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Activity Report 2012

Project-Team NEUROMATHCOMP

Mathematical and Computational Neuroscience

IN COLLABORATION WITH: Laboratoire Jean-Alexandre Dieudonné (JAD)

RESEARCH CENTER
Sophia Antipolis - Méditerranée

THEME
Computational Medicine and Neurosciences

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Project-Team NEUROMATHCOMP

Keywords: Computational Neurosciences, Neural Network, Network Dynamics, Stochastic Methods, Stochastic Modeling

Creation of the Project-Team: January 01, 2009 .

1. Members

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Pascal Chossat [CNRS Senior Researcher (DR), HdR]
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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.

Modelling 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 main areas:

1. Neural networks dynamics
2. Mean-field approaches
3. Neural fields
4. Spike train statistics
5. Synaptic plasticity
6. Visual neuroscience
7. Neuromorphic vision

2.2. Highlights of the Year

1. **Organisation of the Workshop on Biological and Computer Vision Interfaces in Firenze October 12, 2012, held in conjunction with ECCV 2012.** This workshop was organised by Olivier Faugeras and Pierre Kornprobst. This workshop was a one-day event with prestigious invited speakers discussing several aspects of biological and computer vision interfaces, namely biological vision, mathematical and computational paradigms for biological and human vision, computational and hardware models of the visual brain and bio-inspired methods for computer vision. More information is available at http://www-sop.inria.fr/manifestations/wbcvi2012/index.shtml
2. **Organisation of the workshop NeuroComp/KEOpS'12, Bordeaux, 10-11 October 2012.** This workshop was joinly organized by F. Alexandre and T. Viéville (Mnemosyne), B. Cessac (Neuromathcomp), A. Palacios and M.J. Escobar (CN Valparaiso). It addressed the following issues (i) neural population dynamics and coding; (ii) architecture (and information flow) at the retinal and the brain level. The workshop was a two days event involving speakers in the field of vision and cognition, robotics, retina healthcare and prosthesis, and dynamical systems modeling. More information is available at http://neurocomp.risc.cnrs.fr/neurocomp-2012/index.php?page=1.
3. **European Union project "MATHEMACS" accepted.** The MATHEMACS project aims to develop a mathematical theory of complex multi-level systems and their dynamics. This is done through a general formulation based on the mathematical tools of information and dynamical systems theories. To ensure that the theoretical framework is at the same time practically applicable, three key application areas are represented within the project, namely neurobiology, human communication, and economics. These areas not only provide some of the best-known epitomes of complex multi-level systems, but also constitute a challenging test bed for validating the generality of the theory since they span a vast range of spatial and temporal scales. Furthermore, they have an important common aspect; namely, their complexity and self-organizational character is partly due to the anticipatory and predictive actions of their constituent units. The MATHEMACS project contends that the concepts of anticipation and prediction are particularly relevant for multi-level systems since they often involve different levels. Thus, as a further unique feature, the project includes the mathematical representation and modeling of anticipation in its agenda for understanding complex multi-level systems.

4. **European Union project "RENVISION" accepted.** RENVISION's goal is twofold: i) to achieve a comprehensive understanding of how the retina encodes visual information through the different cellular layers; ii) to use such insights to develop a retina-inspired computational approach to high-level computer vision tasks. By exploiting the integration of recent advances in high-resolution light microscopy, 3D imaging and high-density multielectrode array technologies, RENVISION will be in an unprecedented position to investigate pan-retinal signal processing at high spatiotemporal resolution, allowing simultaneous recording from the entire population of ganglion cells and functional imaging of inner retinal layers at near-cellular resolution, combined with 3D structural imaging of the whole inner retina. The combined analysis of these complex datasets will require the development of novel multimodal analysis methods. Resting on these neuroscientific and computational grounds, RENVISION will generate new knowledge on retinal processing. It will provide advanced pattern recognition and machine learning technologies to ICTs by shedding a new light on how the output of retinal processing (natural, modelled) solves complex vision tasks such as automated scene categorization and action recognition.

3. Scientific Foundations

3.1. Neural networks dynamics

The study of neural networks is certainly motivated by the dream to understand how brain is working. But, beyond the comprehension of brain or even of simpler neural systems in less evolved animals, there is also the desire to exhibit general mechanisms or principles at work in the nervous system. One possible strategy is to propose mathematical models of neural activity, at different space and time scales, depending on the type of phenomena under consideration. However, beyond the mere proposal of new models, which can rapidly result in a plethora, there is also a need to understand some fundamental keys ruling the behaviour of neural networks, and, from this, to extract new ideas that can be tested in real experiments. Therefore, there is a need to make a thorough analysis of these models. An efficient approach, developed in our team, consists of analysing neural networks as dynamical systems. This allows to address several issues. A first, natural issue is to ask about the (generic) dynamics exhibited by the system when control parameters vary. This naturally leads to analyse the bifurcations occurring in the network and which phenomenological parameters control these bifurcations. Another issue concerns the interplay between neuron dynamics and synaptic network structure.

In this spirit, our team has been able to characterize the generic dynamics exhibited by models such as conductance-based Integrate and Fire models [2], [64], [65], models of epilepsy [77], effects of synaptic plasticity (see the corresponding section below).
Selected publications on this topic.

