BMC Neuroscience

Poster presentation

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Slow population rhythms emerge in noisy inhibitory network models

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from Eighteenth Annual Computational Neuroscience Meeting: CNS*2009
Berlin, Germany. 18–23 July 2009

Published: 13 July 2009

BMC Neuroscience 2009, **10**(Suppl 1):P156 doi:10.1186/1471-2202-10-S1-P156

This abstract is available from: http://www.biomedcentral.com/1471-2202/10/S1/P156

Inhibitory, interneuronal networks are known to underlie high-frequency (gamma, 40–80 Hz) population oscillations, and they are also known to underlie low-frequency rhythms. For example, spontaneous, slow (0.5–4 Hz) rhythms occur in rodent hippocampus [1]. However, it is unclear whether an inhibitory network can generate population oscillations much slower than the intrinsic firing frequencies of its consitutent neurons. Here we show that an inhibitory network model in the absence of any slow processes is able to produce low-frequency rhythms. To obtain this, we bridge our network model simulations with a dynamical mean-field (DMA) model [2] to approximate the location of relevant parameter regimes.

The individual interneuron model is a two-dimensional conductance-based model and the network is formed with fast, inhibitory $GABA_A$ type synapses. The DMA model representing a large all-to-all coupled system consists of 30 equations that include equations describing synaptic noises. Bifurcation analysis is used to explore the DMA model, in particular, to identify parameter regimes for which bursting activities occur. These parameters are used in network simulations. The network model consists of an all-to-all coupled network of 20 interneurons. Each interneuron is described by: $CdV/dt = I_{app} + b\eta - g_L(V-E_L) - g_{Na}m(V-E_{Na}) - g_K n(V-E_K) - g_{syn}(V-E_{syn})\Sigma_i s_i$; $m(V) = 1/(1+\exp(-4/3-V/15))$; $dn/dt = 1/(1+\exp(-5-V/5))-n$; $ds_i/dt = a(1-s_i)/(1+\exp(-V_i/2))-s_i/\tau$, where $\Sigma_i s_i$ sums the (inhibitory) synaptic gating variables from other interneurons in the network, η represents white noise of unit strength and b represents the strength of the noise. Figure 1 shows a raster plot from a 30 second network simulation (left) with the corresponding average summated synaptic activities (right). The parameters used are taken from identified

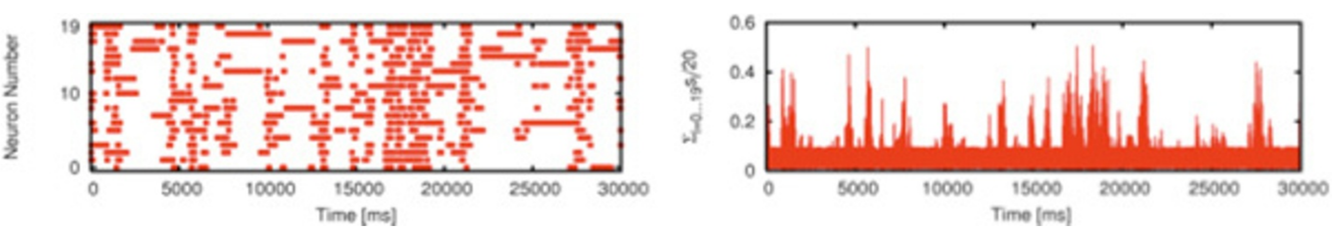

Figure 1
Slow Network Rhythm.

bursting regimes in the DMA model analysis. Parameters values: I_{app}= 4.8 μA/cm^2; b= 0.08 ms$^{1/2}$mA/cm^2; g_L= 8 mS/cm^2; g_K= 10 mS/cm^2; g_{Na}= 20 mS/cm^2; g_{syn}= 0.0263 mS/cm^2; E_L= -80 mV; E_K= -90 mV; E_{Na}= 60 mV; E_{syn}= -85 mV; τ = 10 ms; C = 1 μF/cm^2. The intrinsic firing frequency at I_{app} = 4.8 μA/cm^2 for these neurons (with zero noise) is 52 Hz. Slow population rhythms (approx 0.5 Hz), or bursts of synaptic activities, can be seen to emerge due to a "switching" between sparsely firing and coherently firing network states.

A DMA model analysis has been used to find parameter regimes that allow slow rhythms to be expressed by inhibitory network models. These regimes are identified by bursting activities in a simpler mean-field model. Given the bridging used between the DMA model and the network simulations, we expect that this slow pattern should also occur in much larger network models. We have previously obtained values for synaptic "noise" parameters underlying slow hippocampal rhythms [3]. It will be interesting to determine whether bursting in the DMA models, and thus slow population rhythms in large network simulations, occur using these experimentally-based synaptic noise parameter values. If so, this would suggest a novel way in which slow rhythms could emerge in biological, inhibitory networks.

Acknowledgements
NSERC of Canada.

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