Mean-field methods and multiscale analysis of neuronal populations

3-7 October 2011, CIRM, Marseille

Organizers: Nicolas Brunel and Olivier Faugeras

Schedule

Monday October 3

9.30-9.45	Nicolas Brunel (Paris) Welcome
9.45-10.30	Olivier Faugeras (INRIA) Two or three things I know about mean-field methods for large assemblies of neurons
10.30-11.00	Coffee break
11.00-11.45	Gianluigi Mongillo (Paris) Bi-Stability and Spatio-temporal Irregularity in Neuronal Networks with Non-linear Synaptic Transmission
11.45-12.30	Carl van Vreeswijk (Paris) Analysis of Network Activity in Spiking Networks with Synaptic Depression
12.30-14.00	Lunch break
14.00-14.45	Stefan Rotter (Freiburg) Spike Train Correlations Derived from Anatomical Microstructure
14.45-15.30	Kresimir Josic (Houston) Using linear response techniques to study the structure of network correlations
15.30-16.00	Coffee break
16.00-16.45	Erik Shea-Brown (Seattle) A mechanistic approach to multi-spike patterns in neural circuits

Tuesday, October 4

9.00-9.45	Gérard Ben Arous (New York) A survey of mean field methods: the mathematician's viewpoint
9.45-10.30	Gilles Wainrib (Paris) Averaging principle for stochastic slow-fast systems in neuroscience
10.30-11.00	Coffee break
11.00-11.45	Carson Chow (NIH) Finite size effects in spiking neural networks
11.45-12.30	Jack Cowan (Chicago) Stochastic Wilson-Cowan equations for networks of excitatory and inhibitory neurons
12.30-14.00	Lunch break
14.00-14.45	Magnus Richardson (Warwick) Fast synapses and slow neuromodulators
14.45-15.30	Srdjan Ostojic (New York) From Spiking Neuron Models to Linear-Nonlinear Models
15.30-16.00	Coffee break
16.00-18.00	Poster session

Wednesday, October 5

9.00-9.45	Jaime de la Rocha (Barcelona) Neuronal Variability, Co-variability and Choice Probability
9.45-10.30	Maurizio Mattia (Rome) Heterogeneous attractor modules for motor planning in macaque premotor cortex
10.30-11.00	Coffee break
11.00-11.45	Paolo del Giudice (Rome) Networks of individually bistable neural populations
11.45-12.30	Gasper Tkacik (IST Austria) Statistical mechanics for a network of real neurons
12.30-14.00	Lunch break
14.00-14.45	Aaditya Rangan (New York) Can classical population-dynamics methods capture the dynamics of the visual cortex?
14.45-15.30	David Hansel (Paris) Mechanism of orientation selectivity in primary visual cortex without orientation map
15.30-16.00	Coffee break

Thursday October 6

9.00-9.45	Michael Buice (NIH) Effective Langevin Equations for Heterogeneous Coupled Neural Networks
9.45-10.30	Richard Naud (Lausanne) A population approach to Coding and Decoding with Adapting Neurons
10.30-11.00	Coffee break
11.00-11.45	Cheng Ly (Pittsburgh) The balance between cellular and circuit regulation of low population variability enhances neural coding
11.45-12.30	Samuel Herrmann (Nancy) From stochastic resonance to stationary measures of McKean-Vlasov type equations
12.30-14.00	Lunch break
14.00-14.45	Duane Nykamp (Minnesota) The influence of network structure on neuronal network dynamics
14.45-15.30	Ashok Kumar (Pittsburgh) Slow Dynamics in Balanced Networks with Clustered Connections
15.30-16.00	Coffee break

Friday, October 7

9.00-9.45	Alex Roxin (Barcelona) Oscillations in the bistable regime of neuronal networks
9.45-10.30	Michelle Thieullen (Paris) On spatially extended stochastic models of neurons
10.30-11.00	Coffee break
11.00-11.45	Bruno Cessac (Nice) Dynamical mean-field methods: some remarks and questions
11.45-12.30	Benjamin Lindner (Berlin) Mean-field theory for coupled hair bundles
12.30-14.00	Lunch break

Invited speakers, titles and abstracts

Gérard Ben-Arous (NYU) gba1@nyu.edu

Michael Buice (NIH) buicem@niddk.nih.gov

Effective Langevin Equations for Heterogeneous Coupled Neural Networks

We construct effective Langevin equations for single neurons within coupled neural networks and explore the effects of heterogeneity on the population statistics and stability. The parameters of the Langevin equation are dependent upon the properties of the other neurons within the network. This permits the inference of network properties through measurement of single neuron statistics. We discuss the impact of heterogeneity on the possibility of various coding schemes in the network, for example whether the neurons respect a phase-coding versus a rate-coding mechanism.