3.2. Mean-field approaches

Modelling neural activity at scales integrating the effect of thousands of neurons is of central importance for several reasons. First, most imaging techniques are not able to measure individual neuron activity ("microscopic" scale), but are instead measuring mesoscopic effects resulting from the activity of several hundreds to several hundreds of thousands of neurons. Second, anatomical data recorded in the cortex reveal the existence of structures, such as the cortical columns, with a diameter of about 50μm to 1mm, containing of the order of one hundred to one hundred thousand neurons belonging to a few different species. The description of this collective dynamics requires models which are different from individual neurons models. In particular, when the number of neurons is large enough averaging effects appear, and the collective dynamics is well described by an effective mean-field, summarizing the effect of the interactions of a neuron with the other neurons, and depending on a few effective control parameters. This vision, inherited from statistical physics requires that the space scale be large enough to include a large number of microscopic components (here neurons) and small enough so that the region considered is homogeneous.

Our group is developing mathematical and numerical methods allowing on one hand to produce dynamic mean-field equations from the physiological characteristics of neural structure (neurons type, synapse type and anatomical connectivity between neurons populations), and on the other so simulate those equations. Our investigations have shown that the rigorous dynamics mean-field equations can have a quite more complex structure than the ones commonly used in the literature (e.g. Jansen-Rit, 95) as soon as realistic effects such as synaptic variability are taken into account. Our goal is to relate those theoretical results with experimental measurement, especially in the field of optical imaging. For this we are collaborating with the DYVA team at INT, Marseille.
Selected publications on this topic.

3.3. Neural fields

Neural fields are a phenomenological way of describing the activity of population of neurons by delay integrodifferential equations. This continuous approximation turns out to be very useful to model large brain areas such as those involved in visual perception. The mathematical properties of these equations and their solutions are still imperfectly known, in particular in the presence of different time scales and of noise.
Selected publications on this topic.

3.4. Spike train statistics

The neuronal activity is manifested by the emission of action potentials ("spikes") constituting spike trains. Those spike trains are usually not exactly reproducible when repeating the same experiment, even with a very good control ensuring that experimental conditions have not changed. Therefore, researchers are seeking models for spike train statistics, assumed to be characterized by a hidden probability giving the statistics of spatio-temporal spike patterns. A current goal in experimental analysis of spike trains is to approximate this probability from data. Several approach exist either based on (i) generic principles (maximum likelihood, maximum entropy); (ii) phenomenological models (Linear-Non linear, Generalized Linear Model, mean-field); (iii) Analytical results on spike train statistics in Neural Network models.

Our group is working on those 3 aspects, on a fundamental and on a practical (numerical) level. On one hand, we have published analytical (and rigorous) results on statistics of spike trains in canonical neural network models (Integrate and Fire, conductance based with chemical and electric synapses) [3],[13], [63] . The main result is the characterization of spike train statistics by a Gibbs distribution whose potential can be explicitly computed using some approximations. Note that this result does not require an assumption of stationarity. We have also shown that the distributions considered in the cases (i), (ii), (iii) above are all Gibbs distributions [43], [12]. On the other hand we are proposing new algorithms for data processing [22]. We have developed a C++ software for spike train statistics based on Gibbs distributions analysis and freely available at http://enas.gforge.inria.fr/v3/. We are using this software in collaboration with several biologist groups involved in the analysis of retina spike trains (Centro de Neurociencia Valparaiso; Molecular Biology Lab, Princeton; Institut de la vision, Paris) [26], [22], [55].
Selected publications on this topic.

3.5. Synaptic Plasticity

Neural networks show amazing abilities for information storage and processing, and stimulus-dependent activity shaping, to evolve and adapt. These capabilities are mainly conditioned by plasticity mechanisms, and especially synaptic plasticity, inducing a mutual coupling between network structure and neuron dynamics. Synaptic plasticity occurs at many levels of organization and time scales in the nervous system (Bienenstock, Cooper, and Munroe, 1982). It is of course involved in memory and learning mechanisms, but it also alters excitability of brain areas and regulates behavioural states (e.g. transition between sleep and wakeful activity). Therefore, understanding the effects of synaptic plasticity on neurons dynamics is a crucial challenge. On experimental grounds, different synaptic plasticity mechanisms have been exhibited from the Hebbian's ones (Hebb, 1949) to Long Term Potentiation (LTP) and Long Term Depression (LTD), and more recently to Spike

Time Dependent Plasticity (STDP) (Markram, Lubke, Frotscher, and Sakmann, 1997; Bi and Poo, 2001). Synaptic plasticity implies that activity guides the way synapses evolve; but the resulting connectivity structure in turn can raise new dynamical regimes. This interaction becomes even more complex if the considered basic architecture is not feed-forward but includes recurrent synaptic links, like in cortical structures. Understanding this mutual coupling between dynamics and topology and its effects on the computations made by the network is a key problem in computational neuroscience.

Our group is developing mathematical and numerical methods to analyse this mutual interaction. Especially, we have shown that plasticity mechanisms, Hebbian-like or STDP, have strong effects on neuron dynamics complexity, such as dynamics complexity reduction, and spike statistics (convergence to a specific Gibbs distribution via a variational principle), resulting in a response-adaptation of the network to learned stimuli [73], [74],[4]. Also, we are currently studying the conjugated effects of synaptic and intrinsic plasticity in collaboration with H. Berry (Inria Beagle) and B. Delord, J. Naudé, ISIR team, Paris.

Selected publications on this topic.

3.6. Visual neuroscience

Our group focuses on the visual system to understand how information is encoded and processed resulting in visual percepts. To do so, we propose functional models of the visual system using a variety of mathematical formalisms, depending on the scale at which models are built, such as spiking neural networks or neural fields. So far, our efforts have been mainly focused on the study of retinal processing and motion integration at the level of V1 and MT cortical areas.

At the retina level, we are modelling its circuitry [6] and we are studying the statistics of the spike train output (see, e.g., the software ENAS http://enas.gforge.inria.fr/v3/). Real cell recordings are also analysed in collaboration with Institut de la Vision (Paris). At the level of V1-MT cortical areas, we are investigating the temporal dynamics of motion integration for a wide range of visual stimuli [38], [41], [23], [39], [42] [75], [62][5]. This work is done in collaboration with Institut de Neuroscience de la Timone (Marseille).

