Twentieth Annual Computational Neuroscience Meeting CNS*2011

Workshop on

Relevance of coherent neural activity for brain functionality

Stockholm, July 28th, 2011

Organizers:

Michael Rosenblum (Potsdam)
Alessandro Torcini (Firenze)

Program

09:00 – 09:15	**Welcome**
09:20 – 09:40	**Complex collective dynamics after synchrony breaking** Michael Rosenblum, Potsdam
09:45 – 10:05	**Coherent activity in excitatory neural networks** Alessandro Torcini, Sesto Fiorentino
10:10 – 10:30	**Signal detection in neural populations: the importance of heterogeneity** Jorge F. Mejías, Ottawa
10:35 – 10:50	**Coffee Break**
10:50 – 11:10	**Enhanced neuronal coherence in the temporal lobe following eye movements** Kari Hoffmann, York University
11:15 – 11:35	**Collective chaos and chimera states in pulse-coupled neural networks** Simona Olmi, Firenze
11:40 – 12:00	**Analysis of Network Activity in Spiking Networks with Synaptic Depression** Carl van Vreeswijk, Paris
12:05 – 14:00	**Lunch**
14:00 – 14:20	**Membrane properties and excitatory-inhibitory balance control gamma frequency oscillations arising from feedback inhibition** John A. White, University of Utah
14:25 – 14:45	**Control of persistent state through spatial correlations in background activity and applications in a working memory network** Mario Di Poppa , Paris
14:50 – 15:10	**Gamma-Power in a Fronto-Parietal Network Predicts Motor-Imagery Performance** Moritz Grosse-Wentrup, Tübingen
15:15 – 15:30	**Coffee Break**
15:30 – 15:50	**On a possible mechanism of birhytmicity in simple models of neuronal ensembles** Michael Zaks, Berlin
15:55 – 16:15	**Networks of phase-amplitude neural oscillators** Kyle Wedgwood, Nottingham
16:20 – 17:00	**Final Discussion**

Abstracts

Complex collective dynamics after synchrony breaking

Michael Rosenblum
Potsdam University
Germany

The talk starts with an overview of the topic of minisymposium and continues by the analysis of the collective dynamics in an ensemble of nonlinearly coupled Stuart-Landau oscillators. Synchronized for weak coupling, the ensemble exhibits various regimes of partial synchrony with increase of coupling parameters. In particular, we report a novel quasiperiodic regime which appeares after destruction of synchrony via Hopf bifurcation. We also illustrate this regime by numerical study of globally coupled Hindmarsh-Rose neurons.

Coherent activity in excitatory neural networks

Alessandro Torcini
Consiglio Nazionale delle Ricerche - Istituto dei Sistemi Complessi
Italy

We will review the main results concerning collective dynamics in fully coupled leaky integrate-and-fire neuronal networks by following the seminal works of C. van Vreeswijk and L-F. Abbott on the subject. In particular, we will focus our interest on the Partial Synchronization (PS) regime, which is characterized by a coherent periodic activity of the network and a quasi-periodic dynamics of the single neurons. Furthermore, we will analyze the influence of disorder and network topology on the stability and dynamical properties of the PS regime.

Signal detection in neural populations: the importance of heterogeneity

Jorge F. Mejías
Ottawa University
Canada

It is known that neural systems display a prominent heterogeneity in individual neuron properties, even among populations of same-class neurons. However, the effect of such heterogeneity in the dynamics of neural populations has not been fully understood up to date. Here, we present a detailed theoretical and numerical study of the implications of heterogeneity in the properties of neural populations. Our study reveals important effects of heterogeneity in several properties of interest, such as the mean firing rate, the irregularity of the mean activity, or the synchronization properties of the network. We also study the role of heterogeneity in networks with realistic synaptic dynamics (such as short-term depression). Finally, our results show that heterogeneity in neural excitability allows for different information processing strategies, where the concrete strategy used depends on the level of correlation among individual neurons. This establishes a direct relation between (optimal) heterogeneity levels and neural correlation levels.

Enhanced neuronal coherence in the temporal lobe following eye movements

Kari Hoffmann
York University
Canada

Saccadic eye movements (SEMs) strongly influence visual perception in primates. During visual exploration of the environment (active vision) SEMs produce suppression during saccades and enhancement upon fixation, in early visual areas. The influence of eye movements on neural population dynamics is less well understood, and its influence in higher-order visual areas is unclear. For example, the superior temporal sulcus (uSTS), is critical for perception of faces, objects, and biological motion, and shows frequency-dependent coherence during processing of these visual stimulus categories. Whether visually-evoked responses are modulated by SEMs is unknown. In this study, we examined how SEMs modulate local field potentials (LFPs) in the uSTS of macaque monkeys during a free viewing task with static face and non-face object stimuli. Stimulus-driven eye movements lead to short latency (40 ms) LFP activity mediated by phase concentration (i.e. inter-trial coherence) in uSTS. This response was distinct from the image-evoked response. Furthermore, near-coincident image onsets and fixation onsets like those that occur in active vision led to an enhanced image-evoked response through greater phase concentration in the alpha (8-14 Hz), beta (14-30 Hz), and gamma (30-60 Hz) bands. These same frequency bands show spike-phase modulation of single-unit activity. Together, these results demonstrate enhanced neuronal coherence in STS following eye movements, revealing a plausible neural basis for the enhancement of visual processing in active vision.