Bruno Cessac (Nice) bruno.cessac@inria.fr

Dynamical mean-field methods: some remarks and questions

We review different analytical methods to obtain dynamic mean-field equations in neuronal networks: naive mean-field approaches, local chaos hypothesis, generating functional, large deviations. We compare them, discuss their consequences and address a few related open problems.

Carson Chow (NIH) carsonc@niddk.nih.gov

Finite size effects in spiking neural networks

Jack Cowan (Chicago) cowan@math.uchicago.edu

Stochastic Wilson-Cowan equations for networks of excitatory and inhibitory neurons

We have recently found a way to describe large-scale neural activity in terms of non-equilibrium statistical mechanics. This allows us to calculate the effects of fluctuations and correlations on neural activity. Major results of this formulation include a role for critical branching, and the demonstration that there exists a non-equilibrium phase transition in neocortical activity which is in the same universality class as directed percolation. Here we show how the population dynamics of interacting excitatory and inhibitory neural populations can be described in similar terms, and how such a theory can be used to explain the origins and properties of random bursts of synchronous activity (avalanches), population oscillations (quasi-cycles), synchronous oscillations (limit-cycles) and fluctuation-driven spatial patterns (quasi-patterns).

Paolo Del Giudice (Rome) paolo.delgiudice@iss.infn.it

Networks of individually bistable neural populations

I will report some preliminary results obtained in the study of 'networks of networks' built of sparsely connected recurrent, individually bistable neural populations. Inspired by strategies used to evaluate the complexity of the state space in the theory of spin glasses, we explore ways to characterize distributed attractors emerging in such networks of networks, depending on the relative strengths of recurrent (inhomogeneous) self-excitation of the single populations, and the inter-populations couplings, and get information on the determinants of the stochastic transitions between such global attractor states.

Jaime de la Rocha (Barcelona) jrochav@clinic.ub.es

Neuronal Variability, Co-variability and Choice Probability

Cortical neurons in sensory areas respond to external stimuli unreliably, a feature which could strongly constrain information encoding. This trial-to-trial variability is, in most cases, partly shared between nearby neurons. When using ambiguous stimuli in a perceptual decision task, single neuron variability also correlates with perceptual variability, something generally measured by the Choice Probability (CP) [1]. The current mechanistic model reproducing this variability, co-variability and CP is built upon two principles: cortical circuits operate in a balanced state, and information is encoded in population rates. In the balanced state of large recurrent networks, neurons counterbalance the large supra-threshold excitation with large negative inhibition coming from I cells rendering a subthreshold highly-fluctuating net current [2,3]. It has been generally assumed that neurons in this state share an irreducible fraction of their spiking variability reflecting the fraction of anatomically shared inputs [4]. As a consequence, population rate codes are intrinsically noisy and single neuron CP simply reveals the impact if this population noise on the discrimination of stimuli near the perceptual threshold [5]. We will challenge this framework by showing that in a balanced state, the strong and fast inhibitory feedback de-correlates neural firing in the presence of large fractions of shared inputs. We will show that a densely connected sensory network in the balanced state shows marginal correlations and no CP. We investigate two extensions of the balanced sensory circuit giving rise to correlations and CP values compatible with observed data: (1) a minimal mesoscopic structure defining two sensory populations oppositely tuned with strong reciprocal inhibition; (2) top-down excitatory connections from a decision module onto the sensory circuit. We study the structure of correlations and the dynamics of CP in each model. We find that the time-course of CP is different in each model, capturing the causal role of the population variability on the decision in the first, and the dynamics of the decision circuit projected on the sensory network in the second. We will discuss the implications of these results on interpreting neuronal variability and propose experimentally testable predictions to disambiguate the different causes of this variability.