Selected publications on this topic.

3.7. Neuromorphic vision

From the simplest vision architectures in insects to the extremely complex cortical hierarchy in primates, it is fascinating to observe how biology has found efficient solutions to solve vision problems. Pioneers in computer vision had this dream to build machines that could match and perhaps outperform human vision. This goal has not been reached, at least not on the scale that was originally planned, but the field of computer vision has met many other challenges from an unexpected variety of applications and fostered entirely new scientific and technological areas such as computer graphics and medical image analysis. However, modelling and emulating with computers biological vision largely remains an open challenge while there are still many outstanding issues in computer vision.

Our group is working on neuromorphic vision by proposing bio-inspired methods following our progress in visual neuroscience. Our goal is to bridge the gap between biological and computer vision, by applying our visual neuroscience models to challenging problems from computer vision such as optical flow estimation [76], coding/decoding approaches [20], [21], [37] [69], [68] or classification [14] [66].

Selected publications on this topic.

4. Software

4.1. Virtual Retina: A Large-Scale Simulator of Biological Retina

Participants: Bruno Cessac, Maria-Jose Escobar [Universidad Técnica Federico Santa María, Valparaiso, Chile], Christobal Nettle [Universidad Técnica Federico Santa María, Valparaiso, Chile], Pierre Kornprobst [correspondent], Adrien Wohrer [Group for Neural Theory - ENS, Paris, France].

Virtual Retina is a simulation software developped by Adrien Wohrer during his PhD [79], [78] that allows large-scale simulations of biologically-plausible retinas.

Virtual Retina has a variety of biological features implemented such as (i) spatio-temporal linear filter implementing the basic center/surround organization of retinal filtering, (ii) non-linear contrast gain control mechanism providing instantaneous adaptation to the local level of contrast; (iii) spike generation by one or several layers of ganglion cells paving the visual field.

Virtual Retina is under Inria CeCill C open-source licence, so that one can download it, install it and run it on one's own sequences. Virtual Retina also offers a web service (v 2.1), so that users may test directly the main software on their own data, without any installation. This webservice was developed in collaboration with Nicolas Debeissat (engineer, 2002).

We are now interested in the analysis of the collective behavior of ganglion cells responses. To take this collective behavior into account, Virtual Retina needs to be extended since in its current version, ganglion cells are independent. Other evolutions of Virtual Retina are also investigated by external partners like the role/implementation of starbust amacrine cells involved in direction selectivity (collaboration with Universidad Técnica Federico Santa María, Valparaiso, Chile, and Centro de urociencia de Valaparaiso) (see also e.g., [70]).

- IDDN number: IDDN.FR.001.210034.000.S.P.2007.000.31235
- Version: v 2.2.2 (September 2011)
- Link: http://www-sop.inria.fr/neuromathcomp/public/software/virtualretina

4.2. Event Neural Assembly Simulation

Participants: Bruno Cessac [correspondent], Sélim Kraria [Inria DREAM], Olivier Marre [Institut de la vision, Paris], Hassan Nasser, Thierry Viéville [Inria Mnemosyne Bordeaux].

Enas 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, Matlab or the Scilab platform).
- Original modules for the analysis of spike train statistics intended 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 allows 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;
- Discrete 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 present purpose. This is done with the support of an ADT Inria.

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

5. New Results

5.1. Neural Networks as dynamical systems

5.1.1. Dynamics and spike trains statistics in conductance-based Integrate-and-Fire neural networks with chemical and electric synapses

Participants: Rodrigo Cofré, Bruno Cessac [correspondent].

We investigate the effect of electric synapses (gap junctions) on collective neuronal dynamics and spike statistics in a conductance-based Integrate-and-Fire neural network, driven by a Brownian noise, where conductances depend upon spike history. We compute explicitly the time evolution operator and show that, given the spike-history of the network and the membrane potentials at a given time, the further dynamical evolution can be written in a closed form. We show that spike train statistics is described by a Gibbs distribution whose potential can be approximated with an explicit formula, when the noise is weak. This potential form encompasses existing models for spike trains statistics analysis such as maximum entropy models or Generalized Linear Models (GLM). We also discuss the different types of correlations: those induced by a shared stimulus and those induced by neurons interactions. This work has been presented in several conferences [43], [45], [46], [47], [31], [48] and submitted to Chaos, Solitons and Fractals [13].

5.1.2. Parameter estimation in spiking neural networks: a reverse-engineering approach

Participants: Horacio Rostro-Gonzalez [Holistic Electronics Research Lab, University of Cyprus], Bruno Cessac [correspondent], Thierry Viéville [Inria Mnemosyne].

This work presents a reverse engineering approach for parameter estimation in spiking neural networks (SNNs). We consider the deterministic evolution of a time-discretized network with spiking neurons, where synaptic transmission has delays, modeled as a neural network of the generalized integrate and fire type. Our approach aims at by-passing the fact that the parameter estimation in SNN results in a non-deterministic polynomial-time hard problem when delays are to be considered. Here, this assumption has been reformulated as a linear programming (LP) problem in order to perform the solution in a polynomial time. Besides, the LP problem formulation makes explicit the fact that the reverse engineering of a neural network can be performed from the observation of the spike times. Furthermore, we point out how the LP adjustment mechanism is local to each neuron and has the same structure as a 'Hebbian' rule. Finally, we present a generalization of this approach to the design of input–output (I/O) transformations as 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. Numerical verifications and illustrations are provided. This work has been published in Journal of Neural Engineering [24].