Collective chaos and chimera states in pulse-coupled neural networks

Simona Olmi
Universitá degli Studi di Firenze
Italy

Understanding the collective motion of networks of oscillators is crucial in many contexts, starting from neuronal circuits [1]. So far, most of the efforts have been devoted to the characterization of strong forms of synchronization. However, more subtle phenomena, like the onset of coherent oscillations in an ensemble of neurons can also play a relevant role for information coding. A peculiar coherent state, termed Chimera, appears in two symmetrically coupled populations of oscillators, where a population fully synchronizes while the other exhibit an asynchronous dynamics [2]. This can represents an idealized mathematical representation of the so-called unihemispheric sleep. Many creatures sleep with only half their brain at a time [3]. Such phenomenon was first reported in dolphins and other sea mammals and, recently, in birds; when brain waves are recorded, the awake side of the brain shows desynchronized electrical activity, corresponding to millions of neurons oscillating out of phase, whereas the sleeping side is highly synchronized. In our study we have investigated the dynamics of two symmetrically coupled populations of identical leaky integrate-and-fire neurons characterized by excitatory coupling [4]. Upon varying the coupling strengths between and within the two populations, we found symmetry-breaking transitions that lead to the onset of various chimera states. To be more specific, in the observed chimera states one population is fully synchronized, while the other one is in the so-called Partially Synchronous (PS) regime. This regime is characterized by a coherent periodic activity at a collective level (somehow corresponding to to the Local Field Potential), while the single neurons behaves quasi-periodically [5]. To our knowledge this represents the first evidence of chimera states in pulse-coupled neural networks.

Furthermore a new regime, where the two populations are both PS but with a different degree of synchronization have been also observed. Even more interesting is the identification of a regions of parameters where the coherent activity of the network, characterized by collective variables, becomes chaotic. Collective chaos, meant as irregular dynamics of coarse-grained observables, has been found in ensembles of fully coupled one-dimensional maps as well as in two-dimensional continuous-time oscillators. In both classes of models, the single dynamical unit can behave chaotically under the action of a periodic forcing. Only a few examples of low-dimensional chaotic collective motion have been found in ensembles of phase oscillators because in this setup there is little space for a high-dimensional dynamics [6]. The computation of the the finite-amplitude Lyapunov exponent allows us to firmly establish the chaoticity of the (collective) dynamics in a finite region of the phase plane. The further numerical study of the standard Lyapunov spectrum reveals the presence of several positive exponents, indicating that the microscopic dynamics is high-dimensional.

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2. Abrams DM, Strogatz SH, Phys Rev Lett 2004 93:174102-174105.
3. Rattenborg NC, Amlaner CJ, Lima SL, Neurosci Biobehav Rev 2000, 24:817-842.
4. Olmi S, Politi A, Torcini A, EPL 2010, 92: 60007.
5. van Vreeswijk C, Phys Rev E 1996, 54:5522-5537.
6. Watanabe S, Strogatz SH, Phys Rev Lett 1993, 70:2391-2394.

Analysis of Network Activity in Spiking Networks with Synaptic Depression

Carl van Vreeswijk
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France

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.

Membrane properties and excitatory-inhibitory balance control gamma frequency oscillations arising from feedback inhibition

John A. White
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USA

Computational studies as well as in vivo and in vitro results have shown that many cortical neurons fire in a highly irregular manner and at low average firing rates. These patterns seem to persist even when highly rhythmic signals are recorded by local field potential electrodes or other methods that quantify the summed behavior of a local population. Models of the gamma rhythm in which network oscillations arise through stochastic synchrony have been proposed that capture the variability observed in the spike output of single cells while preserving network-level organization. We extend upon these results by constructing model networks constrained by experimental measurements and probing the effect of several biophysical parameters on network-level activity. We find in simulations that gamma-frequency oscillations are enabled by a high level of incoherent synaptic conductance, similar to the barrage of noisy synaptic input that cortical neurons have been shown to receive in vivo. This incoherent synaptic input increases the emergent network frequency by shortening the time scale of the membrane in excitatory neurons and by facilitating a temporal balance between excitation and inhibition due to decreased spike latency in inhibitory neurons. These mechanisms are demonstrated in simulations and in vitro current-clamp and dynamic-clamp experiments. Results further indicate that the balance between excitatory and inhibitory currents controls network stability as well as sensitivity to external inputs.

