ca (see fig. 5 of [2]). Both experimentally and in the model, the IEI shows a peak (at about 10 sec) with a very long tail (around 40-60 sec the histogram is still significantly non zero). Looking at different classes of nonlinearity, we observe that some classes of nonlinearity can enhance the ratio between the height of the PSD peak and the strength of noise, for a critical range of noise intensities, in a collective stochastic resonance fashion [3]. Indeed, solid line in Fig. 2.b shows the typical maximum that has become the fingerprint of *Stochastic Resonance* phenomena [4].

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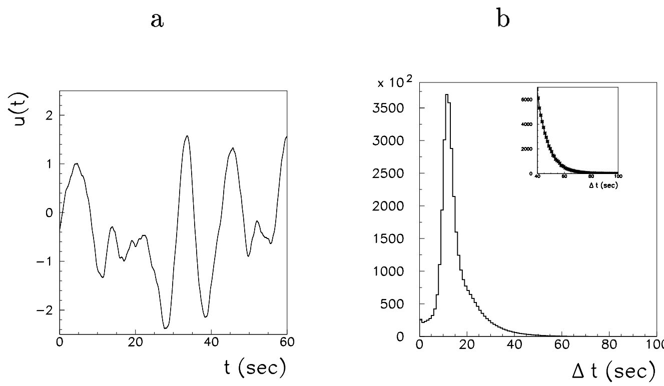

FIG. 1. A. The time behavior of the state variable $u_i(t), i = 1, \ldots, N$ in the numerical simulation in the regime B, with noise $\Gamma = 0.004$. Lines $u_i(t)$, $i = 1, .., N = 10$, overlaps each other because of synchrony. All units $u_i(t)$ shows synchronous aperiodic oscillatory activity. B. Histogram of Inter Synchronous Event Intervals, in regime B with $\Gamma = 0.0004$. Inset. Zoom of the IEI at long times.

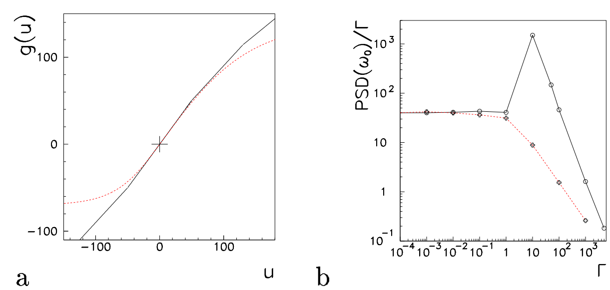

FIG. 2. A. Two activation functions for excitatory units u_i. Red dashed line shows a saturating activation function, while solid line shows a piece-wise-linear function, whose slope increases before decreasing when u is raised from its stationary value (cross). B. Ratio $R = PSD(\omega_0)/\Gamma$ as a function of the noise level Γ. Red dashed line correspond to the saturating activation function shown in red in A, while the solid black line to the solid line activation function in A.