Stochastic Models in Neuroscience

CIRM, Luminy Marseille (France)

18 - 22 January 2010

Organising committee
N. Berglund, S. Mancini (MAPMO, FDP, Université d'Orléans)
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B. Perthame (Paris), D. Talay (Nice)

http://www.fdp.org/colloques/neurostoch

Schedule

Monday, 18th January 2010

9h00 - 9h10 *Welcome introduction*

9h10 - 9h50 A. Destexhe *How much stochastic is neuronal activity ?*

9h55 - 10h25 J.A. Carrillo *Analysis of Integrate and Fire models*

10h30 - 10h50 *Coffee Break*

10h50 - 11h20 E. Buckwar *Effects of feedback delays on stochastic signals in extended neural populations*

11h25 - 12h05 P. Bressloff *On the master equation approach to stochastic neurodynamics*

12h30 - 14h00 *Lunch*

14h00 - 14h40 N. Brunel *Stochastic dynamics of spiking neuron models and implications for network dynamics*

14h45 - 15h15 B. Joshi *Coupled Poisson process model for sleep-wake cycling*

15h20 - 16h00 S. Ditlevsen *The Morris Lecar neuron model gives rise to the Ornstein-Uhlenbeck leaky integrate-and-fire model*

16h05 - 16h25 *Coffee Break*

16h25 - 16h55 G. Wainrib *Multiscale Analysis of Hybrid Processes and Reduction of Stochastic Neuron Models*

17h00 - 17h40 P. Jahn *Modeling membrane potentials in motoneurons by time-inhomogeneous diffusion leaky integrate-and-fire models*

Tuesday, 19th January 2010

9h00 - 9h40	W. Gerstner *Drift-Diffusion for Feature Fusion: The power and limits of stochastic models of decision making*
9h45 - 10h25	S. Bonaccorsi *Evolution equation on networks with stochastic inputs*
10h30 - 10h50	*Coffee Break*
10h50 - 11h20	K. Newhall *Synchrony in Stochastic Pulse-Coupled Neuronal Network Models*
11h25 - 12h05	T. Knösche *TBA*
12h30 - 14h00	*Lunch*
14h00 - 14h40	D. Mc Laughlin *TBA*
14h45 - 15h15	A. Samson *Minimum contrast estimate for the parameters of the stochastic Morris-Lecar model*
15h20 - 16h00	R. Brette *What is the integration time constant of neurons?*
16h05 - 16h25	*Coffee Break*
16h25 - 16h55	M. Riedler *Modeling neuronal membranes with Piecewise Deterministic Processes*
17h00 - 17h40	B. Lindner *Signal amplification and information transmission in neural systems*
17h45 - 19h30	*Poster Session*: D. David-Rus, S. El Boustani, A. Goltsev, D. Holtsein, A. Jarynowski, D. Landon, H. Sprekeler

Wednesday, 20th January 2010

9h00 - 9h40 G. Deco *Stochastic dynamics as a principle of brain function*

9h45 - 10h25 O. Faugeras *Inter Spike Intervals probability distribution and Double Integral Processes*

10h30 - 10h50 *Coffee Break*

10h50 - 11h20 X. Wang *Mechanisms for simple perceptual decision-making processes*

11h25 - 12h05 B. Cessac *Spikes trains statistics from a dynamical systems perspective*

12h30 - 14h00 *Lunch*

14h00 - 19h30 *Free*

Thursday, 21st January 2010

9h00 - 9h40	H. Tuckwell *Weak noise effects on rhythmic spiking in point and spatial models*
9h45 - 10h25	R. Höpfner *Modelization of membrane potentials and information transmission in large systems of neurons*
10h30 - 10h50	*Coffee Break*
10h50 - 11h20	E. Bibbona *Consistent estimates for the parameters of LIF neuronal models*
11h25 - 12h05	O. Lafitte *Stability of a nerve impulse: construction of the associated Evans function*
12h30 - 14h00	*Lunch*
14h00 - 14h40	M. Van Rossum *Synaptic learning rules: a drunk man's walk to remember*
14h45 - 15h15	T. Schwalger *Effects of noisy adaptation on neural spiking statistics*
15h20 - 16h00	L. Sacerdote *Copulae and network modeling*
16h05 - 16h25	*Coffee Break*
16h25 - 16h55	L. Gollo *Active dendrites stochastic neuronal model*
17h00 - 17h40	R. Sirovich *Signal estimation from intracellular recordings in the Feller neuronal model*
19h00 - ...	*Social Dinner*

