Activity Report 2014

Team NEUROSYS

Analysis and modeling of neural systems by a system neuroscience approach

RESEARCH CENTER
Nancy - Grand Est

THEME
Computational Neuroscience and Medecine

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Team NEUROSYS

Keywords: Brain Computer Interface, Computational Neurosciences, Data Analysis, Multiscale Models, Stochastic Models

Creation of the Team: 2013 January 01.

1. Members

Research Scientists
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Nicole Voges [CNRS, until Jun 2014]

Faculty Members
Laurent Bougrain [Univ. Lorraine, Associate Professor]
Laure Buhry [Univ. Lorraine, Associate Professor]

Engineers
Pedro Garcia Rodriguez [Inria, granted by FP7 MATHANA project]
Eric Nichols [Inria, granted by FP7 MATHANA project]
Guillaume Serriere [Inria]

PhD Students
Mariia Fedotenkova [Inria]
Francesco Giovannini [Inria, from May 2014]
Meysam Hashemi [Inria]
Cecilia Lindig Leon [Inria]

Post-Doctoral Fellow
Tamara Tosic [Inria]

Visiting Scientists
Liejune Shiau [Professor at University of Houston, from May 2014 until Jun 2014]
Kevin Green [PhD-student at University of Oshawa in Canada, from Feb 2014 until May 2014]

Administrative Assistant
Laurence Benini [Inria]

Others
Sébastien Rimbert [Inria, Master student, from Jul 2014 until Sep 2014]
Thomas Tassone [Inria, Master student, from Jun 2014 until Aug 2014]

2. Overall Objectives

2.1. General objectives

The team aims at understanding the dynamics of neural systems on multiple scales and develops methods to invent monitoring devices. The approach is inspired by systems neuroscience, which relates microscopic modifications in neural systems to macroscopic changes in behavior. The team employs this systems neuroscience approach and develops models and data analysis tools in order to bridge the gap between microscopic and mesoscopic, and mesoscopic and macroscopic/behavior activity. These bridges are necessary to better understand neural systems and, in turn, control the neural systems. They also may allow to develop data monitors utilising the derived principles. As a long-term goal, the team shall develop such devices in medicine with application in general anaesthesia.

3. Research Program

3.1. Main Objectives

The main challenge in computational neuroscience is the high complexity of neural systems. The brain is a complex system and exhibits a hierarchy of interacting subunits. On a specific hierarchical level, such subunits evolve on a certain temporal and spatial scale. The interactions of small units on a low hierarchical level build up larger units on a higher hierarchical level evolving on a slower time scale and larger spatial scale. By virtue of the different dynamics on each hierarchical level, until today the corresponding mathematical models and data analysis techniques on each level are still distinct. Only few analysis and modeling frameworks are known which link successfully at least two hierarchical levels.

Once having extracted models for different description levels, typically they are applied to obtain simulated activity which is supposed to reconstruct features in experimental data. Although this approach appears straight-forward, it implies various difficulties. Usually the models involve a large set of unknown parameters which determine the dynamical properties of the models. To optimally reconstruct experimental features, it is necessary to formulate an inverse problem to extract optimally such model parameters from the experimental data. Typically this is a rather difficult problem due to the low signal-to-noise ratio in experimental brain signals. Moreover, the identification of signal features to be reconstructed by the model is not obvious in most applications. Consequently an extended analysis of the experimental data is necessary to identify the interesting data features. It is important to combine such a data analysis step with the parameter extraction procedure to achieve optimal results. Such a procedure depends on the properties of the experimental data and hence has to be developped for each application separately.

3.2. Challenges

Eventually the implementation of the models and analysis techniques achieved promises to be able to construct novel data monitor. This construction involves additional challenges and stipulates the contact to realistic environments. By virtue of the specific applications of the research, the close contact to hospitals and medical enterprises shall be established in a longer term in order to (i) gain deeper insight into the specific application of the devices and (ii) build specific devices in accordance to the actual need. Collaborations with local and national hospitals and the pharmaceutical industry already exist.

3.3. Research Directions

- From the microscopic to the mesoscopic scale:
  One research direction focusses on the *relation of single neuron activity* on the microscopic scale *to the activity of neuronal populations*. To this end, the team investigates the stochastic dynamics of single neurons subject to external random inputs and involving random microscopic properties, such as random synaptic strengths and probability distributions of spatial locations of membrane ion channels. Such an approach yields a stochastic model of single neurons and allows the derivation of a stochastic neural population model.
  This bridge between the microscopic and mesoscopic scale may be performed via two pathways. The analytical and numerical treatment of the microscopic model may be called a *bottom-up approach*, since it leads to a population activity model based on microscopic activity. This approach allows to compare theoretical neural population activity to experimentally obtained population activity. The *top-down approach* aims at extracting signal features from experimental data gained from neural populations which give insight into the dynamics of neural populations and the underlying microscopic activity. The work on both approaches represents a well-balanced investigation of the neural system based on the systems properties.

