INSTITUT NATIONAL DE RECHERCHE EN INFORMATIQUE ET EN AUTOMATIQUE

Project-Team neuromathcomp

Mathematical and Computational Neuroscience

Paris - Rocquencourt, Sophia Antipolis - Méditerranée

Theme : Computational Medicine and Neurosciences

Activity Report

2010

Table of contents

1. Team

Research Scientists

Olivier Faugeras [Team leader,Senior Researcher (DR), scientific leader, HdR]
Bruno Cessac [Senior Researcher (DR), HdR]
Pascal Chossat [CNRS Senior Researcher (DR), HdR]
Pierre Kornprobst [Researcher (CR), HdR]
Jonathan Touboul [Researcher, Minister of Industry Engineer detached at INRIA from July 1st, 2010]

PhD Students

Javier Baladron [Ph.D. student, European MRT fellowship via ITN-FACETS funding, Université de Nice Sophia Antipolis, from the 1st of February 2010]
Diego Fasoli [Ph.D. student, European MRT fellowship via ITN-FACETS funding, Université de Nice Sophia Antipolis, from the 20th of January 2010]
Grégory Faye [Ph.D. student, MESR and Monitorat grant, Université de Nice Sophia Antipolis, from the 1st October 2009]
Mathieu Galtier [Ph.D. student, half financed Grant from the PACA Region and from INRIA fundings, Université de Nice Sophia Antipolis, from the 1st of October 2008]
Geoffroy Hermann [Ph.D. student, ENST detached at INRIA, from the 1st, July 2008]
Hassan Nasser [Ph.D. Student, INRIA contract from the 1st of October 2010]
Horacio Rostro-Gonzalez [Ph.D. student, Conacyt grant and INRIA allowance, Université de Nice Sophia Antipolis, from the 1st, October 2007 until the 31st, December 2010]
Émilien Tlapale [Ph.D. student, half financed Grant from the PACA Region and from INRIA fundings, Université de Nice Sophia Antipolis, from the 1st of October 2007 until the 30th of September 2010 and INRIA contract from the 1st of October 2010]
Juan-Carlos Vasquez [Ph.D. student, MESR and Monitorat grant, Université de Nice Sophia Antipolis, from the 1st of October 2007 until the 30th September 2010 and UNSA contract with INRIA allowance from the 1st of October 2010]
Romain Veltz [Ph.D. student, ENPC Funding, from the 1st of October 2008]

Post-Doctoral Fellows

Neil Bruce [PostDoc, INRIA Searise funding, from the 1st, September 2008, until th 31st of January 2010]
James Rankin [PostDoc INRIA contract, from the 20th of September 2010]
Vivien Robinet [PostDoc, INRIA Searise funding, from the 1st of September 2010]
Serafim Rodriguez [PostDoc located in the UNIC/CNRS Laboratory of Gif sur Yvette, INRIA ANR/HR Cortex funding, from the 1st, December 2009, until the 31st, May 2010]

Administrative Assistant

Marie-Cécile Lafont [Engineer Assistant (AI)]

Other

Hassan Nasser [Intern Fellowship, INRIA contract from the 1st of March 2010 until the 31st of August 2010]

2. Overall Objectives

2.1. Presentation

NEUROMATHCOMP focuses on the exploration of the brain from the mathematical and computational perspectives.

We want to unveil the principles that govern the functioning of neurons and assemblies thereof and to use our results to bridge the gap between biological and computational vision.

Our work is quite mathematical but we make heavy use of computers for numerical experiments and simulations. We have close ties with several top groups in biological neuroscience. We are pursuing the idea that the "unreasonable effectiveness of mathematics" can be brought, as it has been in physics, to bear on neuroscience.

Computational neuroscience attempts to build models of neurons at a variety of levels, microscopic, i.e., the single neuron, the minicolumn containing of the order of one hundred or so neurons, mesoscopic, i.e., the macrocolumn containing of the order of $10^4 - 10^5$ neurons, and macroscopic, i.e., a cortical area such as the primary visual area V1.

Modeling such assemblies of neurons and simulating their behaviour involves putting together a mixture of the most recent results in neurophysiology with such advanced mathematical methods as dynamic systems theory, bifurcation theory, probability theory, stochastic calculus, theoretical physics and statistics, as well as the use of simulation tools.

We conduct research in the following three main areas.

1. Modeling and simulating single neurons.
2. Modeling and simulating assemblies of neurons.
3. Visual perception modeling.

3. Scientific Foundations

3.1. Computational Neurosciences

Understanding the principles of information processing in the brain is challenging, theoretically and experimentally.

Modeling such assemblies of neurons and simulating their behaviour involves putting together a mixture of the most recent results in neurophysiology with such advanced mathematical methods as dynamical systems theory, bifurcation theory, probability theory, stochastic calculus, theoretical physics, and statistics, as well as the use of simulation tools [54]

In order to test the validity of the models we rely heavily on experimental data. These data come from single or multi electrode recordings and optical imaging and are provided by our collaborations with neurophysiology laboratories such as the UNIC http://www.unic.cnrs-gif.fr/ or the INCM http://www.incm.cnrs-mrs.fr/, the Centro de Neurociencia in Valparaiso http://www.cnv.cl/, and the Institut de la Vision http://www.institut-vision.org/. Other sources of measurements such as functional MRI, MEG and EEG are either obtained in collaboration with the EPI Athena as it is the case for EEG, or from other collaborative efforts such as the one with La Timone hospital in Marseille, or Neurospin.

The NeuroMathComp team works at the three levels. We proposed a realistic model of single neurons [9] by making use of physiological data and the theory of dynamical systems and bifurcations. At this level of analysis we also proposed a variety of theoretical tools from the theory of stochastic calculus [7] and solved an open problem of determining the probability law of the spike intervals for a simple but realistic neuron model, the leaky integrate and fire with exponentially decaying synaptic currents [8]. We also provided a mathematical analysis [5], through bifurcation theory, of the behaviour of a particular mesoscopic model, the one due to Jansen and Rit [62]. We also proposed mean-field techniques for bridging the gap between the microscopic and mesoscopic scales [4]. Finally we studied in detail several models for the statistics of spike trains in networks of neurons [3], [2].

We also started some efforts at the macroscopic level, in particular for modeling visual areas, see Section 3.2.

3.2. Biological and Computer Vision

Another scientific focus of the team is the combined study of computer and biological vision. We think that a more detailed knowledge of the visual perception in humans and primates can have a potential impact on algorithm design and performance. Thus, we develop so-called bio-inspired approaches to model visual tasks. This work is multidisciplinary: It involves knowledge from neuroscience and physiology, and tries to reproduce what psychophysical experiments reveal. As a final goal, we want to compete with recent computer vision approaches (see, e.g. [1] for a presentation of variational approaches in computer vision).

The models that we develop will be bio-inspired with two main goals:

- Reproduce the functional architecture of the brain. Considering a given scale of observation of the brain's activity, this will define the proper mathematical formalism to consider. For example, at the microscopic scale, the nervous system uses spikes as a way to emit and code the information. So we need to define systems able to generate relevant spiking patterns with spiking neuron models (see, e.g., the Virtual Retina simulator [10]) but also statistical tools to analyse these spikes. At the macroscopic scale, we will be only interested on the brain's activity at a population level, so that the neural field formalism will be useful (see, e.g., a neural field model for motion estimation presented in [50]). .
- Reproduce the percept and biological results. Validation of these models is crucial. Since we claim that our models are bio-inspired, our goal is also to validate them thanks to biology. For example, we showed that Virtual Retina reproduces closely single cell measurements acquired on cat ganglion cells. At the perceptual level, our models should also be able to reproduce a percept, which may be non trivial to reproduce with standard computer vision approaches. For example, we compared the results of the bio-inspired motion model [18] and more generally, we proposed in [6] a new way to evaluate motion estimation based on human performance.

Computer vision is another way to benchmark our approaches and prove their efficiency on real applications, and it is one of our goal to show how such bio-inspired approaches can compete with state-of-the-art computer vision approaches. For example, this has been successfully accomplished for the problems of action recognition [59], [58] and motion estimation [40].

4. Software

4.1. Virtual Retina

Participants: Bruno Cessac, Pierre Kornprobst [correspondent], Hassan Nasser, Adrien Wohrer [Group for Neural Theory of the Ecole Normale Supérieure, Paris].

We developed a retina simulation software which transforms a video into spike trains [71] (see also Adrien Wohrer PhD [73]). This project was developped in the scope of the EC project FACETS. Our goal was twofold: Allow large scale simulations (up to 100,000 neurons) in reasonable processing times and keep a strong biological plausibility (see [74] for a review), taking into account implementation constraints. The underlying model includes a linear model of filtering in the Outer Plexiform Layer, a well-posed shunting feedback at the level of bipolar cells accounting for rapid contrast gain control [72], and a spike generation process modeling ganglion cells. We proved the pertinence of our software by reproducing several experimental measurements from single ganglion cells such as cat X and Y cells. This software is an evolutionary tool for neuroscientists that need realistic large-scale input spike trains in subsequent treatments, and for educational purposes. We also developed a web service, so that one may test directly the main software on his own data, without any installation. Virtual Retina was distributed in 2007 with an open-source licence (CeCILL C). Up to our knowledge, this is the only free retina simulator that allows to reproduce a spiking output from a video stream, which has been confronted to fine biological data.