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Olivier Faugeras (INRIA) olivier.faugeras@inria.fr

Two or three things I know about mean-field methods for large assemblies of neurons

I consider a variety of networks of rate or spiking neurons. In this context I describe two classes of rigourous mathematical methods that allow to derive the limit, when the number of neurons goes to infinity, of the network equations. In both cases the major result is that of the propagation of chaos and in general the loss of the Markov property of the solutions to the network equations. The first class of methods is inspired by what has been done for the analysis of Langevin spin glass dynamics in particular by Sompolinsky and his colleagues and by Ben Arous and Guionnet. The synaptic weights are modelled as random variables but no dynamics on these weights is considered. One is led to distinguish quenched or averaged (annealed) results. The second class of methods is inspired by what has been done by McKean, Tanaka, and Sznitman for the analysis of systems of interacting particles. The synaptic weights are modelled here as random processes. The second class turns out to be more amenable to a detailed analysis of the behaviour of the solutions to the mean-field equations at least at the time of writing this abstract. I discuss results concerning the phenomenon of propagation of chaos and try to relate it to some recent experimental findings and to such questions as the optimality of information processing. I present some numerical experimental results related to the influence of the noise on the solutions in particular with respect to synchronization in the context of bifurcation theory. I present some open problems related to possible extensions of these models and techniques.

David Hansel (Paris Descartes) david.hansel@univ-paris5.fr

Mechanism of orientation selectivity in primary visual cortex without orientation map

Most neurons in primary visual cortex (V1) have an orientation selective response. This is true for animals such as cats and primates, in which V1 has an orientation map, as well as for species without such a map, e.g. rodents. The mechanism for orientation selectivity remains a matter of debate. Whether selectivity is primarily due to feedforward connectivity or to recurrent interactions has not been settled. If the mechanism is primarily feedforward, the presence or absence of an orientation map hardly matters, but if recurrent interactions are important the spatial organization of preferred orientations could affect the mechanism. Theoretical studies of orientation selectivity have, up to now, focused on models of V1 with orientation map. The proposed recurrent mechanisms rely on the fact that, with a map, neurons mostly receive recurrent connections from cells

with similar preferred orientations. The connectivity in V1 without map is hotly debated.
Unclear is whether connections depend on the difference in stimulus feature preferences. With such a preference, the distributions of orientations of cells projecting to a neuron would be similar to that in cortices with a map and the same mechanism could operate. In contrast, when connectivity is independent of difference in preferred orientation, this distribution is flat. How can orientation tuning arise in this case?
I will argue in my talk that orientation selectivity arises naturally in V1 without feature dependent connectivity if it operates in the balanced regime. To this end, I will consider a network consisting of an excitatory and an inhibitory population of randomly connected neurons with, on average, K recurrent inputs from each population. The strengths of the recurrent connections are of order 1/sqrt(K). Neurons also receive a feedforward input, with an untuned part of order sqrt(K) and a random orientation dependent part of order 1. Feedforward input, total excitatory and total inhibitory feedback are all much larger than the rheobase. Nevertheless neurons fire at a reasonable rate because the net feedback approximately cancels the feedforward input. Because of the connectivity, the total excitatory and inhibitory feedback are almost untuned. As a result, the untuned part of the feedforward input is approximately canceled by the feedback, but its much smaller tuned part is not. This results in an output of the cells with significant orientation tuning. The heterogeneity in tuning curves is large.
This study predicts that the average voltage of the neurons, relative to rest, shows clear orientation tuning, but the size of the voltage fluctuations are orientation independent.
Work done in collaboration with Carl van Vreeswijk.

Samuel Herrmann (Nancy) herrmann@iecn.u-nancy.fr

From stochastic resonance to stationary measures of McKean-Vlasov type equations

The aim of the talk is to present a first step in studying stochastic resonance for huge systems of interacting particles. These systems can be compared to self-stabilizing diffusions, i.e. processes attracted by their own law satisfying nonlinear stochastic differential equations (McKean–Vlasov). In this framework, several results are pointed out: the importance of the system inertia (exit problem), the large deviations behavior of nonlinear diffusions in the small noise limit and the existence of several invariant measures (exactly three invariant measures in the selected model).