5.2. Mean field approaches

5.2.1. Noise-induced behaviors in neural mean field dynamics

Participants: Olivier Faugeras [correspondent], Geoffroy Hermann, Jonathan Touboul [Inria Bang].

The collective behavior of cortical neurons is strongly affected by the presence of noise at the level of individual cells. In order to study these phenomena in large-scale assemblies of neurons, we consider networks of firing-rate neurons with linear intrinsic dynamics and nonlinear coupling, belonging to a few types of cell populations and receiving noisy currents. Asymptotic equations as the number of neurons tends to infinity (mean field equations) are rigorously derived based on a probabilistic approach. These equations are implicit on the probability distribution of the solutions which generally makes their direct analysis difficult. However, in our case, the solutions are Gaussian, and their moments satisfy a closed system of nonlinear ordinary differential equations (ODEs), which are much easier to study than the original stochastic network equations, and the statistics of the empirical process uniformly converge towards the solutions of these ODEs. Based on this description, we analytically and numerically study the influence of noise on the collective behaviors, and compare these asymptotic regimes to simulations of the network. We observe that the mean field equations provide an accurate description of the solutions of the network equations for network sizes as small as a few hundreds of neurons. In particular, we observe that the level of noise in the system qualitatively modifies its collective behavior, producing for instance synchronized oscillations of the whole network, desynchronization of oscillating regimes, and stabilization or destabilization of stationary solutions. These results shed a new light on the role of noise in shaping collective dynamics of neurons, and gives us clues for understanding similar phenomena observed in biological networks. This work has been published in the SIAM Journal on Applied dynamical Systems [25].

5.2.2. Mean-field description and propagation of chaos in networks of Hodgkin-Huxley neurons

Participants: Javier Baladron, Diego Fasoli, Olivier Faugeras [correspondent], Jonathan Touboul [Inria Bang].

We derive the mean-field equations arising as the limit of a network of interacting spiking neurons, as the number of neurons goes to infinity. The neurons belong to a fixed number of populations and are represented either by the Hodgkin-Huxley model or by one of its simplified version, the FitzHugh-Nagumo model. The synapses between neurons are either electrical or chemical. The network is assumed to be fully connected. The maximum conductances vary randomly. Under the condition that all neurons' initial conditions are drawn independently from the same law that depends only on the population they belong to, we prove that a propagation of chaos phenomenon takes place, namely that in the mean-field limit, any finite number of neurons become independent and, within each population, have the same probability distribution. This probability distribution is a solution of a set of implicit equations, either nonlinear stochastic differential equations resembling the McKean-Vlasov equations or non-local partial differential equations resembling the McKean-Vlasov-Fokker-Planck equations. We prove the well posedness of the McKean-Vlasov equations, i.e. the existence and uniqueness of a solution. We also show the results of some numerical experiments that indicate that the mean-field equations are a good representation of the mean activity of a finite size network, even for modest sizes. These experiments also indicate that the McKean-Vlasov-Fokker-Planck equations may be a good way to understand the mean-field dynamics through, e.g. a bifurcation analysis. This work has appeared in the Journal of Mathematical Neuroscience [11].

5.3. Neural fields theory

5.3.1. Localized radial bumps of a neural field equation on the Euclidean plane and the Poincaré disk

Participants: Grégory Faye [correspondent], James Rankin, David, J.B. Lloyd [Department of Mathematics at the University of Surrey].

We analyze radially symmetric localized bump solutions of an integro-differential neural field equation posed in Euclidean and hyperbolic geometry. The connectivity function and the nonlinear firing rate function are chosen such that radial spatial dynamics can be considered. Using integral transforms, we derive a PDE for the neural field equation in both geometries and then prove the existence of small amplitude radially symmetric spots bifurcating from the trivial state. Numerical continuation is then used to path-follow the spots and their bifurcations away from onset in parameter space. It is found that the radial bumps in Euclidean geometry are linearly stable in a larger parameter region than bumps in the hyperbolic geometry. We also find and path-follow localized structures that bifurcate from branches of radially symmetric solutions with D6-symmetry and D8-symmetry in the Euclidean and hyperbolic cases, respectively. Finally, we discuss the applications of our results in the context of neural field models of short term memory and edges and textures selectivity in a hypercolumn of the visual cortex. This work has been accepted for publication in Nonlinearity [57].

5.3.2. Center manifold for delayed neural fields equations

Participants: Olivier Faugeras [correspondent], Romain Veltz [Salk Institute,San Diego,USA].

We develop a framework for the study of delayed neural fields equations and prove a center manifold theorem for these equations. Specific properties of delayed neural fields equations make it impossible to apply existing methods from the literature concerning center manifold results for functional differential equations. Our approach for the proof of the center manifold theorem uses the original combination of results from Vanderbauwhede and colleagues together with a theory of linear functional differential equations in a history space larger than the commonly used set of time-continuous functions. This work has been submitted to the SIAM Journal on Applied Mathematics and is under revision [27].

5.3.3. Reduction method for localized solutions

Participant: Grégory Faye [correspondent].

We present a reduction method to study localized solutions of an integrodifferential equation defined on the Poincaré disk. This equation arises in a problem of texture perception modeling in the visual cortex. We first derive a partial differential equation which is equivalent to the initial integrodifferential equation and then deduce that localized solutions which are radially symmetric satisfy a fourth order ordinary differential equation. This work has appeared in the “Comptes Rendus Mathematique” [15].

5.3.4. Spatially localized solutions

Participants: Pascal Chossat, Grégory Faye [School of Mathematics,University of Minnesota, correspondent], James Rankin.