- From the mesoscopic to the macroscopic scale:
  The other research direction aims to link neural population dynamics to macroscopic activity and behaviour or, more generally, to phenomenological features. This link is more indirect but a very powerful approach to understand the brain, e.g., in the context of medical applications. Since real neural systems, such as in mammals, exhibit an interconnected network of neural populations, the team studies analytically and numerically the network dynamics of neural populations to gain deeper insight into possible phenomena, such as traveling waves or enhancement and diminution of certain neural rhythms. Electroencephalography (EEG) is a wonderful brain imaging technique to study the overall brain activity in real time noninvasively. However it is necessary to develop robust techniques based on stable features by investigating the time and frequency domains of brain signals. Two types of information are typically used in EEG signals: (i) transient events such as evoked potentials, spindles and K-complexes and (ii) the power in specific frequency bands.

4. Application Domains

4.1. General remarks

The research directions of the team are motivated by general anaesthesia (GA) that has attracted our attention in the last years. The following paragraphs explain in some detail the motivation of our work on the four major phenomena of GA: loss of consciousness, immobility, amnesia and analgesia.

During general anaesthesia, the electroencephalogram (EEG) on the scalp changes characteristically: increasing the anaesthetic drug concentration the amplitudes of oscillations in the α-band ($\sim 8-12$Hz) and in the $\delta-$band ($2-8$Hz) increase amplitudes in frontal electrodes at low drug concentrations whereas the spectral power decreases in the $\gamma-$band ($\sim 20-60$Hz). This characteristic change in the power is the basis of today's EEG-monitors that assist the anaesthesist in the control of the anaesthesia depths of patients during surgery. However, the conventional monitors exhibit a large variability between the patients detected anaesthetic depth and their real depth. Moreover, a certain number of patients re-gain consciousness during surgery (about $1-2$ out of 1000) and a large percentage of patients suffer from diverse after-effects, such as nausea or long-lasting cognitive impairments such as partial amnesia (from days to weeks). Since surgery under general anaesthesia is part of a hospital's everyday practice, a large number of patients suffer from these events everyday. One reason for the lacking control of such disadvantagous effects is the dramatic lack of knowledge on what is going on in the brain during general anaesthesia and a weak EEG-online monitoring system during anaesthesia. Consequently, to improve the situation of patients during and after surgery and to develop improved anaesthetic procedures or even drugs, research is necessary to learn more about the neural processes in the brain and develop new monitoring machines.

4.2. Level of consciousness

The EEG originates from coherent neural activity of populations in the cortex. Hence to understand better the characteristic power changes in EEG during anaesthesia, it is necessary to study neural population dynamics subject to the concentration of anaesthetic drugs and their action on receptors on the single neuron level. We study mathematical models which will be constrained by the signal features extracted from experimental data, such as EEG (data provided by Jamie Sleigh, University of Auckland and Christoph Destrieux, University of Tours), Local Field Potentials (data provided by Flavio Frohlich, University of North Carolina - Chapel Hill) and behavior. The combination of model and analysis of experimental data provides the optimal framework to reveal new knowledge on the neural origin of behavioral features, such as the loss of consciousness or the un-controlled gain of consciousness during surgery. For instance, modelling studies show that the characteristic changes of spectral power (second-order statistics) are not sufficient to deduce all underlying neural mechanisms. Consequently, additional higher-order statistical measures may provide additional insight into underlying neural mechanisms and may provide a novel marker for the loss of consciousness.

Moreover, the constant supervision of anaesthesized patients in intensive care is a demanding task for the personnel in hospital practice. It is almost not possible to take care of a patient constantly and hence the todays' medicine demands monitoring devices that control automatically the level of anaesthetic drugs based on the patients' neural activity (e.g., EEG). Brain-Computer-Interfaces (BCI) have already demonstrated their potential for the detection of consciousness in non-responsive patients. We will apply the data analysis techniques known in BCI to extract new markers for the depth of anaesthesia. More specifically, for deeper anaesthesia, auditory-evoked and Event-Related Desynchronization/Event-Related Synchronization (ERD/ERS) BCI could be used to better identify the state of consciousness in patients under anaesthesia. In this context, we have established a first contact to the University of Wuerzburg. Another research direction will link intracranial EEG and scalp EEG by characterising micro-awake episodes during sleep.