Kresimir Josic (Houston) josic@math.uh.edu

Using linear response techniques to study the structure of network correlations

Linear response techniques are a powerful tool for the analysis of network dynamics. They have primarily been used to characterize the relations between the spike trains of cells. However, they can also be used to analyze correlations between cells' membrane potential fluctuations. I will address the question of how membrane potential correlations are related to input statistics and to spiking correlations. Surprisingly, spiking correlations and membrane potential correlations respond distinctly to changes in cells' firing rates. Therefore care needs to be taken when assuming that membrane potentials and firing rates can be used interchangeably to characterize a cell's response.
I will also show that linear response techniques can be used in a natural way to characterize the structure of activity in neuronal networks. They offer a powerful tool to relate the structure of inputs and a network's architecture with the statistics of its response.

Ashok Kumar (Pittsburgh) alk@cmu.edu
Slow Dynamics in Balanced Networks with Clustered Connections
We investigate the relationship between neuronal network dynamics and clustering of excitatory connections in recurrent networks of excitatory and inhibitory neurons. Long timescale behavior in which clusters of neurons transiently increase their firing rates are promoted by this connection structure. These slow fluctuations produce an additional source of long timescale variability in the network dynamics not present in models of recurrent networks with homogeneous connectivity. We study how the degree of clustering and strength of external stimuli control the timescale of these slow rate transitions. Our work demonstrates that nontrivial excitatory connection structures in balanced networks can unveil new collective network dynamics.

Benjamin Lindner (Dresden) benjamin.lindner@physik.hu-berlin.de
Mean-field theory for coupled hair bundles

Cheng Ly (Pittsburgh) cheng70@gmail.com
The balance between cellular and circuit regulation of low population variability enhances neural coding
The responses of cortical neurons are significantly variable across presentation trials of a fixed stimulus. The coordinated response variability of neurons within a population is critical for theories of both sensory and motor coding, as it is thought to limit the accuracy of population-wide neural representation. Despite the impact of variability on neural function, the cellular and circuit mechanisms that shape the trial-to-trial variability of population response are vastly understudied. We use a combination of experimental and computational techniques to establish how threshold nonlinearities and feedforward inhibition combine to decorrelates the trial-to-trial variability of populations of pyramidal cells (E-cells) in layer 2/3 of rat whisker-barrel cortex. Simultaneously recorded extracellular

spike trains from pairs of E-cells show consistently low co-variability of spiking activity in spontaneous and stimulus evoked states. Theoretical analysis of simple network models shows the co-variability during low intensity stimuli is diluted by spike threshold nonlinearties, while inhibition (I)-mediated cancellation of co-variability occurs for high intensity stimuli. Our theory requires that the co-variability of I-E cells is larger than that of the E-E pairs, and this prediction is verified with simultaneous recordings of I-E pairs. We show how this combined mechanism of active decorrelation of population variability leads to a drastic increase in the population information about whisker velocity. The generic cellular and circuit components of our study suggest that low network variability over a broad range of neural states may generalize across the nervous system.

Maurizio Mattia (Rome) mattia@iss.infn.it

Heterogeneous attractor modules for motor planning in macaque premotor cortex

Cognitive functions rely on the concerted activity of multiple neuronal assemblies supporting distributed computation, of which motor planning is a prominent example. With other primate brain areas, dorsal premotor cortex (PMd) is involved in preparing arm movements, and more generally in integrating set-related and motor information and in selecting potential options, even when actions are only observed and not explicitly performed. Although theoretical attempts have been reported, underlying cortical computational strategies and related neuronal machinery still remain elusive. Here we show that in macaque monkeys performing a reaching countermanding task, motor plans coded in PMd can be detected as multi-unit activity (MUA) patterns resulting from a network of cortical modules. We found sudden and stereotyped MUA sharp transitions (STs), signalling an increase or a decrease in the population firing, as a late reaction to target appearance, and predicting at single trial level forthcoming actions. Occurrence of such STs was observed even when movement was successfully cancelled after a stop signal or during delay epochs of delayed reaching task, excluding that they are the mere substrate of the motor execution. We developed a multi-modular network of spiking neurons model which accounted for STs and predicted a peculiar modulation of high-frequency Fourier components of unfiltered local field potentials (LFP). In vivo observations confirmed such theoretical framework, providing a strong evidence that local synaptic reverberation was in action, making neuronal modules bistable. Our results demonstrate that motor plans mature in PMd as an emergent cooperative representation driven by a subset of "active" modules with strong self-excitation, capable to amplify subthreshold input and to recruit other "passive" modules with weaker synaptic local feedback. What emerges is a quite general computational machinery composed of a web of bistable modules acting as interacting "flip-flops", which recovers and extends the long-standing theory of attractor networks.