The existence of spatially localized solutions in neural networks is an important topic in neuroscience as these solutions are considered to characterize working (short-term) memory. We work with an unbounded neural network represented by the neural field equation with smooth firing rate function and a wizard hat spatial connectivity. Noting that stationary solutions of our neural field equation are equivalent to homoclinic orbits in a related fourth order ordinary differential equation, we apply normal form theory for a reversible Hopf bifurcation to prove the existence of localized solutions; further, we present results concerning their stability. Numerical continuation is used to compute branches of localized solution that exhibit snaking-type behaviour. We describe in terms of three parameters the exact regions for which localized solutions persist. This work has appeared in the Journal of Mathematical Biology [16].

5.3.5. Bumps in the Poincaré disk

Participants: Grégory Faye [School of Mathematics,University of Minnesota, correspondent], David, J.B. Loyd, James Rankin.

We analyze radially symmetric localized bump solutions of an integro-differential neural field equation posed in Euclidean and hyperbolic geometry. The connectivity function and the nonlinear firing rate function are chosen such that radial spatial dynamics can be applied. Using integral transforms, we derive a PDE of the neural field equation in both geometries and then prove the existence of small amplitude radially symmetric spots bifurcating from the trivial state. Numerical continuation is then used to path-follow the spots and their bifurcations away from onset in parameter space. It is found that the radial bumps in Euclidean geometry are linearly stable in a larger parameter region than bumps in the hyperbolic geometry. We also find and path follow localized structures that bifurcate from branches of radially symmetric solutions with D6-symmetry and D8-symmetry in the Euclidean and hyperbolic cases, respectively. Finally, we discuss the applications of our results in the context of neural field models of short term memory and edges and textures selectivity in a hypercolumn of the visual cortex. This work has been submitted to Nonlinearity.

5.4. Spike trains statistics

5.4.1. Natural image identification from spike train analysis

Participants: Geoffrey Portelli, Olivier Marre [Institution de la Vision, Paris, France], Marc Antonini [Laboratoire I3S, UMR CNRS, Universite´ Nice Sophia Antipolis, France], Michael Berry II [Princeton Neuroscience Institute, Department of Molecular Biology, Princeton University, Princeton, NJ 08544, USA], Pierre Kornprobst [correspondent].

We started a new activity to analyse how natural images are encoded in retinal output. This work is related to [67], [72] where synthetic stimuli are used. Here, we recorded a population of 100-200 ganglion cells of a salamander retina, while flashing 720 natural images from the Torralba database [71] plus one control image, each repeated 10 times. We characterized the response of each cell by two parameters : the latency of the first spike after the stimulus onset, and the firing rate. A distribution of these two features was then estimated for each neuron and natural image. Pooling the information across all the neurons, a discriminability coefficient between pairs of image is proposed, using either the rate or the latency, or both. We also provide a way to identify a given image among others based on the rate–latency distributions. Preliminary results have been presented in [40]. Results showed that, on average, the discriminability was better based on the latency than on the rate. The most discriminable pairs were different using the rate or the latency, so these two features conveyed complementary information. In addition, we observe a similar evolution of the identification performance when the rate, or the latency, or both are used.

5.4.2. Spike train statistics from empirical facts to theory: the case of the retina

Participants: Bruno Cessac [correspondent], Adrian Palacios [CINV-Centro Interdisciplinario de Neurociencia de Valparaiso, Universidad de Valparaiso].

This work focuses on methods from statistical physics and probability theory allowing the analysis of spike trains in neural networks. Taking as an example the retina we present recent works attempting to understand how retina ganglion cells encode the information transmitted to the visual cortex via the optical nerve, by analyzing their spike train statistics. We compare the maximal entropy models used in the literature of retina spike train analysis to rigorous results establishing the exact form of spike train statistics in conductance-based Integrate-and-Fire neural networks. This work has been published in Mathematical Problems in Computational Biology and Biomedicine, F. Cazals and P. Kornprobst, Springer [55].

5.4.3. Gibbs distribution analysis of temporal correlations structure in retina ganglion cells

Participants: Juan-Carlos Vasquez, Olivier Marre [Institution de la Vision, Paris, France], Adrian Palacios [CINV-Centro Interdisciplinario de Neurociencia de Valparaiso, Universidad de Valparaiso], Michael Berry II [Princeton Neuroscience Institute, Department of Molecular Biology, Princeton University, Princeton, NJ 08544, USA], Bruno Cessac [correspondent].

We present a method to estimate Gibbs distributions with spatio-temporal constraints on spike trains statistics. We apply this method to spike trains recorded from ganglion cells of the salamander retina, in response to natural movies. Our analysis, restricted to a few neurons, performs more accurately than pairwise synchronization models (Ising) or the 1-time step Markov models (Marre et al. (2009)) to describe the statistics of spatio-temporal spike patterns and emphasizes the role of higher order spatio-temporal interactions. This work has been presented in several conferences [29], [30], [28] and pusblished in J. Physiol. Paris [26].

5.4.4. Spatio-temporal spike trains analysis for large scale networks using maximum entropy principle and Monte-Carlo method

Participants: Hassan Nasser, Olivier Marre [Institut de la Vision, Paris, France], Bruno Cessac [correspondent].

Understanding the dynamics of neural networks is a major challenge in experimental neuroscience. For that purpose, a modelling of the recorded activity that reproduces the main statistics of the data is required. We present a review on recent results dealing with spike train statistics analysis using maximum entropy models (MaxEnt). Most of these studies have been focusing on modelling synchronous spike patterns, leaving aside the temporal dynamics of the neural activity. However, the maximum entropy principle can be generalized to the temporal case, leading to Markovian models where memory effects and time correlations in the dynamics are properly taken into account. We also present a new method based on Monte-Carlo sampling which is suited for the fitting of large-scale spatio-temporal MaxEnt models. The formalism and the tools presented here will be essential to fit MaxEnt spatio-temporal models to large neural ensembles. This work has been presented in several conferences [54], [51], [53], [52] and accepted in Journal of Statistical Mechanics [22].