Virtual Retina allows to generate simulated retinal responses which are precise for *individual* ganglion cells and artificial stimuli. However, one crucial question in the community is now to analyse *collective* ganglion cells responses to both articial and natural stimuli. To do so, the development of Virtual Retina has to follow to take into account this new objective. This will be also possible thanks to the statistical tools to analyse spike trains which are jointly developped in the team by Bruno Cessac etal. (see section 4.2)

Website: `http://www-sop.inria.fr/odyssee/software/virtualretina/`

Virtual Retina is under CeCILL C licence.
APP logiciel Virtual Retina: IDDN.FR.OO1.210034.000.S.P.2007.000.31235

4.2. Event neural assembly Simulation

Participants: Frederic Alexandre, Bruno Cessac, Jeremy Fix, Olivier Rochel, Horacio Rostro-Gonzalez, Thierry Viéville [correspondent], Juan-Carlos Vasquez.

This is a library providing numerical tools for the simulation of neural networks and the analysis of spike trains either coming from neural simulators or from biological experiments.

It is designed mainly as

- An existing simulator plug-in (e.g. MVASpike or other simulators via the NeuralEnsemble meta-simulation platform),
- Additional modules for computations with neural unit assembly on standard platforms (e.g. Python or the Scilab platform).
- Original modules for the analysis of spike train statistics intended, in the mid term, to be used by the neuroscientists community.

Achievements include:

- Spike trains statistical analysis via Gibbs distributions. They are based on the estimation of a parametric Gibbs potential optimaly characterizing the statistics of empirical spike trains (by minimisation of the Kullback-Leibler divergence between the empirical measure and the Gibbs measure). From this, classical statistical indicators such as firing rate, correlations, higher order moments and statistical entropy are obtained. Also, the form of the Gibbs potential provides essential informations on the underlying neural network and its structure. This method does not only allow us to estimate the spikes statistics but also to compare different models, thus answering such questions about the neural code as: are correlations (or time synchrony or a given set of spike patterns,. . .) significant with respect to rate coding?
- Spiking network programing for exact event's sequence restitution;
- Siscrete neural field parameters algorithmic adjustments and time-constrained event-based network simulation reconciling clock and event based simulation methods.

Compared to existing libraries Enas offers new computational methods taking into account time constraints in neural networks (such as memory effects), based on theoretical methods rooted in statistical physics and applied mathematics. The algorithms used are based on linear programming, nonlinear parameter estimations, statistical methods. The C/C++ code has been organized as "bean java" to ease its use by programmers non specialized in advanced object programming. As a consequence the code is distributed in the form of an include source for the lightest and the most universal integration into users codes. The standard algorithms are based on the best free libraries in the domain such as gsl http://www.gnu.org/software/gsl.

Event neural assembly simulation is developed in gForge. It is under CeCILL C licence
APP logiciel Enas: IDDN.FR.OO1.360008.000.S.P.2009.000.10600.

Its development as a friendly software designed for the neuroscience community is our next purpose (ADT proposal).

Website: http://enas.gforge.inria.fr/

5. New Results

5.1. Analysis of single neuron models

5.1.1. On the simulation of nonlinear bidimensional spiking neuron models

Participant: Jonathan Touboul.

Bidimensional spiking models currently gather a lot of attention for their simplicity and their ability to reproduce various spiking patterns of cortical neurons. They are particularly used for large network simulations. These models describe the dynamics of the membrane potential by a nonlinear differential equation that blows up in finite time, coupled to a second equation for adaptation. Spikes are emitted when the membrane potential blows up or reaches a threshold θ. The precise simulation of the spike times and of the adaptation variable is critical for it governs the spike pattern produced, and is hard to compute accurately because of the exploding nature of the system at the spike times. We thoroughly studied the precision of fixed time-step integration schemes for this type of models and demonstrated that these methods produce systematic errors that are unbounded, as the cutoff value is increased, in the evaluation of the two crucial quantities: the spike time and the value of the adaptation variable at this time. Precise evaluation of these quantities therefore involve very small time steps and long simulation times. In order to achieve a fixed absolute precision in a reasonable computational time, we proposed here a new algorithm to simulate these systems based on a variable integration step method that either integrates the original ordinary differential equation or the equation of the orbits in the phase plane, and compared this algorithm with fixed time-step Euler scheme and other more accurate simulation algorithms.

This work has been accepted for publication in Neural Computation [20], and code is provided in Matlab and C.

5.2. Statistical analysis of spike trains

Processing and encoding of information in neural dynamics is a very active research field, although still much of the role of neural assemblies and their internal interactions remains unknown. With the advent of new Multi-Electrod Arrays (MEA) techniques, the simultaneously recording of the activity of groups of neurons (up to several hundreds) over a dense configuration, supply today a critical database to unravel the role of specific neural assemblies. The goal of the present project is to propose to the neuroscientists community statistical methods and numerical tools to analysing spike train statistics. Our work is grounded on theoretical results on Gibbs distributions in neural networks which as lead us to propose a C/C++ library of algorithms freely available at http://enas.gforge.inria.fr/. We are currently analysing real data statistics.

5.2.1. Spike trains statistics in Integrate and Fire Models: exact results

Participant: Bruno Cessac [correspondent].

We provide rigorous and exact results characterizing the statistics of spike trains in a network of leaky integrate and fire neurons, where time is discrete and where neurons are exposed to noise, without restriction on the synaptic weights. Using methods in chains with complete connections we show the existence and uniqueness of an invariant measure of Gibbs type and discuss its properties. We also discuss Markovian approximations and relate them to the approaches currently used in computational neuroscience to analyse experimental spike trains statistics. This establishes a rigorous ground for the current investigations attempting to characterize real spike trains data with Gibbs distributions, such as the Ising-like distribution, using the maximal entropy principle. In this setting, Ising model appears as the "next step" after the Bernoulli model (independent neurons) since it introduces spatial pairwise correlations, but not time correlations. The range of validity of this approximation is discussed together with possible approaches allowing to introduce time correlations, with algorithmic extensions.

This work has been accepted for publication in Journal of Mathematical Biology [12].

5.2.2. *Entropy-based parametric estimation of spike train statistics: numerical method*

Participants: Bruno Cessac [correspondent], Juan-Carlos Vasquez, Thierry Viéville.

We propose a generalization of the existing maximum entropy models used for spike trains statistics analysis. We bring a simple method to estimate Gibbs distributions, generalizing existing approaches based on Ising model or one step Markov chains to arbitrary parametric potentials. Our method enables one to take into account memory effects in dynamics. It provides directly the free-energy density and the Kullback-Leibler divergence between the empirical statistics and the statistical model. It does not assume a specific Gibbs potential form and does not require the assumption of detailed balance. Furthermore, it allows the comparison of different statistical models and offers a control of finite-size sampling effects, inherent to empirical statistics, by using large deviations results. A numerical validation of the method is proposed and the perspectives regarding spike-train code analysis are also discussed. The corresponding numerical algoritms have been included in the Enas library developed at INRIA gforge under Cecill-C licence http://enas.gforge.inria.fr/.

This work has been submitted to the Journal of Computational Neuroscience [70], presented at the Neurocomp 2010 conference and published in the proceedings [41], [42].

5.2.3. *Applications of parametric estimation by Gibbs distributions to experimental data*

Participants: Bruno Cessac [correspondent], Hassan Nasser, Adrian Palacios, Horacio Rostro-Gonzalez, Juan-Carlos Vasquez, Thierry Viéville.

We apply the formalism of Gibbs distributions to characterizing the statistics of multi-unit spike trains in bio-inspired simulated data from Virtual Retina, but also experimental data obtained from Multi-Electrode- Array (MEA) recordings from retina provided by Adrian Palacios (Centro de Neurociencia Valparaiso).

This work has been presented at the Neurocomp 2010 conference and published in the proceedings [44].

5.2.4. *Multi-resolution Schauder approach to multidimensional Gauss-Markov processes*

Participants: Thibaud Taillefumier [Department of Mathematical Physics, The Rockefeller University], Jonathan Touboul.

The study of multidimensional stochastic processes involves complex computations in intricate functional spaces. In particular, the diffusion processes, which include the practically important Gauss-Markov processes, are ordinarily defined through the theory of stochastic integration. Inspired by the Lévy-Cieselski construction of the Wiener process, we proposed an alternative representation of multidimensional Gauss-Markov processes as expansions on well-chosen Schauder bases, with independent random coefficients of normal law with zero mean and unitary variance. We thereby offered a natural multi-resolution description of Gauss-Markov processes as limits of the finite-dimensional partial sums of the expansion, that are strongly almost-surely convergent. Moreover, such finite-dimensional random processes constitute an optimal approximation of the process, in the sense of minimizing the associated Dirichlet energy under interpolating constraints. This approach allows simpler treatment in many applied and theoretical fields and we provide a short overview of applications we are currently developing.

This contribution is currently submitted and corresponds to the arXiv preprint [66].

5.3. Coding by spikes

Our goal here is a better understanding of the extent to which computing and modeling with spiking neuron networks might be biologically plausible and computationally efficient. Based on a thorough characterization of the main constraints on spiking neural networks dynamics this has lead us to propose new algorithms to infer the structure of the network from its spike trains and to propose an FPGA implentation of spiking neural networks.

5.3.1. *Neural coding by spikes*

Participants: Bruno Cessac [correspondent], Hélène Paugam-Moisy, Thierry Viéville.