Gianluigi Mongillo (Paris Descartes) gianluigi.mongillo@univ-paris5.fr

Bi-Stability and Spatio-temporal Irregularity in Neuronal Networks with Non-linear Synaptic Transmission

We present a Mean-Field (MF) theory for spiking networks with dynamic synapses, originating from short-term plasticity (STP) and operating in the balanced regime. The theory reveals a novel mechanism for bi-stability which relies on the non-linearity of synaptic interactions. As synaptic non-linearity is mainly controlled by spiking rates, bi-stability tolerates significant variations in the input statistics. In both states the network operates in the fluctuation-driven regime, thus producing activity patterns characterized by strong spatio-temporal irregularity. Joint work with: David Hansel and Carl van Vreeswijk

Richard Naud (Lausanne) richard.naud@epfl.ch

A population approach to Coding and Decoding with Adapting Neurons

How can information be encoded and decoded in populations of adapting neurons? And how can this code be read? Here we use approximation methods valid at low population-activities to address these questions. The results are based on a spike-response model where adaptation is mediated by a linear summation of the trailing effect of each previous spike. We derive a self-consistent equation for encoding external stimuli in the population activity. This encoding formula accurately predicts population activity calculated from 100 000 repeated simulations of our spike-response model. We show that the population activity can be decoded by taking into account a weighted sum of the past activity. We also explore how the linear filter is affected by different spike-triggered adaptation dynamics and find that the adaptation profiles of regular spiking neurons make a high-pass filter while the properties of some GABAergic fast-spiking neurons create a strong band-pass. Finally, we derive an approximation of the auto-correlation of spike trains and show that the equation is compatible with simulations. The results can be used to make mean-field theory models of neuron networks closer to experimental observations. The theory presented here helps in bridging the gap between the dynamics of single-neurons and that of populations.

Duane Nykamp (Minnesota) nykamp@math.umn.edu

The influence of network structure on neuronal network dynamics

Evidence is emerging that local connectivity among neurons contains a microstructure that deviates from standard random network models. I develop a simple network model that captures key correlations among network edges and investigate its consequences on the dynamics of populations of interacting excitatory and inhibitory neurons. The primary influences of the network structure can be captured by a mean-field model. The mean-field analysis demonstrates how correlations among network edges that form chains have a profound influence on network dynamics.

Srdjan Ostojic (Columbia) so2310@.edu

From Spiking Neuron Models to Linear-Nonlinear Models

In the recent years linear-nonlinear (LN) models have become a popular way of describing neural activity elicited by a time-varying input. In these models, the output firing rate is obtained by processing the input through a cascade consisting of two consecutive stages: (i) a linear temporal filter is applied to the input; (ii) the outcome is transformed non-linearly to obtain a firing rate. Such a decomposition in two sequential processing stages is mathematically appealing, however from a biophysical perspective it seems difficult to identify two distinct mechanism that would correspond to the two stages. An alternative is therefore to model neural data using integrate-and-fire (IF) models which incorporate some essential biophysical mechanisms. In this communication, we examine the relationship between IF and LN models by representing a pool of integrate-and-fire neurons as a LN cascade. To this end, we exploit known analytic results for IF models, that we complement with numerical simulations.

Aaditya Rangan (NYU) rangan@cims.nyu.edu

Can classical population-dynamics methods capture the dynamics of the visual cortex?

The mammalian primary visual cortex (V1) is a relatively well studied area of the brain. Many experimental phenomena, such as orientation tuning, surround suppression and background fluctuations can be rationalized by appealing to firing-rate models or standard population-dynamics models. However, after investigating a simple network model of V1 which exhibits many experimentally observed phenomena including those mentioned above, we find that the dynamic regime of this model exhibits many causally connected transiently correlated subpopulations of neurons. We have reason to believe that these strong transient correlations within our network are (i) biologically reasonable and consistent with recent experiments, and (ii) difficult, if not impossible, to capture by examining the ensemble-average dynamics of any subnetwork within our system. These investigations have led us to question the utility of most population-dynamics frameworks which are built on an ensemble-average representation of the underlying network dynamics.