4.3. Immobility

A research direction will be to take benefit of the relationship between the motor activity and anesthesia. Indeed, even if no movement is visually perceptible, a study by electroencephalographic recordings of brain activity in motor areas, quantifying the characteristics of amplitude and phase synchronization observed in the alpha and beta frequency bands, may reveal an intention movement. This feature is important because it demonstrates that the patient is aware. Thus, we will develop an experimental protocol in collaboration with an anesthesiologist of the regional hospital on stimulating the median nerve at forearm level to track the evolution of the shape of the beta rebound in the motor cortex for various doses of the anesthetic agent.

4.4. Amnesia

Patients sometimes develop post-traumatic disorders associated with the surgery they underwent because they either woke up during the surgery or because the amnesiant effect of the general anaesthesia was only partial, declarative memory being maintained in some unexplained cases. It is still unknown how memory can be maintained under general anaesthesia and it needs to be investigated to improve the recovery from anaesthesia and to avoid as much as possible post-traumatic disorders. To learn more about memory under anaesthesia, we will focus our theoretical studies on the oscillation regimes observed in the hippocampus, mainly in the theta and gamma ranges, which are correlated with memory formation and retrieval.

4.5. Analgesia

One of the most important aspect in general anaesthesia is the loss of pain. During surgery, it is very difficult to find out wether the anesthesized patient feels pain and hence will develop cognitive impairement after surgery. Today, the anesthesiologist knows and detects physiological signs of pain, such as sweat, colour of skin or spontaneous unvoluntary movements. However, more objective criteria based on EEG may assist the pain detection and hence improves the patients' situation. To this end, we analyze large sets of patient EEG-data observed during surgery and aim to extract EEG signal features of pain.

5. New Software and Platforms

5.1. Software

5.1.1. Visualization

- The NeuralFieldSimulator [1] computes numerically activity in two-dimensional neural fields by solving integral-differential equations involving transmission delays and visualizes the spatio-temporal activity. The tool includes a GUI that allows the user to choose field parameters. It is written in Python, open-source and is aimed to be promoted to become a major graphical visualization tool in the domain of neural field theory. We aim to establish this simulation software as the first open-source standard simulator for the neural field research community.

[1] https://gforge.inria.fr/projects/nfsimulator/

- *A*naesthesiaSimulator [2] simulates the activity of networks of spiking neurons subject to specific receptor dynamics. The tool is a platform to test effects of anaesthetics on neural activity and is still in its first stage of development. The neural activity is planned to be visualized in a 2D and 3D-plot evolving in time. It is written in Python, open-source and involves heavily the simulation package BRIAN [3].

5.2. Platforms

5.2.1. OpenViBE

This platform [4] is a C++ open-source software devoted to the design, test and use of Brain-Computer Interfaces. The OpenViBE platform consists of a set of software modules that can be integrated easily and efficiently to design BCI applications. Key features of the platform are its modularity, high-performance, portability, its multiple-users facilities and its connection with high-end/Virtual Reality displays. The designer tool of the platform enables to build complete scenarios based on existing software modules using a dedicated graphical language and a simple Graphical User Interface (GUI). This software is available on the Inria Forge [5] under the terms of the LGPL-V2 license. The development of OpenVibe is done in association with other Inria research teams (Hybrid, Athena, Potioc) for the national Inria project: ADT OpenViBE-NT. Neurosys is in charge of machine learning techniques and the interoperability with other tools such as Matlab, BCI2000, or TOBI.

6. New Results

6.1. Highlights of the Year

Microscopic action affects mesoscopic and macroscopic action in neural systems. In the context of general anaesthesia, it is not understood how single neuron properties, such as ion-channel conductivities or anesthetic action on neuron receptors, translate to population dynamics and consequently to behavior. The work of Laure Buhry and Axel Hutt [4] proposes a modelling approach how to bridge the microscopic and the mesoscopic scale. The most interesting aspect is that this model bridge allows to extend standard neural field theory on the mesoscopic scale instead of introducing a new model.
In addition, we have developed strong collaborations with medical doctors. First, we have established a collaboration with Dr. Denis Schmartz and Dr. Claude Meistelmann at the *CHU Nancy* to plan and perform well-controlled resting state experiments under propofol anaesthesia. Second, we are in close contact to Jean-Luc Schaff at the *CHU Nancy* (together with Laurent Koessler at *CRAN*) in the context of sleep monitoring. Dr. Schaff has provided us polysomnographic data measured during sleep of insomnia patients.