Restricting to deterministic spiking neuron networks, we obtained original results on: (i) time constraints, (ii) links between continuous signals and spike trains, (iii) spiking neuron networks parameter adjustment. When implementing spiking neuron networks, for biological simulation or computational purpose, it is important to take into account these constraints, preventing one from implementing unrealistic (e.g. violating physical time constraints) or unecessary (artificially introducing spikes when continuous calculations would be sufficient) mechanisms in neural networks models. This provides fundamental keys to implementing large-scale spiking neuron networks.

This work has been published in Journal of Physiology, Paris [14].

5.3.2. Reverse-engineering of spiking neural networks parameters

Participants: Bruno Cessac [correspondent], Horacio Rostro-Gonzalez, Thierry Viéville.

We consider the deterministic evolution of a time-discretized spiking network of neurons with connection weights having delays, modeled as a discretized neural network of the generalized integrate and fire (gIF) type. The purpose is to study a class of algorithmic methods allowing to calculate the proper parameters (synaptic weights) to reproduce exactly a given spike train generated by an hidden (unknown) neural network. This problem is linear (L) if the membrane potentials are observed and LP (Linear-Programming) if only spike times are observed, in the context of gIF models. The L or LP adjustment mechanism is local to each unit and has the same structure as an "Hebbian" rule. This paradigm is easily generalizable to the design of input-output spike train transformations. This means that we have a practical method to "program" a spiking network, i.e. find a set of parameters allowing us to exactly reproduce the network output, given an input

This work has been published in an INRIA research report and submitted in Journal of Computational Neuroscience, 2010 [64], [63].

5.3.3. Development of FPGA-based efficient reconfigurable architectures for spiking neural networks

Participants: Bruno Cessac, Bernard Girau, Horacio Rostro-Gonzalez, Cesar Torres-Huitzil, Thierry Viéville [correspondent].

Spiking neural networks are able to perform very powerful computations with precise timed spikes. We are developing an FPGA (Field Programmable Gate Array) reconfigurable platform that enables the simulation of in silico models of spiking neural networks. Since the model is directly mapped into a FPGA device, the neural processing is accelerated and the time consumed reduced. We use VHDL and Handel-C to design the reconfigurable architecture of a discrete time Integrate-and-Fire model [55], [13] coded in CUDA, running on GPU.

This work has been presented in the conference Neurocomp 2010 and published in the proceedings [43].

5.4. Mean field analysis of large networks of neurons

The brain activity is characterized by the interaction of a very large number of neurons that are strongly affected by noise. However, signals often arise at macroscopic scales integrating the effect of many neurons into a reliable pattern of activity. In order to study such large neuronal assemblies, one is often led to derive mean-field limits summarizing the effect of the interaction of a large number of neurons into an effective signal.

In this section we address the problem of simplifying the description of a large populations of neurons interacting in a network. The techniques we use fall in the category of what is known in statistical physics and mathematics as mean-field methods.

5.4.1. A new method for establishing the mean-field equations of large populations of spiking or non-spiking neurons

Participants: Olivier Faugeras, Jonathan Touboul.

In [4], we proposed a method based on [61] to derive the mean-field equations of a network of completely connected neural masses falling into P populations. Each neural mass is described by a Wilson and Cowan model perturbed by Brownian noise. The connectivity weights are modelled as independent Gaussian random variables, independent of the Brownians. We showed that when the number of neural masses grew to infinity the activity of the network could be represented by a set of P mean-field equations. These stochastic equations are non-Markov, involving a special process called the interaction process. Their solution is a Gaussian process whose mean can be described by an ordinary differential equation, coupled to a fixed-point equation for the covariance. They can be thought of as describing the law of the limit activity of the network as the number of neurons increases whatever the (frozen) synaptic weights drawn from their law. The resulting equations turned out to be very difficult to analyse.

There are two criticisms of this approach that can be formulated. The first one is the fact that we are considering a network of neural masses, not of individual spiking neurons. The second is that the model of the uncertainty on the synaptic weights is a bit strange: we draw them at random and then assume they are constant over time for each sample. It would seem more realistic to assume that they fluctuate over time. To address these two criticisms we developed a new approach based on the work of Tanaka, McKean and Sznitman. We consider realistic models of spiking neurons such as the one pioneered by Hodgkin and Huxley, assume that the synaptic weights are the sum of a constant and a white noise, therefore fluctuating in time, and prove that one can derive mean-field equations which are well-posed, enjoy a unique solution and such that the average solution of the network converges toward this solution when the network size grows to infinity. We also establish fluctuation results describing the finite size effect.

5.4.2. *Analysis of the mean-field equations for a collection of Wilson and Cowan neural masses*

Participants: Olivier Faugeras, Geoffroy Hermann, Jonathan Touboul.

In the case of the network of neural masses studied in [4], the method described in section 5.4.1 leads to a set mean-field equations whose solution is also a Gaussian random process. The equation for the mean is identical to the one found in [4] but the one describing the variance, the only quantity related to the covariance function appearing in the equation for the mean, is considerably simpler, leading to an ordinary differential equation. Mean and variance can therefore be described by a set of coupled ordinary differential equations whose solutions can be studied for example as functions of the parameters describing the synaptic weights and the inputs. The bifurcations of these solutions with respect to these parameters can also be studied leading to a complete understanding of how the dynamics of the network varies when one progressively increases the variance on the synaptic weights. Non-trivial synchronization or stabilization effects appear as the external or the synaptic noise intensity are varied, in accordance with the simulations of finite-size networks.

5.4.3. *Analysis of the mean-field equations for a collection of conductance-based neuron models*

Participants: Diego Fasoli, Olivier Faugeras, Jonathan Touboul.

In the case of a network of spiking neurons described, e.g., by Fitzhugh Nagumo or Hodgkin Huxley models we introduce a realistic chemical synaptic model based on [57] and derive the mean-field equations using the method described in 5.4.1. Simulation of these equations show that phenomena similar to those described in section 5.4.2, i.e. synchronization and desynchronization, do appear. Unlike the previous case we cannot in general obtain a closed set of equations for the moments of the limit law and we must rely on the analysis of the corresponding Fokker-Planck equation and the bifurcations of its solutions.

This work was partially funded by the FACETS-ITN grant and the ERC advanced grant NerVi number 227747.

5.4.4. *Finite-size and correlation-induced effects in Mean-field Dynamics*

Participants: Jonathan Touboul, Bard Ermentrout.

Classical mean-field approaches consider the evolution of a deterministic variable, the mean activity, thus neglecting the stochastic nature of neural behavior. In this article, we build upon a recent approach that includes correlations and higher order moments in mean-field equations, and study how these stochastic effects influence the solutions of the mean-field equations, both in the limit of an infinite number of neurons and for large yet finite networks. We show that, though the solutions of the deterministic mean-field equation constitute uncorrelated solutions of the new mean-field equations, the stability properties of limit cycles are modified by the presence of correlations, and additional non-trivial behaviors including periodic orbits appear when there were none in the mean field. The origin of all these behaviors is then explored in finite-size networks where interesting mesoscopic scale effects appear. This study leads us to show that the infinite-size system appears as a singular limit of the network equations, and for any finite network, the system will differ from the infinite system.

This work is currently submitted and corresponds to the arXiv preprint [68].

5.4.5. Neural Mass Activity, Bifurcations and Epilepsy

Participants: Jonathan Touboul, Fabrice Wendling [INSERM U642 (Rennes)], Patrick Chauvel [INSERM U751, Assistance Publique des Hôpitaux de Marseille Timone], Olivier Faugeras.

We propose and explore a general framework for studying neural mass models given by ordinary differential equations and link their behaviors with typical cortical behaviors, with a special focus on epileptic patterns, by the study of the (codimension 2 and 3) bifurcations of the vector field and of the stochastic properties of the solutions of these equations. This systematic approach based on a dictionary linking vector field bifurcations and epilepsy-related phenomena is then applied to a simple model of choice, the Jansen and Rit model. This model features most phenomena of interest. A more complex recent model (featuring the same behaviors), the Wendling and Chauvel model, can also be studied with these tools. These studies allow to test hypothesis and investigate the effect of medication in a model-based approach and to test physiological and anatomical facts and predictions on the origin of pathological cortical behaviors.

This work is submitted and corresponds to the arxiv preprint [69].

5.4.6. Can power-law scaling and neuronal avalanches arise from stochastic dynamics?

Participants: Jonathan Touboul, Alain Destexhe [UNIC, CNRS (Gif-sur-Yvette)].

The presence of self-organized criticality in biology is often evidenced by a power-law scaling of event size distributions, which can be measured by linear regression on logarithmic axes. We show that such a procedure does not necessarily mean that the system exhibits self-organized criticality. We first provide an analysis of multisite local field potential (LFP) recordings of brain activity and show that event size distributions defined as negative LFP peaks can be close to power-law distributions. However, this result is not robust to change in detection threshold, or when tested using more rigorous statistical analyses such as the Kolmogorov–Smirnov test. Similar power-law scaling is observed for surrogate signals, suggesting that power-law scaling may be a generic property of thresholded stochastic processes. We next investigate this problem analytically, and show that, indeed, stochastic processes can produce spurious power-law scaling without the presence of underlying self-organized criticality. However, this power-law is only apparent in logarithmic representations, and does not survive more rigorous analysis such as the Kolmogorov–Smirnov test. The same analysis was also performed on an artificial network known to display self-organized criticality. In this case, both the graphical representations and the rigorous statistical analysis reveal with no ambiguity that the avalanche size is distributed as a power-law. We conclude that logarithmic representations can lead to spurious power-law scaling induced by the stochastic nature of the phenomenon. This apparent power-law scaling does not constitute a proof of self-organized criticality, which should be demonstrated by more stringent statistical tests.