Friday, 22nd January 2010

9h00 - 9h40 L. Zambotti *A probabilistic study of neural complexity*

9h45 - 10h25 M. Richardson *Dynamics of populations and networks of neurons with voltage-activated and calcium-activated currents*

10h30 - 10h50 *Coffee Break*

10h50 - 11h30 V. Jirsa *TBA*

11h25 - 12h05 N. Parga *Dynamics of densely connected networks of model neurons and of cortical circuits*

12h30 - 14h00 *Lunch*

Titles and Abstracts

Enrico Bibbona

Consistent estimates for the parameters of LIF neuronal models

Stefano Bonaccorsi

Evolution equation on networks with stochastic inputs

In this talk I will discuss some recent results on stochastic evolution equations which arise in the modeling of certain problems in neurobiology. A key feature of these models is the kind of noise involved, which is a gaussian (or even non gaussian) process and shows self-similarity and long-range dependence properties.

Paul Bressloff

On the master equation approach to stochastic neurodynamics

We consider a master equation formulation of stochastic neurodynamics for a recurrent network of synaptically coupled homogeneous neuronal populations each consisting of N identical neurons. The state of the network is specified by the fraction of active or spiking neurons in each population, and transition rates are chosen so that in the thermodynamic or mean-field limit we recover standard rate-based models. We derive the lowest order corrections to these rate equations for large but finite N using the Van Kampen system-size expansion, and show how this is related to the path-integral approach of Buice and Cowan. We also describe applications of the master equation approach to (i) studying the noise amplification of neural oscillations and (ii) calculating exit times from metastable states.

Romain Brette

What is the integration time constant of neurons?

Because the membrane potential relaxes to equilibrium after stimulation, two synchronous input spikes are more likely to make a neuron fire than two widely separated spikes. The characteristic time that separates these two behaviors is called the integration time constant. Classically, one relates it to the membrane time constant or to the half-width of postsynaptic potentials, implicitly assuming that effects on the membrane potential directly transfer to spiking probabilities. However, the threshold introduces nonlinearities in the input-output relationship. I will show that the integration time constant of neurons is in fact shorter than expected and depends on the statistics of background activity, the synaptic weights and threshold properties. It implies that neurons are very sensitive to fine correlations in their inputs.

Nicolas Brunel

Stochastic dynamics of spiking neuron models and implications for network dynamics

Evelyn Buckwar

Effects of feedback delays on stochastic signals in extended neural populations

José Antonio Carrillo

Analysis of Integrate and Fire models

We will discuss some properties of the solutions of a Fokker-Planck equation for an integrate and fire neuron model. We are able to give situations in which no, one or two stationary solutions are allowed. Blow-up of solutions is allowed in this model if the density is extremely concentrated onto the firing voltage. The linear case is completely understood by general relative entropy methods. Extensions and further ongoing directions will be discussed. This is a work in collaboration with B. Perthame and M.J. Cáceres.

Bruno Cessac

Spikes trains statistics from a dynamical systems perspective

We review recent results dealing with the analysis of spike train statistics in neural networks models, using methods from dynamical systems (thermodynamic formalism). We discuss why Gibbs distributions are natural candidates and present some consequences at the theoretical and algorithmic level.

Gustavo Deco

Stochastic dynamics as a principle of brain function

Alain Destexhe

How much stochastic is neuronal activity ?

This talk will overview different measurements of the stochastic activity of neurons, at the single-cell and population levels. Aspects covered will include the irregular and asynchronized firing activity of neurons in awake animals, the apparent Poisson nature of neuronal discharges, the Gaussian nature of fluctuations at the level of the membrane potential and the nature of the underlying conductance fluctuations. We will examine to what extent models can reproduce these observations, and point to aspects that models do not reproduce well.