5.4.5. Spike train statistics and Gibbs distributions

Participants: Rodrigo Cofré, Bruno Cessac [correspondent].

We introduce Gibbs distribution in a general setting, including non stationary dynamics, and present then three examples of such Gibbs distributions, in the context of neural networks spike train statistics: (i) Maximum entropy model with spatio-temporal constraints; (ii) Generalized Linear Models; (iii) Conductance based Inte- grate and Fire model with chemical synapses and gap junctions. This leads us to argue that Gibbs distributions might be canonical models for spike train statistics analysis. This work has been presented in several conferences [43], [31] and submitted to J. Physiol. Paris [12].

5.5. Visual Neuroscience

5.5.1. Neural fields models for motion integration: Characterising the dynamics of multi-stable visual motion stimuli

Participants: Olivier Faugeras, Pierre Kornprobst, Guillaume S. Masson [Institut de Neurosciences de la Timone, UMR 6193, CNRS, Marseille, France], Andrew Meso [Institut de Neurosciences de la Timone, UMR 6193, CNRS, Marseille, France], James Rankin.

We are investigating the temporal dynamics of the neural processing of a multi-stable visual motion stimulus with two complementary approaches: psychophysical experiments and mathematical modelling. The so called “barber pole” stimulus is considered with an aperture configuration that supports horizontal (H), diagonal (D) or vertical (V) perceived directions for the same input. The phenomenon demonstrates an interesting variable and dynamic competition for perceptual dominance between underlying neural representations of the three directions. We study the temporal dynamics of this phenomenon with a neural fields, population-level representation of activity in MT, a cortical area dedicated to motion estimation. Numerical tools from bifurcation analysis are used to investigate the model’s behaviour in the presence of different types of input; this general approach could be applied to a range of neural fields models that are typically studied only in terms of their spontaneous activity. The model reproduces known multistable behaviour in terms of the predominant interpretations (percepts) of the barber pole stimulus.

We probe the early processing from stimulus presentation to initial perceived direction (before perceptual reversals). The basic dynamic properties of the early transition from D to H/V are well predicted by the model. This work has been presented in the European Conference on Vision Perception (ECVP) [38], [41] and it has been published in [23].

We are extending this work to investigate the longer term dynamics for which perceptual reversals are known to occur, due to competition between 1D motion cues aligned with the grating's motion direction and 2D motion cues aligned with aperture edges. This work has been presented in the Vision Sciences Society 12th Annual Meeting (VSS) [39], [42].

5.6. Neuromorphic Vision

Participants: Khaled Masmoudi [Laboratoire I3S, UMR CNRS, Universite´ Nice Sophia Antipolis, France], Marc Antonini [Laboratoire I3S, UMR CNRS, Universite´ Nice Sophia Antipolis, France], Pierre Kornprobst.

In the scope of Khaled Masmoudi's PhD [9], we have developed bio-inspired schemes for image coding. This is a new area of research on which very few teams are committed. We have proposed schemes for encoding/decoding images directly using the functional architecture of the retina and the properties of its spiking output (e.g., using Laplacian pyramids model and the rank-order coding [69], [68][20], [21] and the Virtual Retina simulator [37] from Adrien Wohrer during his PhD [79], [78]).

6. Partnerships and Cooperations

6.1. National Initiatives

6.1.1. ANR

6.1.1.1. KEOPS

See section "International Initiatives" below.

6.2. European Initiatives

6.2.1. FP7 Projects

6.2.1.1. BRAINSCALES

Title: BrainScaleS: Brain-inspired multiscale computation in neuromorphic hybrid systems

Type: COOPERATION (ICT)

Defi: Brain-inspired multiscale computation in neuromorphic hybrid systems

Instrument: Integrated Project (IP)

Duration: January 2011 - December 2014

Coordinator: Universitaet Ruprecht- Karls Heidelberg (Germany)

Others partners: Nederlandse Akademie van Wetenschappen, Amsterdam; Universitetet For Miljo Og Biovitenskap, Aas; Universitat Pompeu Fabra, Barcelona; University of Cambridge, Cambridge; Debreceni Egyetem, Debrecen; Technische Universität Dresden, Dresden; CNRS-UNIC, Gif-sur-Yvette; CNRS-INCM, Marseille; CNRS-ISM, Marseille; TUG, Graz; Ruprecht-Karls-Universität Heidelberg, Heidelberg; Forschungszentrum Jülich GmbH, Jülich; EPFL LCN, Lausanne; EPFL-BBP, Lausanne; The University Of Manchester, Manchester; KTH, Stockholm; Universität Zürich, Zürich

See also: http://brainscales.kip.uni-heidelberg.de/

Abstract: 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 started on January 1st, 2011 and is funded for four years.

6.2.1.2. FACETS-ITN

Title: FACETS-ITN

Instrument: Initial Training Network (ITN)

Duration: September 2009 - August 2013

Coordinator: Universität Heidelberg- Ruprecht-Karls (Germany)

See also: http://facets.kip.uni-heidelberg.de/ITN/index.html

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`

6.2.1.3. MATHEMACS

Title: Mathematics of Multilevel Anticipatory Complex Systems

Type: Collaborative project (generic) (FP7-ICT)

Defi: develop a mathematical theory of complex multilevel systems and their dynamics.