This work has appeared in PloS ONE, [19].

5.5. Neural fields

Quoting from the book [57]: “There are two main approaches to the analysis and modeling of networks of neurons. In one approach, the details of the action potentials (spikes) matter a great deal. In the second approach we do not care about the timing of the individual neurons; rather we are concerned only with the firing rates of populations.” This section deals with the second approach.

Specifically, neural or cortical fields are continuous assemblies of mesoscopic models, also called neural masses, of neural populations that are fundamental in the modeling of macroscopic parts of the brain. Neural fields are described by nonlinear integro-differential equations. The solutions to these equations represent the state of activity of these populations when submitted to inputs from neighbouring brain areas. Understanding the properties of these solutions is essential in advancing our understanding of the brain.

5.5.1. Some theoretical and numerical results for delayed neural field equations

Participants: Olivier Faugeras, Gregory Faye.

We studied neural field models with delays which define a useful framework for modeling macroscopic parts of the cortex involving several populations of neurons. Nonlinear delayed integro-differential equations describe the spatio-temporal behavior of these fields. Using methods from the theory of delay differential equations, we show the existence and uniqueness of a solution of these equations. A Lyapunov analysis gives us sufficient conditions for the solutions to be asymptotically stable. We also presented a fairly detailed study of the numerical computation of these solutions. This is, to our knowledge, the first time that a serious analysis of the problem of the existence and uniqueness of a solution of these equations has been performed. Another original contribution of ours is the definition of a Lyapunov functional and the result of stability it implies. We illustrate our numerical schemes on a variety of examples that are relevant to modeling in neuroscience.

This work was presented at the Neurocomp 2010 conference, [35].

This work has appeared in Physica D, special issue on Mathematical Neuroscience, [16]. This work was partially funded by the ERC advanced grant NerVi number 227747.

5.5.2. Local/global analysis of the stationary solutions of some neural field equations

Participants: Olivier Faugeras, Romain Veltz.

We studied the dependency of the stationary solutions of the neural fields equations with respect to the stiffness of the nonlinearity and the contrast of the external inputs. This is done by using degree and bifurcation theories in the context of functional, in particular infinite dimensional, spaces. The joint use of these two theories allowed us to make new detailed predictions about the global and local behaviours of the solutions. We also provided a generic finite dimensional approximation of these equations which allows us to study in great details two models. The first model is a neural mass model of a cortical hypercolumn of orientation sensitive neurons, the ring model [65]. The second model is a general neural field model where the spatial connectivity is described by heterogeneous Gaussian-like functions.

This work has appeared in SIAM Journal on Applied Dynamical Systems, [21].

This work was partially funded by the ERC advanced grant NerVi number 227747.

5.5.3. Some theoretical results for a class of neural mass equations

Participants: Pascal Chossat, Olivier Faugeras, Grégory Faye.

We studied the neural field equations introduced by Chossat and Faugeras in [56] to model the representation and the processing of image edges and textures in the hypercolumns of the cortical area V1. The key entity, the structure tensor, intrinsically lives in a non-Euclidean, in effect hyperbolic, space. Its spatio-temporal behaviour is governed by nonlinear integro-differential equations defined on the Poincaré disc model of the two-dimensional hyperbolic space. Using methods from the theory of functional analysis we show the existence and uniqueness of a solution of these equations. In the case of stationary, i.e. time independent, solutions we perform a stability analysis which yields important results on their behavior. We also present an original study, based on non-Euclidean, hyperbolic, analysis, of a spatially localised bump solution in a limiting case. We illustrate our theoretical results with numerical simulations.

This work is submitted in SIAM Journal on Applied Dynamical Systems. Part of this work was presented at the Neurocomp 2010 conference, [47]

This work was partially funded by the ERC advanced grant NerVi number 227747.

5.5.4. *Illusory persistent states in the Ring Model of visual orientation selectivity*

Participants: Olivier Faugeras, Romain Veltz.

Our goal is to understand the dynamics of the cortical states of parts of the primate visual cortex when stationary (independent of time) stimuli are presented. A first step to achieve this goal is to understand the stationary cortical states. These neural mass models have been used to describe the activity of neural populations that are found in the visual cortex of primates. They feature stationary solutions, when submitted to a stationary input. These solutions depend quite sensitively on such parameters of the model as the stiffness of the nonlinearity and the contrast of the external input. The use of bifurcation theory allows us to make new detailed predictions about the global and local behaviours of the solutions. We apply these results to the study of a neural mass model of a cortical hypercolumn of orientation sensitive neurons called the ring model [65].

This work is submitted in PlosCompBio [51]

This work was partially funded by the ERC advanced grant NerVi number 227747.

5.5.5. *Bifurcation of hyperbolic planforms*

Participants: Pascal Chossat, Olivier Faugeras, Grégory Faye.

Motivated by a model for the perception of textures by the visual cortex in primates, we analysed the bifurcation of periodic patterns for nonlinear equations describing the state of a system defined on the space of structure tensors, when these equations are further invariant with respect to the isometries of this space. We showed that the problem reduces to a bifurcation problem in the hyperbolic plane $\mathcal{D}$ (Poincaré disc). We made use of the concept of periodic lattice in $\mathcal{D}$ to further reduce the problem to one on a compact Riemann surface $\mathcal{D}/G$, where G is a cocompact, torsion-free Fuchsian group. The knowledge of the symmetry group of this surface allowed to carry out the machinery of equivariant bifurcation theory. Solutions which generically bifurcate are called "H-planforms", by analogy with the "planforms" introduced for pattern formation in Euclidean space. This concept is applied to the case of an octagonal periodic pattern, where we are able to classify all possible H-planforms satisfying the hypotheses of the Equivariant Branching Lemma. These patterns are however not straightforward to compute, even numerically, and we described a method for computation illustrated with a selection of images of octagonal H-planforms.

This work has been accepted for publication in the Journal of Nonlinear Science, [15].

This work was partially funded by the ERC advanced grant NerVi number 227747.

5.5.6. *Toward a spatial network of ring models*

Participants: Javier Baladron, Olivier Faugeras.

We consider a spatial two-dimensional network of a special kind of neural masses, the ring model [65] studied in section 5.5.4. Such a network has been studied for example in [53] in the context of equivariant bifurcation theory. Our goal is to solve the network equations as fast as possible on a GPU architecture without for arbitrary spatial (N) and angular resolutions (P). A naive discretization of the problem leads to solving a set of $N^2 \times P$ coupled nonlinear ordinary differential equations. The PG-kernel approach, (for Pingerle-Goursat) kernel, proposed in [21] consists in approximating the operator defined by the spatial connectivity function between the neural masses by a finite-range operator. This is obtained by writing the connectivity function as a sum of Q products of functions and leads to solving a set of Q coupled nonlinear ordinary differential equations *independently* of the spatial and angular resolutions. If $Q << N^2 \times P$ a significant gain in computation time is possible.

This work was partially funded by the FACETS-ITN grant and the ERC advanced grant NerVi number 227747.

5.6. Visual perception modeling

5.6.1. Analysing and reproducing retinal collective responses

Participants: Bruno Cessac [correspondent], Pierre Kornprobst, Hassan Nasser.

Our simulator Virtual Retina http://www-sop.inria.fr/odyssee/software/virtualretina/, see section 4.1 accurately reproduces the receptive fields and the individual responses of standard ganglion cells (magno and parvo). It also correctly mimics features such as contrast gain control. Finally, it allows the simulation of about 100.000 neurons while the classical techniques of Multi Electrod Arrays are limited to a few hundred of neurons. From this point of view, simulation is a bit ahead of experimental measurements. However, some fundamental connections- intra or inter-retinal layers, as well as essential feedbacks, have not been implemented yet (especially negative loop between amacrine and ganglion cells). As a consequence, the collective response of ganglion cells is not satisfactory and statistics of outgoing spike trains is not realistic, as revealed by a thorough comparison between spikes emitted by Virtual retina and real data acquisition, using the algorithm developed in the Enas library http://enas.gforge.inria.fr/ [52], see section 4.2. In interactions with several biologists teams (A. Palacios, http://www.cnv.cl/; M. Berry, O. Marre http://www.molbio.princeton.edu/, S. Picaud http://www.institut-vision.org/) our goal is now to design a more elaborated and realistic structure for Virtual Retina producing more realistic statistics. The final goal is to have a simulation tool allowing realistic simulations prior to experiments design, as well as an exploration tool unveiling the connections between specific retinal circuits and specific functions [60].

5.6.2. Modelling the dynamics of motion integration with a new luminance-gated diffusion mechanism

Participants: Pierre Kornprobst, Guillaume Masson [Institut de Neurosciences Cognitives de la Méditerranée, UMR 6193, CNRS, Marseille, France], Émilien Tlapale.