Susanne Ditlevsen

The Morris Lecar neuron model gives rise to the Ornstein-Uhlenbeck leaky integrate-and-fire model

We analyse the stochastic-dynamical process produced by the Morris Lecar neuron model, where the randomness arises from channel noise. Using multi-scale analysis, we show that in a neighborhood of the stable point, representing quiescence of the neuron, this two-dimensional stochastic process can be approximated by an Ornstein-Uhlenbeck modulation of a constant circular motion. The firing of the Morris Lecar neuron corresponds to the Ornstein-Uhlenbeck process crossing a boundary. This result motivates the large amount of attention paid to the Ornstein-Uhlenbeck leaky integrate-and-fire model. A more detailed picture emerges from simulation studies.

Olivier Faugeras

Inter Spike Intervals probability distribution and Double Integral Processes

The problem of finding the probability distribution of the first hitting time of a Double Integral Process (DIP) such as the Integrated Wiener Proces (IWP) has been an important and difficult endeavor in stochastic calculus. It has applications in many fields of physics (first exit time of a particle in a noisy force field) or in biology and neuroscience (spike time distribution of an integrate-and- fire neuron with exponentially decaying synaptic current). The only results available are an approximation of the stationary mean crossing time and the distribution of the first hitting time of the IWP to a constant boundary. We generalize these results and find an analytical formula for the first hitting time of the IWP to a continuous piecewise cubic boundary. We use this formula to approximate the law of the first hitting time of a general DIP to a smooth curved boundary, and we provide an estimation of the convergence of this method. The accuracy of the approximation is computed in the general case for the IWP and the effective calculation of the crossing probability can be carried out through a Monte-Carlo method. We discuss the application of our method to the determination of the ISI pdf of popular neuron models such as IF and GIF.

Wulfram Gerstner

Drift-Diffusion for Feature Fusion: The power and limits of stochastic models of decision making

Leonardo Gollo

Active dendrites stochastic neuronal model

The goal is to present the main results of a stochastic model of neuron with active dendritic tree recently published (Gollo et al. 2009) as well as the mathematical description of the model and the corresponding approximative solution that shows good agreement with simulations and experimental data.

Gollo LL, Kinouchi O, Copelli M (2009) Active Dendrites Enhance Neuronal Dynamic Range. PLoS Comput Biol 5(6): e1000402. doi:10.1371/journal.pcbi.1000402 http://www.ploscompbiol.org/article/info:doi

Reinhard Höpfner

Modelization of membrane potentials and information transmission in large systems of neurons

In a first part of the talk, we present a stochastic model for information transmission in large systems of neurons. Here the membrane potential in the single neuron is modelled as a Cox-Ingersoll-Ross type diffusion with explicit time depence in the drift, and spike generation in this neuron is conditionally Poisson. We give a limit theorem which shows how a large system of neurons processing the same signal can transmit this signal up to some small deformation of its shape. In a second part of the talk, we consider a set of data where the membrane potential in a pyramidal neuron in the cortex is recorded under different experimental conditions. We use nonparametric estimates for diffusion coefficient and drift to make appear three types of diffusion processes which provide realistic models for the membrane potential in this type of neuron.

Patrick Jahn

Modeling Membrane Potentials in Motoneurons by time-inhomogeneous Diffusion Leaky Integrate-and-Fire Models

A commonly used model for membrane potentials in neurons is the diffusion leaky integrate-and-fire model, where the membrane potential $(X_t)_{t\geq 0}$ is assumed to be a solution of a time-homogeneous SDE with linear drift

$$\mathrm{d}X_t = (a - \frac{1}{\tau}X_t)\mathrm{d}t + \sigma(X_t)\mathrm{d}B_t,$$

where $(B_t)_{t \geq 0}$ is a standard Brownian motion and $\sigma(\cdot)$ the diffusion coefficient.