Control of persistent state through spatial correlations in background activity and applications in a working memory network

Mario Di Poppa
École Normale Supérieure, Paris
France

Recordings in primates performing delayed response tasks show that persistent neuronal activity in the prefrontal cortex underlies working memory (WM)(e.g., Fuster and Jervey, 1981, Science: 212, 952-955). Three distinct effects are required for these tasks in addition to activity maintenance: that item-related activity should be turned on rapidly (read-in), that such activity is protected from distractors, and that it is rapidly turned off at the response (clear-out). We suggest that the effects of spike-time correlations in neural activity during the WM task may provide a unified mechanism for all three required phenomena.

We implement a discrete working memory model in which neurons are connected by fast and excitatory AMPA-like synapses and receive excitatory random background activity (noise). In this network we demonstrate that synchronization of spike times can be achieved by increased spatial correlation in the noise and also by transient excitatory input. Synchronization can extinguish the persistent state as was shown by Gutkin et al. (2001 J Comp Neurosci: 11, 121-134) in a spatial working memory model. We show that it is possible to turn-off the persistent state by projecting the transient "clear" signal to only the activated item-network. We find that the excitatory switch on and switch off signals differ only in temporal and not in spatial statistics of spikes.

Furthermore we propose a novel mechanism preventing the activation of a persistent state by distracting stimuli. We find that increased spatial correlation in background activity prevents stable activation of a persistent state. Hence distractors can neither be loaded into their item-networks nor spuriously activated when background correlations in these networks are enhanced. This finding can form the basis for a new paradigm about how the global time scale of a working memory can be modulated.

Gamma-Power in a Fronto-Parietal Network Predicts Motor-Imagery Performance

Moritz Grosse-Wentrup
Max Planck Institute for Biological Cybernetics, Tübingen
Germany

While the neuro-physiological basis of motor imagery has been studied in great detail, little is known on the neural determinants of good or bad motor-imagery performance. In this talk, I present evidence based on EEG recordings in normal subjects that the baseline power of fronto-parietal gamma-oscillations (i.e., oscillations of the electromagnetic field of the brain roughly above 50 Hz) predicts the performance of subsequent motor-imagery on a trial-to-trial basis. Furthermore, our results suggest that the power of these gamma-oscillations is not modulated by the instruction to initiate motor imagery, but oscillates autonomously at predominantly very low frequencies. I analyze these observations in the framework of Causal Bayesian Networks, and argue that they provide support for a causal influence of a fronto-parietal resting-state network on motor-imagery performance.

On a possible mechanism of birhytmicity in simple models of neuronal ensembles

Michael Zaks
von Humboldt University, Berlin, Germany

Polyrhytmicity belongs to important attributes of large neuronal assemblies: recorded extracellular oscillations of human neurons demonstrate alternating epochs of fast and slow oscillations (i.e. gamma- and theta- rhythms). To take account of this phenomenon, most of the existing models include interaction of different units whose intrinsic timescales strongly differ. Here, we discuss a possible mechanism which ensures birhytmicity in simple models of neuronal ensembles in which all elements share the intrinsic timescale. Although the considered dynamical systems are non-generic, they involve typical properties of many existing models in neuroscience. We consider networks built of oscillatory units with the same eigenfrequency; coupling terms in the governing equations are proportional to velocities of the elements. No restrictions are put either on the symmetry of the coupling or on its pattern (mean field, next neighbors, pairwise or triple interactions etc.).

In the parameter space of the ensemble, destabilization of the equilibrium occurs by means of the Hopf bifurcation. On the large part of the stability boundary, the spectrum of the linearized flow contains not one (as usually) but two pairs of purely imaginary eigenvalues. Of the two resulting frequencies, one is typically much lower than the individual frequency of an element, whereas the other one is distinctly higher. Accordingly, in the nonlinear regime the respective ensembles are potentially capable of performing both slow and fast modes of oscillations. We illustrate this general phenomenon by numerical data obtained from ensembles of oscillators with different coupling patterns and coupling functions.

Networks of phase-amplitude neural oscillators

Kyle Wedgwood
School of Mathematical Sciences – University of Nottingham, United Kingdom

It is quite common to describe neural oscillators with a phase variable, thus reducing the model description to that of dynamics on a circle. However, if a limit cycle is not strongly attracting then this reduction may poorly characterise behaviour of the original system. Here we consider a coordinate transformation to a phase-amplitude framework that allows one to track the evolution of distance from the cycle as well as phase on cycle. A number of common models in computational neuroscience (including FitzHugh-Nagumo and Morris-Lecar) are revisited in this framework and their response to pulsatile current forcing is investigated. We highlight the differences between phase and phase-amplitude descriptions, and show that the former can miss some substantial features of neuronal response. Finally we discuss extensions of this work that will allow for the description of networks of limit-cycle oscillators and improve upon the standard weakly coupled phase oscillator approach. In particular we highlight the merits of piece-wise linear modelling for the development of a theory of strongly interacting systems.