The dynamics of motion integration show striking similarities when observed at neuronal, psychophysical, and oculomotor levels. Based on the inter-relation and complementary insights given by those dynamics, our goal was to test how basic mechanisms of dynamical cortical processing can be incorporated in a dynamical model to solve several aspects of 2D motion integration and segmentation. In [18], [46], we proposed a model inspired by the hierarchical processing stages of the primate visual cortex: we describe the interactions between several layers processing local motion and form information through feedforward, feedback, and inhibitive lateral connections. Also, following perceptual studies concerning contour integration and physiological studies of receptive fields, we postulate that motion estimation takes advantage of another low-level cue, which is luminance smoothness along edges or surfaces, in order to gate recurrent motion diffusion. With such a model, we successfully reproduced the temporal dynamics of motion integration on a wide range of simple motion stimuli: line segments, rotating ellipses, plaids, and barber poles. Furthermore, we showed that the proposed computational rule of luminance-gated diffusion of motion information is sufficient to explain a large set of contextual modulations of motion integration and segmentation in more elaborated stimuli such as chopstick illusions, simulated aperture problems, or rotating diamonds. As a whole, in [18] we proposed a new basal luminance-driven motion integration mechanism as an alternative to less parsimonious models, we carefully investigated the dynamics of motion integration, and we established a distinction between simple and complex stimuli according to the kind of information required to solve their ambiguities.

This work was partially supported by the EC IP project FP6-015879 (FACETS), the EC ICT project No. 215866 (SEARISE) and the Région Provence-Alpes-Côte d'Azur.

5.6.3. Bio-inspired motion estimation

Participants: Jan D. Bouecke [Institute of Neural Information Processing, Ulm University, Ulm, Germany], Pierre Kornprobst, Olivier Faugeras, Guillaume Masson [Institut de Neurosciences Cognitives de la Méditerranée, UMR 6193, CNRS, Marseille, France], Heiko Neumann [Institute of Neural Information Processing, Ulm University, Ulm, Germany], Émilien Tlapale.

Our goal is to identify the key biological features to reach a good compromise between bio-inspiration and computational efficiency for the motion estimation problem. Motion estimation is a task performed very well by the primate visual cortex. But motion estimation is also a key feature for many vision and robotic applications, and it is an active field of research in the computer vision community. So the question is: From modelling to evaluation, can biology be a source of inspiration?

This work can be seen as an extension of [18], but the only relation comes from the general structure based on two recurently connected layers (V1 and MT). However, the scope and content of this contribution is very different. More precisely, distinguishing results are:

(i) The model: we choose the neural field formalism which provides a sound mathematical framework to describe the model at a macroscopic scale. Within this framework we defined the cortical activity as coupled integro-differential equations and proved the well-posedness of the model.

(ii) The results: We showed how our model performs on some classical computer vision videos, and compared its behaviour against the visual system on a simple classical video used in psychophysics (while in [18], we only presented results on psychophysical experiments, focusing on the dynamics of motion estimation).

(iii) The proposal of bio-inspired benchmark (see also [40], [45], [49]), which is a novel challenge for modelers in computer vision. We showed how it is possible to benchmark an algorithm with respect to human performance (i.e., based on results obtained in psychophysics).

This work is submitted in IJCV, available as an INRIA research report [67]

This work was partially supported by the EC IP project FP6-015879 (FACETS), the EC ICT project No. 215866 (SEARISE) and the Région Provence-Alpes-Côte d'Azur, and the ERC advanced grant NerVi number 227747.

5.6.4. Another look at the retina as an image dithered scalar quantizer

Participants: Marc Antonini [Laboratoire I3S, Sophia Antipolis, France], Pierre Kornprobst, Khaled Masmoudi [Laboratoire I3S, Sophia Antipolis, France].

Analog-to-digital signal conversion (ADC) is a crucial step in a signal processing chain. Although a wide-range of algorithms is already implemented, the raising interest towards the solutions provided by biological systems to engineering problems motivated our study on how these biological systems tackle the issue of ADC. Interestingly, the mammalians retina offers an appropriate study environment. Indeed, the neural code of the retina consists of a series of uniformly-shaped electrical impulses, the spikes, yielding a binary code. In [36], [37], we base our work on a biologically realistic model of the mammalians retina, and focus on its behavior during the first 30ms of the visual stimuli processing. This leads us to the specification of a novel bio-inspired quantization algorithm. We proved that, under the model assumption, our new bio-inspired quantizer emphasizes high magnitude signals rather than high probability ones. Besides, our system gradually changes across time from a coarse and quasi-uniform quantizer to a refined and highly non-linear one. This yields an original time depending bio-inspired quantization system. The proposed bio-inspired quantizer offers several interesting features as scalability, and introduces time parametrizing in the coding system which opens perspectives for the conception of an implicit bit-allocation mechanism.

6. Other Grants and Activities

6.1. European Initiatives

6.1.1. SEARISE: Smart Eyes, attending and recognizing instances of salient events

Participants: Neil Bruce, Olivier Faugeras, Pierre Kornprobst, Émilien Tlapale.

SEARISE is a three-year project started in March 2008. It involves the following academic partners: Fraunhofer-Gesellschaft (Germany), University of Genoa (Italy), Ulm University (Germany) University of Bangor (Wales). Two industrial partners are also involved: TrackMen Ltd. and LTU Arena.

The SEARISE project develops a trinocular active cognitive vision system, the Smart-Eyes, for detection, tracking and categorization of salient events and behaviours. Unlike other approaches in video surveillance, the system will have human-like capability to learn continuously from the visual input, self-adjust to ever changing visual environment, fixate salient events and follow their motion, categorize salient events depending on the context. Inspired by the human visual system, a cyclopean camera will perform wide range monitoring of the visual field while active binocular stereo cameras will fixate and track salient objects, mimicking a focus of attention that switches between different interesting locations.

The core of this artificial cognitive visual system will be a dynamic hierarchical neural architecture – a computational model of visual processing in the brain. Information processing in Smart-Eyes will be highly efficient due to a multi-scale design: Controlled by the cortically plausible neural model, the active cameras will provide a multi-scale video record of salient events. The processing will self-organize to adapt to scale variations and to assign the majority of computational resources to the informative parts of the scene.

The Smart-Eyes system will be tested in real-life scenarios featuring the activity of people in different scales. In a long-range distance scenario, the system will be monitoring crowd behaviour of sport fans in a football arena. In a short range scenario, the system will be monitoring the behaviour of small groups of people and single individuals. The system's capability for self-adaptation will be specifically demonstrated and quantified compared to systems with 'classical' architecture that are trained once and then used on a set of test scenes.

Website: http://www.searise.eu/web/doku.php

6.1.2. FACETS: Fast Analog Computing with Emergent Transient States

Participants: Romain Brette, Maria-Jose Escobar [Universidad Técnica Federico Santa María, Chili], Olivier Faugeras, Mathieu Galtier, François Grimbert, Horacio Rostro-Gonzalez, Pierre Kornprobst, Théo Papadopoulo, Émilien Tlapale, Jonathan Touboul, Romain Veltz.

FACETS is an integrated project within the biologically inspired information systems branch of IST-FET. The FACETS project aims to address, with a concerted action of neuroscientists, computer scientists, engineers and physicists, the unsolved question of how the brain computes. It combines a substantial fraction of the European groups working in the field into a consortium of 13 groups from Austria, France, Germany, Hungary, Sweden, Switzerland and the UK. About 80 scientists have joined their efforts over a period of 5 years, starting in September 2005 and ending in August 2010. A project of this dimension has rarely been carried out in the context of brain-science related work in Europe, in particular with such a strong interdisciplinary component.

Website: http://facets.kip.uni-heidelberg.de/

6.1.3. ERC NERVI

Participants: Bruno Cessac, Pascal Chossat [CNRS], Olivier Faugeras, Pierre Kornprobst.

Olivier Faugeras responded to the 2008 ERC call "IDEAS". His project, NerVi, submitted to the "Mathematics and Interfaces" panel, has been accepted and obtained a 5 years funding for a total amount of 1.7 Million Euros.

The project is to develop a formal model of information representation and processing in the part of the neocortex that is mostly concerned with visual information. This model will open new horizons in a well-principled way in the fields of artificial and biological vision as well as in computational neuroscience. Specifically the goal is to develop a universally accepted formal framework for describing complex, distributed and hierarchical processes capable of processing seamlessly a continuous flow of images. This framework features notably computational units operating at several spatiotemporal scales on stochastic data arising from natural images. Mean- field theory and stochastic calculus are used to harness the fundamental stochastic nature of the data, functional analysis and bifurcation theory to map the complexity of the behaviours of these assemblies of units. In the absence of such foundations, the development of an understanding of visual information processing in man and machines could be greatly hindered. Although the proposal addresses fundamental problems, its goal is to serve as the basis for ground-breaking future computational development for managing visual data and as a theoretical framework for a scientific understanding of biological vision.

6.1.4. ITN-FACETS

Participants: Javier Baladron, Diego Fasoli, Olivier Faugeras.

This 'Marie-Curie Initial Training Network' (funded by the EU) involves 15 groups at European Research Universities, Research Centers and Industrial Partners in 6 countries. It funds two PhD students in the NeuroMathComp group. Website: http://facets.kip.uni-heidelberg.de/ITN/index.html

6.1.5. BrainScaleS: Brain-inspired multiscale computation in neuromorphic hybrid systems

Participants: Bruno Cessac, Pascal Chossat [CNRS], Olivier Faugeras, Pierre Kornprobst, Jonathan Touboul.