Instrument: Integrated Project (IP)

Duration: October 2012 - September 2015

Coordinator: Fatihcan Atay, Max Planck Institute for Mathematics in the Sciences, Leipzig (Germany)

Other Partners: Max Planck Institute for Mathematics in the Sciences (Leipzig, Germany), Universität Bielefeld (Germany), Chalmers University of Technology (Gothenburg, Sweden), Ca'Foscari University of Venice (Italy), Università Politecnica delle Marche (Ancona, Italy).

See also: http://www.mathemacs.eu/description.html

Abstract: The MATHEMACS project aims to develop a mathematical theory of complex multi-level systems and their dynamics. This is done through a general formulation based on the mathematical tools of information and dynamical systems theories. To ensure that the theoretical framework is at the same time practically applicable, three key application areas are represented within the project, namely neurobiology, human communication, and economics. These areas not only provide some of the best-known epitomes of complex multi-level systems, but also constitute a challenging test bed for validating the generality of the theory since they span a vast range of spatial and temporal scales. Furthermore, they have an important common aspect; namely, their complexity and self-organizational character is partly due to the anticipatory and predictive actions of their constituent units. The MATHEMACS project contends that the concepts of anticipation and prediction are particularly relevant for multi-level systems since they often involve different levels. Thus, as a further unique feature, the project includes the mathematical representation and modeling of anticipation in its agenda for understanding complex multi-level systems.

This project started on October 1st, 2012 and is funded for four years.

6.2.2. Collaborations in European Programs, except FP7

6.2.2.1. ERC NerVi

Program: ERC IDEAS

Project acronym: NerVi

Project title: From single neurons to visual perception

Duration: January 2009 - December 2013

Coordinator: Olivier Faugeras

Abstract: 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.

6.3. International Initiatives

6.3.1. Inria Associate Teams

6.3.1.1. CORTINA

Title: Retina neural network coding

principal investigator: Frédéric Alexandre (Inria Mnemosyne)

International Partner:

Institution: University of Valparaiso (Chile)

Laboratory: Centro Interdiciplinario de Neurociencia de Valparaiso

Researcher: Adrian PALACIOS

International Partner:

Institution: UTFSM Valparaiso (Chile)

Laboratory: Direccion General de Investigacion y Postgrado

Researcher: Maria-Jose ESCOBAR

Duration: 2011 - 2013

See also: http://cortex.loria.fr/Projects/Cortina

Much progress has been made in the last decades in understanding the basic organization and function of the nervous system in general. Contributions to this end have come from various domains including computational neuroscience and numerical science of the information in general.The goal of this associate team is to combine our complementary expertise, from experimental biology and mathematical models (U de Valparaiso and U Federico Santa-Maria) to computational neuroscience (CORTEX and NEUROMATHCOMP), in order to develop numerical tools for the study and characterization of neural coding and related sensory-motor loops. Recording and modeling spike trains from the retina neural network, an accessible part of the brain, is a difficult task that our partnership can address, what constitute an excellent and unique opportunity to work together sharing our experience and to focus in developing computational tools for methodological innovations. To understand How the neural spike coding from natural image sequences works we are addressing the following issues: How visual signals are coded at earlier steps in the case of natural vision? What are their functions? What are the computational "coding" principles explaining (in artificial or biological system) the statistical properties of natural images? We wish to advance our actual knowledge in natural and artificial visual signals processing and apply it to the field of education; to foster better capacities for learning and memory; sensory prosthesis design, to will help unpaired sensory persons to sense the world and physical rehabilitation, among others. In the context of the cooperation between the Inria and Chile we propose to develop new neural decoding algorithms that are transverse to several field and applications.

6.3.2. Participation In International Programs

6.3.2.1. ANR KEOPS

Title: Algorithms for modeling the visual system: From natural vision to numerical applications.

principal investigator: Thierry Viéville (Mnemosyne)

International Partner:

Institution: University of Valparaiso (Chile)

Laboratory: Centro Interdiciplinario de Neurociencia de Valparaiso

Researcher: Adrian PALACIOS

International Partner:

Institution: UTFSM Valparaiso (Chile)

Laboratory: Direccion General de Investigacion y Postgrado

Researcher: Maria-Jose ESCOBAR

Duration: 2011 - 2013

See also: http://cortex.loria.fr/Research/Keops

KEOpS attempts to study and model the non-standard behavior of retinal (ganglion cells) sensors observed in natural scenarios. KEOpS also attempts to incorporate the resulting models into real engineering applications as new dynamical early-visual modules. The retina, an accessible part of the brain, is a unique model for studying the neural coding principles for natural scenarios. A recent study proposes that some visual functions (e.g. movement, orientation, anticipatory temporal prediction, contrast), thought to be the exclusive duty of higher brain centers, are actually carried at the retina level. The anatomical and physiological segregation of visual scenes into spatial, temporal and chromatic channels begins at the retina through the action of local neural networks. However, how the precise articulation of this neural network contributes to local solutions and global perception necessary to resolve natural task remains in general a mystery. KEOpS thus attempts to study the complexity of retinal ganglion cells (the output to the brain) behaviors observed in natural scenarios2 and to apply this result to artificial visual systems. We revisit both the retinal neural coding information sent to the brain, and at the same time, the development of new engineering applications inspired by the understanding of such neural encoding mechanisms. We develop an innovative formalism that takes the real (natural) complexity of retinal responses into account. We also develop new dynamical early-visual modules necessary to solve visual problems task.

6.4. International Research Visitors

6.4.1. Visits of International Scientists

- Panagiota Theodoni, 11-15 september 2012.
- Gasper Tkacik, IST Austria, Wien, 04-07 July 2012.
- Olivier Marre, Institut de la Vision, Paris, 04-07 July 2012.
- Thierry Mora, Laboratoire de Physique Statistique, ENS Ulm Paris, 04-07 July 2012.
- Martin Golubitsky, Mathematical Biology Institute (Columbus Ohio) 09-13 June 2012
- Reiner Lauterbach, Mathematics Departement, Hambourg 09-13 June 2012
- Arnd Scheel, Mathematics Department, U of Minnesota (Minneapolis) 09-13 June 2012.