Magnus Richardson (Warwick) magnus.richardson@warwick.ac.uk

Firing-rate dynamics of neurons with finite-sized synaptic amplitudes

I will present work on the theory of fluctuating synaptic drive with finite-amplitude post-synaptic potentials. The standard approach for treating stochastic synaptic currents has been to approximate them by a Gaussian process in which the amplitudes of the underlying post-synaptic potentials are considered small. Synaptic amplitudes in many brain regions, however, are often sufficiently strong so that relatively few synchronous synaptic events are required to bring a neuron from rest to threshold. Here we show that it is relatively straightforward to generalize existing results for the steady-state rate and firing-rate response calculated in the diffusion approximation to Poissonian synaptic drive with amplitude-distributed EPSPs and IPSPs. This work is in collaboration with Rupert Swarbrick.

Stefan Rotter (Freiburg) stefan.rotter@biologie.uni-freiburg.de

Spike Train Correlations Derived from Anatomical Microstructure

Spike train correlations reflect, among other things, the topology of the network. Correlations are caused, for instance, by direct synaptic interaction between cells and, often more importantly, by shared input to cells. In recent work [1], we considered the contributions of more indirect, multi-synaptic pathways by systematically accounting for the connectivity motifs that arise in recurrent networks of arbitrary topology. Using interacting Poisson processes studied by Hawkes in the 1970s [2] a mathematical analysis was possible that allowed us to relate rates and correlations of the spike trains generated under stationary conditions to the fine-scale anatomical structure of the underlying network. Numerical simulations were employed to demonstrate that the dynamic model based on interacting stochastic point processes can also provide an excellent approximation to networks of LIF neurons, via linear response theory. Specifically, we considered power series expansions of firing rates and pairwise correlations, respectively, in terms of the kernel matrix that encodes synaptic connectivity. The components of this expansion turned out to directly correspond to the essential structural motifs of the network. Depending on the degree of recurrence of the network, we were able to predict the influence of multi-synaptic pathways on the activity dynamics, and thus identify those network motifs that make significant contributions to spike train correlations and, therefore, also to the amplitude fluctuations of mass signals (LFP, ECoG, EEG and others). This work demonstrates that the microstructure of neuronal networks in the brain, the uncovering of which is subject of the emerging field of "connectomics", exerts strong and specific influence on the resulting activity dynamics. Interacting stochastic point processes represent a valuable tool to characterize the spiking dynamics of recurrent networks with arbitrary topology. Our approach also represents a promising starting point for the study of non-equilibrium network dynamics [3].

References

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Oscillations in the bistable regime of neuronal networks

Oscillations occur readily in simulations of networks of recurrently coupled inhibitory and excitatory neurons. The frequency of fast oscillations, in the gamma range or above, is essentially set by the time scale of the synaptic kinetics [1]. Slower oscillations can also emerge due to an interplay between the excitatory and inhibitory populations, in which inhibition lags. Furthermore, in simulations of networks in a quasi-linear regime, i.e. no bistability, both of these mechanisms may play a role in setting the frequency of oscillations [1]. The scenario is different for networks operating in the bistable regime. In this case, the strong recurrent excitation favors the excitation-inhibition loop mechanism and oscillations emerge at the saddle-node in a so-called Takens-Bogdanov bifurcation (TB).
Using the two-dimensional Wilson-Cowan equations, I study the nature of oscillations in the vicinity of the Takens-Bogdanov bifurcation. Several of the predicted dynamical behaviors are confirmed in simulations of networks of leaky integrate-and-fire neurons: population spikes, oscillation frequency and amplitude positively and negatively correlated with mean firing rate respectively. Finally, I discuss multi-unit recordings from anesthetized mice during slow-wave sleep, which is hypothesized to occur due to bistable network dynamics (hysteresis loop) in the presence of slow negative feedback, e.g. adaptation. I show that oscillations are present in the up-state of the slow-wave activity and share some qualitative features with those see in network simulations. This is suggestive that the cortical circuit during slow-wave activity may be operating near a TB bifurcation.
[1] Brunel and Wang, J. Neurophysiol. 2003.