The BrainScaleS project aims at understanding function and interaction of multiple spatial and temporal scales in brain information processing. The fundamentally new approach of BrainScaleS lies in the in-vivo biological experimentation and computational analysis. Spatial scales range from individual neurons over larger neuron populations to entire functional brain areas. Temporal scales range from milliseconds relevant for event based plasticity mechanisms to hours or days relevant for learning and development. In the project generic theoretical principles will be extracted to enable an artificial synthesis of cortical-like cognitive skills. Both, numerical simulations on petaflop supercomputers and a fundamentally different non-von Neumann hardware architecture will be employed for this purpose. Neurobiological data from the early perceptual visual and somatosensory systems will be combined with data from specifically targeted higher cortical areas. Functional databases as well as novel project-specific experimental tools and protocols will be developed and used. New theoretical concepts and methods will be developed for understanding the computational role of the complex multi-scale dynamics of neural systems in-vivo. Innovative in-vivo experiments will be carried out to guide this analytical understanding. Multiscale architectures will be synthesized into a non-von Neumann computing device realised in custom designed electronic hardware. The proposed Hybrid Multiscale Computing Facility (HMF) combines microscopic neuromorphic physical model circuits with numerically calculated mesoscopic and macroscopic functional units and a virtual environment providing sensory, decision-making and motor interfaces. The project also plans to employ petaflop supercomputing to obtain new insights into the specific properties of the different hardware architectures. A set of demonstration experiments will link multiscale analysis of biological systems with functionally and architecturally equivalent synthetic systems and offer the possibility for quantitative statements on the validity of theories bridging multiple scales. The demonstration experiments will also explore non-von Neumann computing outside the realm of brain-science. BrainScaleS will establish close links with the EU Brain-i-Nets and the Blue Brain project at the EPFL Lausanne. The consortium consists of a core group of 10 partners with 13 individual groups. Together with other projects and groups the BrainScaleS consortium plans to make important contributions to the preparation of a future FET flagship project. This project will address the understanding and exploitation of information processing in the human brain as one of the major intellectual challenges of humanity with vast potential applications.

This project starts on January 1st, 2011 and is funded for four years.

Website: http://brainscales.kip.uni-heidelberg.de/

7. Dissemination

7.1. Animation of the scientific community

Bruno Cessac is a reviewer for the CONYCIT (Chile) and COFECUB (Brasil) program and for the reviews Physica D, Nonlinearity, Chaos, Journal of Statistical Physics, IEEE Transaction in Neural Networks, Journal of Mathematical Biology, Journal of Computational Neuroscience. He was a lecturer in Valparaiso at the School PRIMAVERA “Computing with spikes: results and challenges” in November 2010. He is in charge of internships organisation in the Master of Computational Biology, Nice.

Pascal Chossat is director of the Centre International de Rencontres Mathématiques (CIRM) in Marseille, an international conference centre in mathematics jointly operated by CNRS and the French Mathematical Society. He stepped down in June 2010. He is deputy scientific director of INSMI, the newly created mathematics institute of CNRS, in charge of the international relations of CNRS in this field. He is the coordinator of a geographic EraNet (EC program) named New Indigo for the development of scientific networks between European member states and India.

Olivier Faugeras is a member of the French Academy of Sciences, the French Academy of Technology. He is on the Editorial board of the International Journal of Computer Vision (IJCV). He is the co-editor in chief of the Journal of Mathematical neuroscience, Springer: Website: http://www.mathematical-neuroscience.com/ He is a member of the Institut Thématique Multi-organismes Neurosciences, Sciences cognitives, Neurologie, Psychiatrie. He is a member of the ERC PE1 panel for 2010-2011. He was the chairman of the AERES evaluation committee of the TIMC laboratory in Grenoble (June 2010). He was a member of the ANR evaluation SVSE4 panel for neuroscience.

Pierre Kornprobst was a member of the comité de suivi doctoral (CSD) until May. He is the coordinator of the Master of Science in Computational Biology from Université Nice Sophia Antipolis (Website: http://www.computationalbiology.eu). The scientific goal of this program is to focus on the human being from different perspectives (understanding and modeling functional aspects or interpreting biomedical signals from various devices) and at different scales (from molecules to organs and the whole organism).

7.2. Teaching

- Bruno Cessac was Maître de conférences in Nice University until September 2010. He is now research director at INRIA. He has been teaching thermodynamics (L2 level), quantum physics (L2 level), probability theory (L3 level), C programming (L3 level), linear algebra (L3 level), statistical physics (M1 level), neural networks dynamics (M2 level, master of physics and master of computational biology), for Physics students. He is still teaching theoretical methods in neuronal dynamics analysis in the Master of Computational Biology, Nice.
- Olivier Faugeras teaches at the ENS Paris the course ”Mathematical methods for neuroscience“ part of the Master MVA and the ENS Math/Info section - (27h).
- Grégory Faye is a teaching assistant of analysis courses for first year students L1 at UNSA (Université de Nice) (64h).
- Hassan Nasser is a teaching assistant at the Ecole Polytechnique Universutaire de Nice. He his teaching microprocessors and numeric electronic (L3, 64h).
- Émilien Tlapale teaches "Programming in C++", at EPU (Université de Nice-Sophia Antipolis) in the electronic department (fifth year).

7.3. Participation to workshops, seminars and miscellaneous invitations

In 2010 Bruno Cessac has been invited:

- to the Conference "Stochastic models in neuroscience", Marseille, 18-22 January 2010 at CIRM;
- to the "Workshop School Chaos and Dynamics in Biological Networks" Cargese 3-8 May 2010;
- to the "Workshop on Spike Train Measures and Their Applications to Neural Coding” 2/3 June 2010 in Plymouth/UK;
- to give a lecture in Valparaiso at the School PRIMAVERA “Computing with spikes: results and challenges” in November 2010.

Pascal Chossat gave invited talks at

- 13e Rencontre du Non Linéaire, organizers M. Lefranc, C. Letellier and L. Pastur, 10- 12/03/2010, “Bifurcations dans l’espace hyperbolique en relation avec un modèle de perception des structures visuelles par le cortex”,
- Congrès "8th AIMS Conference on Dynamical Systems, Differential Equations and Applications", Dresdeen 25-28/05/2010, “Bifurcation of patterns in hyperbolic space”,
- Colloque "Géométrie, Mécanique et Dynamique", organizers J-P Ortega and J. Marsden, CIRM 12-16/07/2010, “Bifurcation of patterns in hyperbolic space”,
- Colloque franco-japonais "Reaction-diffusion systems: experiment, modeling and analysis", organizer D. Hilhorst, Orsay 21-22/10/2010, “Bifurcation of patterns in hyperbolic space in relation with a model of visual cortical perception”,
- Colloque WAMCE 2010, organizer C. Schaerer, Asuncion (Paraguay) 25-26/10/2010, “Bifurcation of patterns in hyperbolic space in relation with a model of visual cortical perception”.

Olivier Faugeras gave invited talks at

- the CIRM Workshop, “Stochastic models in neuroscience”, Marseille, January, [27],
- the Ladislav Tauc Conferences and I.T.M.O. Neurosciences Joint Meeting: MULTISCALE ANALYSIS of NEURAL SYSTEMS, Gif-s-Yvette, February, [26],
- the Workshop "Maths pour l’image", Orléans, April, [28],
- the AIMS Conference Spatially Structured Oscillations and Waves in Neural Media, Dresden, May, [29],
- the ITMO Workshop on multiscale analysis in neuroscience, Paris, College de France, July, [25],
- the OCCAM workshop on Future challenges in mathematical and computational neuroscience, Oxford, September, [33],
- the Workshop on Progress in neural field theory, Reading, September, [30],
- the Symposium in honor of Mike Brady, Oxford, September, [31],
- the Tauc conference, "From Mathematical Image Analysis to Neurogeometry of the Brain", Gif-sur-Yvette, December.
- He was the plenary speaker at ECCV2010, the 11th European Conference in Computer Vision, Heraklion, Crete, September, [32].
- He gave a talk on the future challenges in mathematical neuroscience at OF’60 (Website: `http://www-sop.inria.fr/manifestations/of60/`), the one-day scientific meeting on Artificial Vision, Biological Vision and Computational Neuroscience organized at the INRIA Sophia Antipolis – Méditerranée research centre to celebrate his 60th birthday.

In 2010 Pierre Kornprobst has been invited:

- to the symposium "Multi-scale analysis of neural systems: taking the challenge seriously", Gif-sur-Yvette, 15-16 February 2010;
- to Colloque “Méthodes mathématiques pour l’image”, Orléans 1-3 April 2010.

Jonathan Touboul gave an invited talk at OF’60.

7.4. Acknowledgements

We thank Théo Papadopoulo of the Athena Project Team for his careful proofreading of the original version of this document. This has allowed us to produce a better version of this report.

Olivier Faugeras warmly thanks all his friends and colleagues who made OF'60 (Website: http://www-sop.inria.fr/manifestations/of60/) possible. Special thanks go to Nicholas Ayache, Jean-Daniel Boissonnat, Rachid Deriche, Gérard Giraudon, Agnès Cortell, Agnès Bessière and Marc Barret.

8. Bibliography

Major publications by the team in recent years

[1] G. AUBERT, P. KORNPROBST. *Mathematical problems in image processing: partial differential equations and the calculus of variations (Second edition)*, Applied Mathematical Sciences, Springer-Verlag, 2006, vol. 147.