However, real data contains very often time-inhomogeneous patterns. Moreover, we can observe from data that the time-constant τ decreases when neuronal activity increases. Further, $\sigma^2(\cdot)$ turns out to be a linear function of X_t, which leads to the Feller neuronal model. The issue is to model the cycling behavior of membrane potentials in motoneurons from an active network during mechanical stimulation and to take a varying τ and a linear $\sigma^2(\cdot)$ into account. In a first step we use nonparametric methods in the data analysis which help to apply further regression methods in order to fit the model to data.

This is a joint work with S. Ditlevsen, R. W. Berg and J. Hounsgaard

Viktor Jirsa

TBA

Badal Joshi

Coupled Poisson process model for sleep-wake cycling

Thomas Knösche

TBA

Olivier Lafitte

Stability of a nerve impulse: construction of the associated Evans function

Benjamin Lindner

Signal amplification and information transmission in neural systems

David Mc Laughlin

TBA

Katie Newhall

Synchrony in stochastic pulse-coupled neuronal network models

Many pulse-coupled dynamical systems possess synchronous attracting states. Even stochastically driven model networks of Integrate and Fire neurons demonstrate synchrony over a large range of parameters. We study the interplay between fluctuations which de-synchronize and synaptic coupling which synchronizes the network by calculating the probability to see repeated cascading total firing events, during which all the neurons in the network fire at once.ăThe mean time between total firing events characterizes the perfectly synchronous state, and is computed from a first-passage time problem in terms of a Fokker-Planck equation for a single neuron.

Néstor Parga

Dynamics of densely connected networks of model neurons and of cortical circuits

Magnus Richardson

Dynamics of populations and networks of neurons with voltage-activated and calcium-activated currents

A current goal of theoretical neuroscience is the development of a framework that allows for predictions about the emergent states of neuronal networks from the biophysical properties of constituent neurons. Population-based modelling, using the Fokker-Planck formalism, is one promising approach. However, the form of the Fokker-Planck equation for neurons with biophysically reasonable properties rapidly becomes awkward or impossible to solve. Here a rather efficient Threshold Integration scheme is demonstrated for solving the network FP equation. This method greatly simplifies the calculation of many quantities central to the analysis of populations and recurrent networks of neurons such as the steady-state rate, spike-train spectrum, first-passage-time density and the dynamical response to patterned synaptic conductance modulation. The method works equally well for non-linear integrate-and-fire models, such as the experimentally verified exponential model. The method generalizes to networks comprised of many neuronal classes with distinct expression patterns of gated currents and so promises to allow for the modelling of emergent states in neural tissue at significantly increased levels of detail.

Martin Riedler

Modelling neuronal membranes with Piecewise Deterministic Processes

We develop a model of an excitable membrane by Piecewise Deterministic Processes (PDPs), which are a class of hybrid Markov processes that are able to capture the dynamics of deterministic continuous motion influenced by discrete random jump processes depending on the deterministic motion themselves. We will ague that this model isăclose to the biophysical reality, yetăstill analytically tractable and also relevant in practice.ăPDPs naturally arise as the model for a space-clamped patch of excitable membrane where the single voltage gated ion channels are modelled by

Markov kinetic schemes and the time evolution of the transmembrane voltage potential is governed by an ordinary differential equation. To model non-space clamped membranes we have extended the PDP theory to allow for spatial dynamics. An advantage of the PDP framework is that it already provides a rich theory that can be exploited for further analysis. In particular, via the Kolmogorov backward equation we can derive analytically a fully continuous approximation by diffusion processes to the PDP model by systems of stochastic differential equations (SDEs). As stochastic differential equations are analytically even more tractable this description of the membrane provides further analytical advantages as well as, more practical, algorithms based on SDE models will allow for much faster simulations than algorithms based on the complete Markov kinetics, especially for ever larger systems.

