Internship Master 2 subject

Research Center

INRIA Sophia Antipolis - Méditerranée, Equipe-Projet INRIA Neuromathcomp and Tosca

Localisation

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Financial Support

The master student will be paid by Inria

Title

A stochastic model of gamma phase modulated orientation selectivity.

This internship aims at studying theoretically the interplay between oscillations generated by noisy populations of neurons and the repartition of the spiking times within the oscillations in response to oriented stimuli.

Keywords: oscillations, nonlinear waves, ring model, stochastic bifurcations, equivariant dynamics.

Context

Knowledge of the mechanisms used by neurons to transmit information is far from being complete. The scientific issues are major, both for a single neuron and for a network of neurons with billions of connections, like in a human brain.

Nowadays, classical deterministic models for population of neurons are improved upon by the addition of a stochastic component. This noise is an attempt to describe one or several sources of noise that exist in the brain *e.g.* coming from the opening and closing of ionic channels across the neural membrane for example. On the other hand, each neuron is included in a potentially noisy environment, which is changing with time: for example, the (non-deterministic) activity of the other neurons in the network will change the behavior of the studied neuron. This is external noise.

There have been recently numerous studies trying to relate the spike timing of individual neurons and the oscillatory rhythms in the local field potentials (LFP) of the neural populations. The LFP spectrum has been mostly explained using population dynamics tuned such that the LFP oscillations cannot be seen in single neuron activity (see, for example, [4, 2]). Most of these deterministic models suggest that the populations are poised close to an oscillatory instability *e.g.* a Hopf bifurcation.

The interplay between the orientation selectivity of neurons in primary visual cortex V1 in **awake** macaques and these LFP oscillations has recently been studied experimentally in [5]. The authors found that the spike probability was locked on the LFP phase (in the gamma-band) with maximum occurring at zero phase lag. Then, they look at the link between the LFP phase and the preferred orientation V1 neurons [3] for which they introduce a measure called the orientation selectivity index (OSI). They showed that the spike based OSI of the (orientation tuned) neurons are gamma-phase locked with zero lag but there seems to be a phase advance for the OSI at the population level. Finally, they demonstrated that the noise is minimal at phase zero of the LFP.

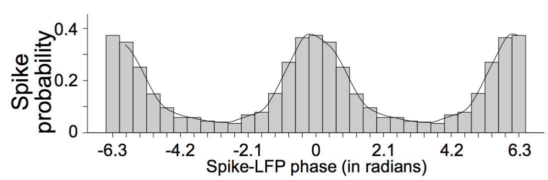

Figure 1: Approximated spike density over LFP phase.

Subject of the internship

The aim of the internship is to study a model that accounts for the experiments described in [5]. We consider a firing rate model of a piece of visual cortex which is comprised of excitatory cells and inhibitory cells labeled by their preferred orientation θ. More precisely, we look at the following model $V = (E, I)$:

$$\begin{aligned}
\tau_E dE(\theta,t) &= \Big(-E(\theta,t) + \int_{-\pi/2}^{\pi/2} J_{EE}(\theta-\bar\theta)S(E(\bar\theta,t)) - J_{EI}(\theta-\bar\theta)S(I(\bar\theta,t))d\bar\theta\Big)\,dt \\
&\quad + I_E^{ext}(\theta,t)dt + \sigma(\theta)dB_E(\theta,t) \\
\tau_I dI(\theta,t) &= \Big(-I(\theta,t) + \int_{-\pi/2}^{\pi/2} J_{II}(\theta-\bar\theta)S(I(\bar\theta,t)) - J_{IE}(\theta-\bar\theta)S(E(\bar\theta,t))d\bar\theta\Big)\,dt \\
&\quad + I_I^{ext}(\theta,t)dt + \sigma(\theta)dB_I(\theta,t)
\end{aligned}$$

The external current I_i^{ext} represents the thalamus input which is supposed to give a small clue about the orientation of the drifting grating (with frequency

ω_{drift}):

$$I_i^{ext} = I_i(1 + \varepsilon \cos 2(\theta - \theta_{stim}) \cos(\omega_{drift} t)).$$

The nonlinearity S represent the $f - I$ curve of the neurons and the synaptic connections are written $J_{EE}(\theta), \cdots$. Finally, the noise is modeled with Gaussian processes $B_E(\theta, t), B_I(\theta, t)$. To reproduce the experiments, we will first look at a network tuned close to a Hopf bifurcation with $O(2)$ symmetry [1] when the noise is small.

Advisor

The student will be advised by Etienne Tanré (`Etienne.Tanre@inria.fr`) and Romain Veltz (`Romain.Veltz@inria.fr`) of the teams Neuromathcomp and Tosca.

Skills and profile

The student will use standard tools issued from dynamical system, stochastic calculus and numerical probabilities.

References

[1] P. Chossat and R. Lauterbach. *Methods in Equivariant Bifurcations and Dynamical Systems*. World Scientific, 2000.

[2] H. Ozeki, I. Finn, E. Schaffer, K. Miller, and D. Ferster. Inhibitory stabilization of the cortical network underlies visual surround suppression. *Neuron*, 62(4):578–592, May 2009.

[3] D. Purves. *Neuroscience*. Sinauer Associates, Publishers, Sunderland, Mass., 2004.

[4] M. Tsodyks, W. Skaggs, T. Sejnowski, and B. McNaughton. Paradoxical effects of external modulation of inhibitory interneurons. *The Journal of Neuroscience*, 17(11):4382 –4388, June 1997.

[5] T. Womelsdorf, B. Lima, M. Vinck, R. Oostenveld, W. Singer, S. Neuenschwander, and P. Fries. Orientation selectivity and noise correlation in awake monkey area v1 are modulated by the gamma cycle. *Proceedings of the National Academy of Sciences*, February 2012.