[2] B. CESSAC. *A discrete time neural network model with spiking neurons II. Dynamics with noise*, in "J.Math. Biol., accepted", 2010 [*DOI :* 10.1007/S00285-010-0358-4], http://www.springerlink.com/content/j602452n1224x602/.

[3] B. CESSAC, M. SAMUELIDES. *From neuron to neural networks dynamics.*, in "EPJ Special topics: Topics in Dynamical Neural Networks", 2007, vol. 142, n^{o} 1, p. 7–88 [*DOI :* 10.1140/EPJST/E2007-00058-2], http://lanl.arxiv.org/abs/nlin/0609038.

[4] O. FAUGERAS, J. TOUBOUL, B. CESSAC. *A constructive mean field analysis of multi population neural networks with random synaptic weights and stochastic inputs*, in "Frontiers in Computational Neuroscience", 2009, vol. 3, n^{o} 1 [*DOI :* 10.3389/NEURO.10.001.2010], http://www.frontiersin.org/computational_neuroscience/10.3389/neuro.10/001.2009/abstract.

[5] F. GRIMBERT, O. FAUGERAS. *Bifurcation Analysis of Jansen's Neural Mass Model*, in "Neural Computation", December 2006, vol. 18, n^{o} 12, p. 3052–3068.

[6] É. TLAPALE, P. KORNPROBST, J. D. BOUECKE, H. NEUMANN, G. S. MASSON. *Evaluating motion estimation models from behavioural and psychophysical data*, in "BIONETICS", 2010.

[7] J. TOUBOUL, O. FAUGERAS. *The spikes trains probability distributions: a stochastic calculus approach*, in "Journal of Physiology, Paris", December 2007, vol. 101/1-3, p. 78–98.

[8] J. TOUBOUL, O. FAUGERAS. *First hitting time of Double Integral Processes to curved boundaries*, in "Advances in Applied Probability", 2008, vol. 40, n^{o} 2, p. 501–528.

[9] J. TOUBOUL. *Bifurcation Analysis of a General Class of Nonlinear Integrate-and-Fire Neurons*, in "SIAM Journal on Applied Mathematics", 2008, vol. 68, n^{o} 4, p. 1045-1079, http://link.aip.org/link/?SMM/68/1045/1.

[10] A. WOHRER, P. KORNPROBST. *Virtual Retina : A biological retina model and simulator, with contrast gain control*, in "Journal of Computational Neuroscience", 2009, vol. 26, n^{o} 2, 219, DOI 10.1007/s10827-008-0108-4.

Publications of the year

Articles in International Peer-Reviewed Journal

[11] J. D. BOUECKE, É. TLAPALE, P. KORNPROBST, H. NEUMANN. *Neural Mechanisms of Motion Detection, Integration, and Segregation: From Biology to Artificial Image Processing Systems*, in "EURASIP, special issue on Biologically inspired signal processing: Analysis, algorithms, and applications", 2010, (to appear).

[12] B. CESSAC. *A discrete time neural network model with spiking neurons II. Dynamics with noise*, in "J.Math. Biol., accepted", 2010 [*DOI :* 10.1007/S00285-010-0358-4], http://www.springerlink.com/content/j602452n1224x602/.

[13] B. CESSAC. *A view of Neural Networks as dynamical systems*, in "International Journal of Bifurcations and Chaos", 2010, vol. 20, n^{o} 6, p. 1585-1629 [*DOI :* 10.1142/S0218127410026721], http://lanl.arxiv.org/abs/0901.2203.

[14] B. CESSAC, H. PAUGAM-MOISY, T. VIÉVILLE. *Overview of facts and issues about neural coding by spikes*, in "J. Physiol. Paris", February 2010, vol. 104, n^{o} 1-2, p. 5-18 [*DOI :* DOI:10.1016/J.JPHYSPARIS.2009.11.002], http://dx.doi.org/10.1016/j.jphysparis.2009.11.002.

[15] P. CHOSSAT, G. FAYE, O. FAUGERAS. *Bifurcation of hyperbolic planforms*, in "Nonlinear Science", 2010, Accepted for publication., http://arxiv.org/abs/1007.2492.

[16] G. FAYE, O. FAUGERAS. *Some theoretical and numerical results for delayed neural field equations*, in "Physica D", May 2010, vol. 239, n^{o} 9, p. 561–578, Special issue on Mathematical Neuroscience..

[17] A. RAMIREZ, M. RIVERA, P. KORNPROBST, F. LAUZE. *Variational multi-valued velocity field estimation for transparent sequences*, in "Journal of Mathematical Image and Vision", 2010, to appear.

[18] É. TLAPALE, G. S. MASSON, P. KORNPROBST. *Modelling the dynamics of motion integration with a new luminance-gated diffusion mechanism*, in "Vision Research", August 2010, vol. 50, n^{o} 17, p. 1676–1692, http://dx.doi.org/10.1016/j.visres.2010.05.022.

[19] J. TOUBOUL, A. DESTEXHE. *Can power-law scaling and neuronal avalanches arise from stochastic dynamics?*, in "PloS one", 2010, vol. 5, n^{o} 2, e8982.

[20] J. TOUBOUL. *On the simulation of nonlinear bidimensional spiking neuron models*, in "Arxiv preprint arXiv:1008.1954 (Accepted for publication in Neural Computation)", 2010.

[21] R. VELTZ, O. FAUGERAS. *Local/Global Analysis of the Stationary Solutions of Some Neural Field Equations*, in "SIAM Journal on Applied Dynamical Systems", August 2010, vol. 9, n^{o} 3, p. 954–998 [*DOI :* 10.1137/090773611], http://link.aip.org/link/?SJA/9/954/1.

Invited Conferences

[22] B. CESSAC. *Statistical analysis of spike trains.*, in "Workshop School Chaos and Dynamics in Biological Networks", 2010.

[23] B. CESSAC, H. ROSTRO, J.-C. VASQUEZ, T. VIÉVILLE. *Statistics of spike trains: A dynamical systems perspective.*, in "Stochastic models in neuroscience", Marseille, 18-22 January 2010.

[24] B. CESSAC, J.-C. VASQUEZ, T. VIÉVILLE. *Statistical analysis of spike trains.*, in "Workshop on Spike Train Measures and Their Applications to Neural Coding", Plymouth, UK, 2-3 June 2010.

[25] O. FAUGERAS. *Fertilisations STIC/Neurosciences*, in "ITMO neurosciences : 1er colloque annuel", 2010.

[26] O. FAUGERAS. *From individual neurons to models of cortical areas: mean- field, neural masses and neural fields*, in "Ladislav Tauc Conferences and I.T.M.O. Neurosciences Joint Meeting: Multiscale Analysis of Neural Systems", February 2010.

[27] O. FAUGERAS. *Inter Spike Intervals probability distribution and Double Integral Processes*, in "CIRM Workshop, “Stochastic models in neuroscience”", January 2010.

[28] O. FAUGERAS. *Mathématiques de la perception visuelle des contours et des textures*, in "Maths pour l’image", April 2010.

[29] O. FAUGERAS. *Neural fields and visual texture perception*, in "AIMS Conference Spatially Structured Oscillations and Waves in Neural Media", 2010.

[30] O. FAUGERAS. *Neural fields and visual texture perception*, in "Progress in neural field theory", September 2010.

[31] O. FAUGERAS. *The geometries of shapes*, in "Mike Brady Research Symposium", 2010.

[32] O. FAUGERAS. *The Geometry of low-level Vision: Mathematics, Biological and Machine Vision*, in "11th European Conference on Computer Vision (ECCV2010)", 2010.

[33] O. FAUGERAS. *What do we learn from the uncertainty on the synaptic weights in networks of neurons?*, in "OCCAM Computational Neuroscience Workshop", Oxford, 2010.

International Peer-Reviewed Conference/Proceedings

[34] D. ENDRES, F. VINTILA, N. BRUCE, J. D. BOUECKE, P. KORNPROBST, H. NEUMANN, M. GIESE. *Hooligan detection: the effects of saliency and expert knowledge*, in "Perception ECVP", 2010, vol. 39, 193.

[35] G. FAYE, O. FAUGERAS. *New results for delayed neural field equations*, in "Proceedings of the fifth conference on Computational Neuroscience", 2010.

[36] K. MASMOUDI, M. ANTONINI, P. KORNPROBST. *Another look at the retina as an image dithered scalar quantizer*, in "Proceedings of the 11h International Workshop on Image Analysis for Multimedia Interactive Services (WIAMIS)", 2010, ftp://ftp-sop.inria.fr/neuromathcomp/publications/2010/masmoudi-antonini-etal:10b.pdf.

[37] K. MASMOUDI, M. ANTONINI, P. KORNPROBST. *Another look at the retina as an image scalar quantizer*, in "Proceedings of the International Symposium on Circuits and Systems (ISCAS)", 2010, ftp://ftp-sop.inria.fr/neuromathcomp/publications/2010/masmoudi-antonini-etal:10c.pdf.

[38] K. MASMOUDI, M. ANTONINI, P. KORNPROBST. *Encoding and decoding stimuli using a biologically realistic model: the non-determinism in spike timings seen as a dither signal*, in "Research in Encoding And Decoding of Neural Ensembles (AREADNE)", June 2010, 21, http://hal.inria.fr/hal-00481959.

[39] K. MASMOUDI, M. ANTONINI, P. KORNPROBST, L. PERRINET. *A novel bio-inspired static image compression scheme for noisy data transmission over low-bandwidth channels*, in "Proceedings of the 35th International Conference on Acoustics, Speech, and Signal Processing (ICASSP)", 2010, ftp://ftp-sop.inria.fr/neuromathcomp/publications/2010/masmoudi-antonini-etal:10.pdf.