Laura Sacerdote

Copulae and network modeling

Mathematical models for neuron activity are an important tool to increase our comprehension of neural code. Between single neuron models Leaky Integrate and Fire ones are particularly popular. This fact is due to two main features: they can fit a variety of experimental data and they are mathematically simple enough to allow analytical and numerical studies. The use of these models hints on various neuron features. Typical examples are the role of noise in neural transmission or the study of the response of the neuron to periodic stimula. Furthermore their use has allowed the application of information theory to the neuron code. The possibility to record simultaneously from groups of neurons suggests to switch from the single neuron to the network description. Because of the important role of mathematical models in the study of single units, suitable models for networks are needed. Unfortunately the major complexity determined by the large number of interconnected units discourage analytical approaches making object oriented networks or simulation techniques the most popular methods. Alternatively multiparticles models have also been proposed. The main lack of all these studies is their inability to relate single units and network features. Indeed they often oversimplify the description of the units of the network focusing on the links between them.

Here we discuss the possibility to get advantage from our knowledge on single neuron models to determine neural network models. Copulae are the mathematical object allowing to join marginal distributions to get the joint one. The use of copulae has recently been proposed for the statistical description of counts of spikes in network; however their use for modeling purposes has not yet been sufficiently investigated. Here we propose new models using copulae. It should be however noticed that we are presenting preliminary results limited to only two neurons. We limit ourselves to study the coupling between the spike times of two neurons due to the difficulty of the description of the coupling of the point processes describing the spike trains.

We describe the two neurons by means of LIF models and we couple the noise terms in the equations describing the membrane potential dynamics. Then we study the spike times of the modeled neurons and we focus on the copula joining these times. Various properties of these times are discussed and some open problems are listed.

In the talk we also describe some open mathematical problems that should be solved to allow the switching to a larger number of units in the network.

Adeline Samson

Minimum contrast estimate for the parameters of the stochastic Morris-Lecar model

In this talk, we propose to estimate the parameters of the stochastic Morris-Lecar model observed at discrete times. The stochastic Morris-Lecar model is an hypoelliptic stochastic differential model, which can be viewed as an integrated diffusion model using a simple transformation. Therefore, we extend the minimum contrast estimator proposed by Gloter (2006) to our case. We prove the consistency and the asymptotic normality of our estimate under some general assumptions.

Tilo Schwalger

Effects of noisy adaptation on neural spiking statistics

Adaptation and noise are key features of almost any neuron and have a profound impact on signal processing by neurons. This processing might crucially depend on the nature of neural variability. In the first part of my talk, I analytically study a perfect integrate-and-fire neuron with adaptation and either white noise driving or noise resulting from fluctuations in the slow adaptation mechanism. The latter "adaptation noise" could, for instance, arise from channel noise associated to the slow adaption current. Surprisingly, we find a large difference in the statistics of interspike intervals (ISI): in the case of adaptation noise, the stochastic adaptation current can be mapped to an effective colored noise driving giving rise to long-range positive ISI correlations and a pronounced peak of the ISI density. In contrast, when variability stems from white noise one observes anticorrelations and a less pronounced peak. These results suggest that insight into the major source of noise in certain neurons might be gained from the ISI statistics.

In the second part, I study ISI correlations in an excitable system with adaptation, where spikes are driven by fluctuations. To this end, I propose a spiking neuron model with discrete adaptation states which allows for an exact calculation of the ISI correlation coefficient.

Roberta Sirovich

Signal estimation from intracellular recordings in the Feller neuronal model.

The estimation of the input parameters in a Feller neuronal model from a trajectory of the membrane potential sampled at discrete times is studied. These input parameters are identified with the drift and the infinitesimal variance of the underlying stochastic diffusion process with multiplicative noise. The state space of the process is restricted from below by an inaccessible boundary. Further, the model is characterized by the presence of an absorbing threshold, the first hitting of which determines the length of each trajectory and which constrains the state space from above. Both in the presence and in the absence of the absorbing threshold, the efficiency of different known estimators is compared. In addition, a new estimator for the drift term is proposed, and is proved to be more efficient than the others, at least in the explored range of the parameters. The presence of the threshold introduces a bias into the estimates of the drift term and two methods to correct it are suggested.