Erik Shea-Brown (Seattle) etsb@amath.washington.edu
A mechanistic approach to multi-spike patterns in neural circuits
Neural populations can, in principle, produce an enormous number of distinct multi-cell patterns – a number so large that the frequency of these patterns could never be measured experimentally. Remarkably, recent empirical studies show that the activity of many circuits – especially in the retina – is often well captured by simpler descriptions that rely only on the activity of single neurons and neuron pairs.
These pairwise statistical descriptions succeed even in cases where circuit architecture and input signals seem likely to create a more complex set of outputs. We develop a general approach to understanding which circuit architectures and input signals will lead pairwise descriptions to succeed, and which will lead them to fail. We test our approach using models of retinal ganglion cells fit to intracellular recordings from the Rieke lab.
The results provide an explanation for recent experimental findings. These are based on the filtering and spike generation properties of retinal circuitry, in which collective spiking activity arises through common feedforward inputs to spiking cells.
This is joint work with Andrea Barreiro, Fred Rieke, and Julijana Gjorgjieva.

Michèle Thieullen (Université Pierre et Marie Curie) michele.thieullen@upmc.fr
On spatially extended stochastic models of neurons
In this talk we will present a family of stochastic models for the space-time evolution of the transmembrane potential of a single neuron. We will focus on the modelling of intrinsic noise due to the presence of ionic channels along the membrane.

Gasper Tkacik, IST Austria gtkacik@gmail.com
Statistical mechanics for a network of real neurons
In most areas of the brain, information is encoded in the correlated activity of large populations of neurons. Here we build probabilistic models of such population codes using maximum entropy principle from new recordings of more than 100 retinal ganglion cells from a dense patch on the salamander retina. We illustrate how the pairwise maximum entropy (Ising-like) models can be extended to capture better the experimental data. We analyze the qualitative features of these codes and report on their emerging critical behavior. These results can be put into context by a theoretical examination of information-maximizing codes for noisy spiking neurons.

Carl van Vreeswijk (Paris Descartes) cornelis.van-vreeswijk@parisdescartes.fr
Analysis of Network Activity in Spiking Networks with Synaptic Depression
Spiking neural networks with short term plasticity (STP) of the synapses shows dynamical behavior (population spikes) that is not observed in networks without STP. The analytical approach to the activity of spiking neuronal networks has been developed extensively in the last two decades, using the Fokker-Planck approach. Unfortunately this approach is not well suited to study networks with STP. Here I will demonstrate an alternative approach to the analysis pf network stability, based on the analysis of the inter-spike interval distribution. O this approach STP is easily incorporated, and I will show how it can e used to determine under which condition population spikes occur.

Gilles Wainrib (Paris) gwainrib@stanford.edu
Averaging principle for stochastic slow-fast systems in neuroscience
Multiple time-scale stochastic systems appear naturally in biological modelling, in particular in neuroscience. In this talk, based on the stochastic averaging principle, a novel generic approach to study the effects of noise in such systems will be introduced. Several examples ranging from single neuron models to learning neural networks models will be discussed.

Posters

Francesca Barbieri (Torino) barbierifrancesc@gmail.com

The dynamics of local field potential in monkey primary visual cortex during naturalistic stimuli is well captured by a network of excitatory and inhibitory integrate-and-fire neurons

F. Barbieri, A. Mazzoni, N. K. Logothetis, S. Panzeri, N. Brunel

How sensory stimuli are encoded in neuronal activity is a major challenge for understanding perception. A prominent effect of sensory stimulation is to elicit oscillations in Electro-Encephalogram (EEG) and Local Field Potential (LFP) recordings over a broad range of frequencies. The mechanism underlying the emergence of oscillations and their role in encoding sensory information is still not clear. Recent work suggested the idea that different stimulus features could be encoded in the neural activity at different timescales. Belitski et al. [1] recorded LFPs and spiking activity in the primary visual cortex of anesthetized macaques presented with naturalistic movies and found that the power of the gamma and low-frequency bands of LFP carried largely independent information about visual stimuli, while the information carried by the spiking activity was largely redundant with that carried by the gamma-band LFPs. To clarify these findings, Mazzoni et al. [2] simulated a local cortical population with a sparsely connected network of excitatory and inhibitory neurons and compared with the LFPs obtained in [1]. They demonstrated that an increase in external inputs leads both to an increase in spiking activity, and an increase in gamma-range LFP oscillations that are generated by the excitatory-inhibitory interactions, while the low-frequency band of the LFP encodes the dynamics at slow time scales of the input. Furthermore,it was shown that low and high frequencies bands work as essentially independent channels for encoding information, in agreement with the experimental findings [1].

