MODELLING OF PERSISTENT NEURAL ACTIVITY AND MEMORY

Roman Borisyuk

Centre for Theoretical and Computational Neuroscience, University of Plymouth
rborisyuk@plymouth.ac.uk

Persistent neural activity is observed in many brain systems, e.g. in the prefrontal cortex of monkeys, in the dorsal nucleus of the rodent thalamus, in the rat hippocampus, in the goldfish hindbrain, etc. The persistent activity is considered as a neural process underlying memory formation. Persistent activity appears on presentation of a specific short stimulus and lasts for several seconds after the stimulation is gone. For example, experimental recordings from prefrontal neurons of monkeys show the persistent activity during a delayed response task. The persistent activity is more irregular during mnemonic delay period than fixation period (Compte et al., 2003). This evidence corresponds with our population rate model of the metastable state of neural activity, which is described by dynamics of two first moments: the mean of population activity, which is bounded, and the variance, which grows (Kryukov et al., 1990).

To study such important characteristics of the persistent activity as synchronisation, bursting, and spatial dynamics, we simulate a neural network of enhanced integrate-and-fire elements with noise. Using the results of population rate model, we find a region in parameter space corresponding with persistent neural activity of spiking model. Investigation of spatio-temporal dynamics of spiking neural network of excitatory and inhibitory neurons with cortex-like architecture of local coupling and sparse long-length connections shows the existence of persistent neural activity which is similar to the experimental data recorded from prefrontal neurons.

A theoretical background for description of persistent states and memorization of stimuli has been recently developed (Borisyuk & Hoppensteadt, 2004). A theory of epineuronal memory explains how the brain can maintain stable memories and behaviours when its underlying electrical and chemical structures are constantly changing. We study a neural network model, but one whose parameters are governed by a mnemonic landscape function. Parameter configurations are attracted to local maxima of this landscape, which represent memorised parameter configurations. The operating environment changes slowly guided by the mnemonic landscape function and this provide a quasi-static operating environment for the network. We describe shaping the mnemonic landscape, how it acts as a probability density function to guide slow parameter dynamics, and how the parameters shape the network output resulting in the persistent mnemonic state.

References

Borisyuk R., Hoppensteadt F. (2004) A theory of epineuronal memory. Neural Networks, 17:1427-1436

Compte A., Constantinidis C., Tegn'er J., Raghavachari S., Chafee M., Goldman-Rakic P., Wang X.-J. (2003) Temporally irregular mnemonic persistent activity in prefrontal neurons of monkeys during a delayed response task. J. Neurophysiol., 90:3441-3454

Kryukov V.I., Borisyuk G.N., Borisyuk R.M., Kirillov A.B. and Kovalenko Ye.I. (1990) Metastable and unstable states in the brain. In: Stochastic Cellular Systems: Ergodicity, Memory, Morphogenesis, R.L. Dobrushin, V.I. Kryukov, A.L. Toom (eds), part III, 225-358, Manchester University Press.