Henry Tuckwell

Weak noise effects on rhythmic spiking in point and spatial models

Noise has most often been associated with the acceleration of neuronal spiking. For example, with noise the expected value of the membrane potential in the usual LIF models is always towards depolarized states. This is probably generally the case for strong noise, but weak noise can have severe inhibitory effects on rhythmic spiking. This has been demonstrated theoretically in the original Hodgkin-Huxley system of ordinary differential equations (called a point model) as well as experimentally. Near the bifurcation to repetitive spiking, weak noise (or any other appropriate stimulus) may easily drive the system from a limit cycle to a stable rest point, leading to a cessation of spiking for a possibly very long time. Transitions back to the limit cycle may occur with small probability with weak noise but with strong noise the system may switch back and forth from rest to spiking with a small first passage time, leading to an apparent overall increase in spiking activity. Several results are presented which indicate that with increasing weak noise a minimum in spike rate versus noise (called "inverse stochastic resonance") can occur for values of the signal (as opposed to noisy component) near the bifurcation value. On turning to the spatial version (SPDE's), it was found that with noise uniform throughout the length of the neuron, the same sort of phenomena occurred. However, it was a surprise to discover that the only part of the noise which interfered with spiking activity was that where the signal occurred. The probability that there was interference with spiking was investigated as a function of the amount of overlap of signal and noise. If signal and noise were on disjoint intervals, then there was no interference, even if the regions of signal and noise were juxtaposed and no matter how large the region of noise (note that this applies only for weak noise). As the amount of overflap increases, the anount of interference increases to a maximum when the overflap is complete. Unforrtunately there is a paucity of results on the propagation of travelling waves in nonlinear systems of reaction-diffusion systems with noise, so only very heuristic explanations for the SPDE results are presently available. Related results for other neural models will also be presented.

Mark Van Rossum

Synaptic learning rules: a drunk man's walk to remember

The strength of the synapses in the brain are presumably continuously subject to increases and decreases as the result of ongoing learning processes. This realization allows one to approximate the synaptic weight evolution as a stochastic process. This has been used to find fundamental limits of storage (Fusi and Abbott 2007)

Recently we introduced a synaptic information capacity measure based on Shannon information (Barrett and van Rossum). We use this to find the optimal weight dependent learning rules. We find that soft-bound learning rules are somewhat better than hard bound rules, although the improvement is quite small.

Gilles Wainrib

Multiscale Analysis of Hybrid Processes and Reduction of Stochastic Neuron Models

We introduce a method for systematically reducing the dimension of biophysically realistic neuron models with stochastic ion channels exploiting time-scales separation. Based on a combination of sin- gular perturbation methods for kinetic Markov schemes with some recent mathematical developments of the averaging method, the techniques are general and applicable to a large class of models. As an example, we derive and analyze reductions of the stochastic Hodgkin-Huxley model.The bifurcation analysis of the reduced models with the number of channels as a parameter provides insight into some features of noisy discharge patterns, such as the bimodality of interspike intervals distribution.

Xueying Wang

Mechanisms of simple perceptual decision-making process.

Perceptual decision-making, an omnipresent component of everyday life, plays a pivotal role in cognitive tasks. In this presentation, I will talk about mechanisms underlying simple two-option perceptual decision-making processes by studying a biological-realistic reduced two-variable model and phenomenological drift-diffusion models.

Lorenzo Zambotti

A probabilistic study of neural complexity

G. Edelman, O. Sporns and G. Tononi have introduced in theoretical biology the neural complexity of a family of random variables, defining it as a specific average of mutual information over subsystems. We provide a mathematical framework for this concept, studying in particular the problem of maximization of such functional for fixed system size and the asymptotic properties of maximizers as the system size goes to infinity.

(Joint work with Jerome Buzzi)

Posters

Diana David-Rus
Stochastic approach in epigenetic studies

Sami El Boustani
A maximum-likelihood approach based on Master equation to estimate connectivity patterns from 2D large-scale networks

Alexander Goltsev
Stochastic cellular automata model of neural networks

Detlef Holstein
Simulations of stochastic neural networks with scale-free topology

Andrzej Jarynowski
Transion between noise and spike regime

Damien Landon
Spikes probability distribution in FitzHugh-Nagumo model

Henning Sprekeler *Reward-modulated spike timing-dependent plasticity requires a reward prediction system*

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