In this work we reconsider the dynamics of a model of excitatory and inhibitory integrate-and-fire neurons in the presence of time-dependent inputs and compute analytically average firing rate and LFP spectra, together with the information that they convey about the stimulus. The dynamic stimulus was modeled as an Ornstein-Uhlenbeck (OU) process. We then used the analytical formulas to fit the data recorded in anesthetized monkeys. The movie was divided into 2 seconds non overlapping segments and the experimental LFP powers of all movie scenes were fitted with common network parameters while the parameters characterizing the input to the network were let free to vary from scene to scene. We found that the analytical formulas provide excellent fits to the data. This analytical approach can be used to estimate the key parameters underlying changes in the LFP spectral dynamics.

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[2] Mazzoni A et al., Plos Comp. Biol. 2008

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Hierarchical nested organisation of oscillations in an attractor memory network model

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Abstract Oscillations represent an inseparable attribute of neural dynamics. Although there is a growing body of evidence linking them to a plethora of cognitive, perceptual, motoric and other brain processes, yet little is known about the mechanisms underlying these phenomena. Meso-scale network models are suitable for studying oscillatory dynamics as an emergent feature of neuronal activity and, most importantly, as a correlate of the network's functional states. In earlier work we proposed the cortical attractor network model that faithfully reproduced single cell firing statistics and qualitative effects of modulation of the synchronous population activity in working memory tasks. Here we investigate spike-field synchronisation effects and interactions between distinct frequency components of the synthesized local field potentials with emphasis on the phenomenon referred to as nested oscillations. We report the emergence of a hierarchical nested organisation of neural oscillations in physiologically relevant frequency bands (theta, alpha and gamma) during periodic replay of attractor memories in the network. In the absence of such a hierarchical activity during network's idling condition, a prominent upper alpha/lower beta rhythm manifests itself instead. In contrast to earlier studies aimed at modeling neural oscillations, our attractor memory network allows us to elaborate on the functional relevance of emerging rhythms. Providing the description of the model using mean-field formalism, which would facilitate more rigorous treatment of multi-scale dynamics exhibited in larger networks or networks of networks, is intended as part of future work.

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Neural activity underlying the LFP Power Spectrum

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The extracellular field potential measurement is assumed to be one of the most used methods in neuroscience but the precise origin of the signal and its underlying neural activity is still obscure. By using the Power spectrum of the signal, which known to be modulated by different behavioral states and mental processes, we would like to shed light on neural processes responsible for this modulation. The main goal of this study is to find the most simple theoretical model which able to describe the known LFP power spectrum phenomena like

Power Law, Gamma and Alpha power modulation during neural response. In order to reach this goal we will present three main directions: theoretical analysis, modeling population activity by computational simulations and looking for the relation to experimental data. The results gathered thus far show how the population Power Spectrum dependent on the interactions between single neurons. Establishing the link between neural processes implemented by the whole population and the function of single neurons in these processes might help to better understand neural correlates of behavior.

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Sensitivity of noisy neurons to coincident inputs

How do neurons compute? Two main theories compete: neurons could temporally integrate noisy inputs (rate-based theories) or they could detect coincident input spikes (spike-timing-based theories). Correlations at fine timescales have been observed in many areas of the nervous system, but they might have a minor impact. To address this issue, we used a probabilistic approach to quantify the impact of coincidences on neuronal response in the presence of fluctuating synaptic activity. We found that when excitation and inhibition are balanced, as in the sensory cortex in vivo, synchrony in a very small proportion of inputs results in dramatic increases in output firing rate. Our theory was experimentally validated with in vitro recordings of cortical neurons of mice. We conclude that not only are noisy neurons well equipped to detect coincidences, but they are so sensitive to fine correlations that a rate-based description of neural computation is unlikely to be accurate in general.