[40] É. TLAPALE, P. KORNPROBST, J. D. BOUECKE, H. NEUMANN, G. S. MASSON. *Evaluating motion estimation models from behavioural and psychophysical data*, in "BIONETICS", 2010.

[41] J.-C. VASQUEZ, B. CESSAC, T. VIÉVILLE. *Entropy-based parametric estimation of spike train statistics*, in "Statistical Mechanics of Learning and Inference", 2010.

National Peer-Reviewed Conference/Proceedings

[42] B. CESSAC, H. NASSER, J.-C. VASQUEZ. *Spike trains statistics in Integrate and Fire Models: exact results*, in "Proceedings of the NeuroComp2010 Conference", 2010.

[43] H. ROSTRO-GONZALEZ, H. BARRON-ZAMBRANO, C. TORRES-HUITZIL, B. GIRAU. *Low-cost hardware implementations for discrete-time spiking neural networks*, in "Cinquième conférence française de Neurosciences Computationnelles - NeuroComp'10", 2010.

[44] J.-C. VASQUEZ, H. NASSER, A. PALACIOS, B. CESSAC, T. VIÉVILLE, H. ROSTRO-GONZALEZ. *Parametric estimation of Spike train statistics by Gibbs distributions : an application to bio-inspired and experimental data*, in "Proceedings of Neurocomp 2010", Lyon, France, 2010.

Workshops without Proceedings

[45] P. KORNPROBST, É. TLAPALE, J. D. BOUECKE, H. NEUMANN, G. S. MASSON. *A Bio-Inspired Evaluation Methodology for Motion Estimation*, in "VSS", 2010, http://www-sop.inria.fr/neuromathcomp/data/motionpsychobench/.

[46] É. TLAPALE, G. S. MASSON, P. KORNPROBST. *A dynamical neural model of motion integration*, in "VSS", 2010.

Research Reports

[47] G. FAYE, P. CHOSSAT, O. FAUGERAS. *Some theoretical results for a class of neural mass equations*, arXiv, May 2010, n^{o} arXiv:1005.0510v1, Submitted to SIADS., http://arxiv.org/abs/1005.0510v1.

[48] K. MASMOUDI, M. ANTONINI, P. KORNPROBST. *Spike based neural codes : towards a novel bio-inspired still image coding schema*, INRIA, 2010, n^{o} 7302, http://hal.archives-ouvertes.fr/inria-00487034/fr/.

[49] É. TLAPALE, P. KORNPROBST, J. D. BOUECKE, H. NEUMANN, G. S. MASSON. *Towards a bio-inspired evaluation methodology for motion estimation models*, INRIA, June 2010, n^{o} RR-7317, http://hal.inria.fr/inria-00492001/PDF/RR-7317.pdf.

[50] É. TLAPALE, P. KORNPROBST, G. S. MASSON, J. D. BOUECKE, H. NEUMANN. *Bio-inspired motion estimation – From modelling to evaluation, can biology be a source of inspiration?*, INRIA, November 2010, n^{o} 7447, http://hal.inria.fr/inria-00532894/fr/.

[51] R. VELTZ, O. FAUGERAS. *Illusions in the Ring Model of visual orientation selectivity*, arXiv, 2010, Submitted to Plos Comp Bio., http://arxiv.org/abs/1007.2493.

Other Publications

[52] H. NASSER. *Parameter Tuning in virtual retina using Gibbs distribution*, Master of Computational Biology, Ecole Polytechnique Universitaire de Nice, 2010.

References in notes

[53] P. BRESSLOFF, J. COWAN, M. GOLUBITSKY, P. THOMAS, M. WIENER. *Geometric visual hallucinations, Euclidean symmetry and the functional architecture of striate cortex*, in "Phil. Trans. R. Soc. Lond. B", March 2001, vol. 306, n^o 1407, p. 299–330, http://dx.doi.org/doi:10.1098/rstb.2000.0769.

[54] R. BRETTE, M. RUDOLPH, T. CARNEVALE, M. HINES, D. BEEMAN, J. M. BOWER, M. DIESMANN, A. MORRISON, P. H. GOODMAN, F. C. JR. HARRIS, M. ZIRPE, T. NATSCHLÄGER, D. PECEVSKI, G. B. ERMENTROUT, M. DJURFELDT, A. LANSNER, O. ROCHEL, T. VIÉVILLE, E. MULLER, A. P. DAVISON, S. E. BOUSTANI, A. DESTEXHE. *Simulation of networks of spiking neurons: a review of tools and strategies*, in "Journal of Computational Neuroscience", 2007, vol. 23, n^o 3, p. 349–398.

[55] B. CESSAC. *Does the complex susceptibility of the Hénon map have a pole in the upper-half plane ? A numerical investigation.*, in "Nonlinearity", December 2007, vol. 20, p. 2883–2895.

[56] P. CHOSSAT, O. FAUGERAS. *Hyperbolic planforms in relation to visual edges and textures perception*, in "Plos Comput Biol", December 2009, vol. 5, n^o 12, e1000625, http://dx.doi.org/doi:10.1371/journal.pcbi.1000625.

[57] G. B. ERMENTROUT, D. TERMAN. *Foundations Of Mathematical Neuroscience*, Interdisciplinary Applied Mathematics, Springer, 2010.

[58] M.-J. ESCOBAR. *Bio-Inspired Models for Motion Estimation and Analysis: Human action recognition and motion integration*, Université de Nice Sophia-Antipolis, 2009, ftp://ftp-sop.inria.fr/neuromathcomp/publications/phds/escobar:09.pdf.

[59] M.-J. ESCOBAR, G. S. MASSON, T. VIÉVILLE, P. KORNPROBST. *Action Recognition Using a Bio-Inspired Feedforward Spiking Network*, in "International Journal of Computer Vision", 2009, vol. 82, n^o 3, 284, ftp://ftp-sop.inria.fr/neuromathcomp/publications/2009/escobar-masson-etal:09.pdf.

[60] T. GOLLISCH, M. MEISTER. *Eye smarter than scientists believed: neural computations in circuits of the retina*, in "Neuron", January 2010, vol. 65, n^o 2, p. 150–164, http://dx.doi.org/doi:10.1016/j.neuron.2009.12.009.

[61] A. GUIONNET. *Averaged and quenched propagation of chaos for spin glass dynamics*, in "Probability Theory and Related Fields", 1997, vol. 109, n^o 2, p. 183–215.

[62] B. H. JANSEN, V. G. RIT. *Electroencephalogram and visual evoked potential generation in a mathematical model of coupled cortical columns*, in "Biological Cybernetics", 1995, vol. 73, p. 357–366.

[63] H. ROSTRO-GONZALEZ, B. CESSAC, T. VIÉVILLE. *Exact spike-train reproduction with a neural network model*, in "Journal of Computational Neuroscience", 2010, submitted, http://arxiv.org/abs/0905.4810.

[64] H. ROSTRO-GONZALEZ, J.-C. VASQUEZ, B. CESSAC, T. VIÉVILLE. *Reverse-engineering in spiking neural networks parameters: exact deterministic parameters estimation*, INRIA, 2010, RR-7199.

[65] O. SHRIKI, D. HANSEL, H. SOMPOLINSKY. *Rate models for conductance-based cortical neuronal networks*, in "Neural Computation", 2003, vol. 15, n^{o} 8, p. 1809–1841.

[66] T. TAILLEFUMIER, J. TOUBOUL. *Multi-Resolution Schauder Approach to Multidimensional Gauss-Markov Processes*, in "Arxiv preprint arXiv:1009.0533", 2010.

[67] É. TLAPALE, P. KORNPROBST, G. S. MASSON, J. D. BOUECKE, H. NEUMANN. *Bio-inspired motion estimation – From modelling to evaluation, can biology be a source of inspiration?*, INRIA, November 2010, n^{o} 7447, http://hal.inria.fr/inria-00532894/fr/.

[68] J. TOUBOUL, G. B. ERMENTROUT. *Finite-size and correlation-induced effects in Mean-field Dynamics*, in "Arxiv preprint arXiv:1008.2839", 2010, http://arxiv.org/abs/1008.2839.

[69] J. TOUBOUL, F. WENDLING, P. CHAUVEL, O. FAUGERAS. *Neural Mass Activity, Bifurcations and Epilepsy*, in "(Submitted)", 2010.

[70] J.-C. VASQUEZ, T. VIÉVILLE, B. CESSAC. *Entropy-based parametric estimation of spike train statistics*, in "Journal of Computational Neuroscience", 2010, submitted, http://arxiv.org/abs/1003.3157.

[71] A. WOHRER, P. KORNPROBST. *Virtual Retina : A biological retina model and simulator, with contrast gain control*, in "Journal of Computational Neuroscience", 2009, vol. 26, n^{o} 2, 219, DOI 10.1007/s10827-008-0108-4.

[72] A. WOHRER. *Mathematical study of a neural gain control mechanism*, INRIA, 2007, n^{o} 6327.

[73] A. WOHRER. *Model and large-scale simulator of a biological retina with contrast gain control*, University of Nice Sophia-Antipolis, 2008.

[74] A. WOHRER. *The vertebrate retina: A functional review*, INRIA, May 2008, n^{o} 6532.