6.4.1.1. Internships

- Viktor Shcherbakov, Master 2, March-July 2012.

7. Dissemination

7.1. Scientific Animation

Bruno Cessac was a member of the program committee of the conference Neurocomp-KEOPS 2012. He is a reviewer for the CONYCIT (Chile) and COFECUB (Brasil) program and for the journals Physica D, Nonlinearity, Chaos, Journal of Statistical Physics, IEEE Transaction in Neural Networks, Journal of Mathematical Biology, Journal of Computational Neuroscience. He is in charge of internships organisation in the Master of Computational Biology, Nice.

Pascal Chossat 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 and 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. He co-organized a thematic semester at CIRM, Luminy, France, October-December 2011, on “Theoretical, Mathematical and Computational Neuroscience” which featured four one-week workshops and six one-week courses. For more information see Website: http://www-sop.inria.fr/manifestations/SemesterCirm/.

Pierre Kornprobst was a member of the program committee of the conference ICPR 2012. He co-organised with Olivier Faugeras the Workshop on Biological and Computer Vision Interface which was selected as a satellite event of ECCV 2012 (Website: http://www-sop.inria.fr/manifestations/wbcvi2012). He co-edited with Frédéric Cazals the book entitled "*Modeling in Computational Biology and Medicine: A Multidisciplinary Endeavor*" [56], which illustrates the program taught in the Master of Science in Computational Biology (Website: http://cbb.unice.fr) that they launched in 2009.

7.2. Teaching - Supervision - Juries

7.2.1. Teaching

Licence 1 : Grégory Faye, *Mathematics for Biology*, 50h, L1, Université Nice Sophia Antipolis, France.

Licence 1 : Massimiliano Muratori, TP de physique, 45 h, L1, Ecole d'ingénieurs Polytech.

Licence 2 : Rodrigo Cofre, Traitement du signal, 50h, L2, Université Nice Sophia Antipolis, France.

Licence 2, Massimiliano Muratori, TD d'électromagnetisme , 18h, L2, Ecole d'ingénieurs Polytech.

Licence 3 : Hassan Nasser, Electronique numérique, 36h, L3, Université Nice Sophia Antipolis, France

License 3 : Hassan Nasser, Microprocesseurs, 28h, L3, Université Nice Sophia Antipolis, France

Master 2: Bruno Cessac, *Neuronal dynamics*, 36 hours, Master of Computational Biology and Biomedicine, Université Nice Sophia Antipolis, France.

Master 2: Olivier Faugeras, *Mathematical Methods for Neuroscience*, 27h, M2, ENS Paris, France.

7.2.2. Supervision

PhD & HdR

PhD : Grégory Faye, "Symmetry breaking and pattern formation in neural field equations", 2012, supervised by Pascal Chossat and Olivier Faugeras.

PhD in progress: Diego Fasoli, "Mean-field theory of realistic spiking neurons", Université Nice Sophia Antipolis, defence planned in 2013, supervised by Olivier Faugeras.

PhD: Geoffroy Hermann, "Some mean field equations in neuroscience", 2012, supervised by Olivier Faugeras and Jonathan Touboul.

PhD : Khaled Masmoudi, Retina-inspired image coding schemes, Université Nice Sophia Antipolis, October 15, 2012, supervised by Marc Antonini (I3S, CNRS) and Pierre Kornprobst.

Phd in progress: Javier Baladron, "Parallel implementations of mean field and neural field equations", Université Nice Sophia Antipolis, defence planned in 2013, supervised by Olivier Faugeras.

PhD in progress: Hassan Nasser, « Reproducing and anticipating retinal responses», defence planned in 2013, supervised by Bruno Cessac .

PhD in progress: Rodrigo Cofre-Torres, «Statistics of spike trains and neuronals structures», defense planned in 2014, supervised by Bruno Cessac.

PhD in progress: Massimiliano Muratori, « Mean field equations for neural networks and synaptic correlations», defence planned in 2015, supervised by Bruno Cessac .

7.2.3. Juries

Bruno Cessac. Reviewer of Damien Landon's Thesis, "Perturbation et excitabilité dans des modèles de propagation de l'influx nerveux", Orléans, 28-06-12.

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Publications of the year

Doctoral Dissertations and Habilitation Theses

[7] G. FAYE. *Symmetry breaking and pattern formation in some neural field equations*, EDSFA, 2012.

[8] G. HERMANN. *Some mean field equations in neuroscience*, Ecole Polytechnique, January 2012, ftp://ftp-sop.inria.fr/neuromathcomp/publications/phds/hermann:12.pdf.

[9] K. MASMOUDI. *Retina-inspired image coding schemes*, Université de Nice Sophia Antipolis, 2012.

Articles in International Peer-Reviewed Journals

[10] J. BALADRON, D. FASOLI, O. FAUGERAS. *Three applications of GPU computing in neuroscience*, in "Computing in Science and Engineering", 2012.

[11] J. BALADRON, D. FASOLI, O. FAUGERAS, J. TOUBOUL. *Mean-field description and propagation of chaos in networks of Hodgkin-Huxley neurons*, in "The Journal of Mathematical Neuroscience", 2012, vol. 2, n^{o} 1, http://www.mathematical-neuroscience.com/content/2/1/10.

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[29] B. CESSAC. *Lecture on spike train statistics: beyond the maximal entropy models*, in "Neural Coding and Natural Image Statistics 9-13 January 2012, Valparaiso, Chile", 2012.

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