6.2. From the microscopic to the mesoscopic scale

Participants: Laure Buhry, Axel Hutt, Francesco Giovannini, LieJune Shiau
The Highlight of the Year bridges the microscopic scale and the mesoscopic scale. One partial result has already been used in one of our publications [3] to study the link between population dynamics on the mesoscopic scale and the EEG on the macroscopic scale.

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[2] https://gforge.inria.fr/projects/anasim/
[3] http://briansimulator.org/
[4] http://openvibe.inria.fr/
[5] https://gforge.inria.fr/projects/openvibe/

In addition, the work of Francesco Giovannini aims at gaining a better understanding of the effects of anaesthesia on the neural correlates of memory, focusing on how anaesthetics disrupt the interaction between the hippocampus and the cerebral cortex. Studies have shown that these two brain structures exhibit a strong synchronisation of their respective neural activity, when performing memory tasks. Neurophysiology experiments have identified various possible candidate generators for rhythmic activity in the area CA1, CA3 and Dentate Gyrus areas of the hippocampus. However the mechanisms by which cortico- hippocampal synchronisation is elicited, and maintained, are yet to be fully understood. As a first step towards this objective, Francesco obtained a working mathematical model of a biologically plausible hippocampal CA1-3 neural cell, based on the Hodgkin-Huxley neuron, capable of exhibiting long-lasting persistent firing activity when subject to a strong transient stimulus. This behaviour is underlay by an intrinsic membrane current activated by the increase of intracellular Calcium ions, following the discharge of an action potential by the neuron. Our hypothesis is that large ensembles of such persistent-firing neurons could sustain the memory-related rhythmic activity displayed by the hippocampus. In this context, Laure Buhry and Axel Hutt work with LieJune Shiau (University of Houston) on a better understanding of the models used by the community of computational neuroscientists. The goal is to show in which extent models are comparable or interchangeable. We focus on the comparison of oscillatory mechanisms of neuronal populations in different spiking models, especially in the Hodgkin-Huxley and the adaptive exponential integrate-and-fire model.

These latter studies link the two description scales by a bottom-up approach.

Conversely, Axel Hutt and collaboration partners from the University of Noth Carolina - Chapel Hill have analysed Local Field Potentials measured in ferrets prefrontal cortex and visual cortex under anesthesia in a top-down analysis [21]. This data allows to extract network interactions in prefrontal cortex and visual cortex and hence revealing underlying mechanisms in general anaesthesia.

6.3. From the mesoscopic to the macroscopic scale

Participants: Laurent Bougrain, Axel Hutt, Pedro Garcia-Rodriguez, Eric Nichols, Guillaume Serrière, Tamara Tosic, Nicole Voges, Mariia Fedotenkova, Meysam Hashemi, Cecilia Lindig-Leon, Kevin Green, Sébastian Rimbert, Thomas Tassone.

To understand the action of anaesthetic drugs on the EEG-signal observed experimentally, Meysam Hashemi has developed and studied several neural mass models [18], [15], [16], [3]. He has identified the thalamo-cortical loop (TCL) as a possible origin of $\delta-$activity. Since loss of consciousness is accompanied by emerging $\delta-$activity, this work relates the TCL to the loss of consciousness.

Increasing the anaesthetic concentration beyond the point of loss of consciousness, EEG-signals exhibit alternating patterns of high and low activity. This activity is called burst suppression. Since these alternations resemble stochastic jumps between low and high activity resting states, Pedro Garcia-Rodriguez and colleagues are working on a stochastic theory based on neural mass models to describe and reproduce these experimental results. Since the minimum mathematical model for such an effect is two-dimensional and does not exhibit potential dynamics, whereas the majority of literature up to date considers one-dimensional stochastic models obeying potential dynamics, Pedro and colleagues had to develop a new stochastic theory. They can show that the two-dimensional dynamics of the neural mass model can be mapped to a one-dimensional stochastic potential model [14], [13]. This reduction allows to apply standard stochastic theory to describe burst suppression as stochastic transistions. This finding indicates the presence of multiple resting states in the brain and supports a heavily discussed hypothesis on the loss of consciousness.

Biological neural networks are subject to random fluctuations, originating from intrinsic random fluctuations of ions or from external stimulus. The latter neural mass models take into account these fluctuations by assuming additive random input fluctuations. For many decades, these additive fluctuations have been assumed to not affect the stability of the system. However, previous own work has revealed that additive fluctuations tune the stability of nonlinear high-dimensional systems. Since random fluctuations play an important role in the description of neural population dynamics and realistic models consider , it is necessary to study in detail how random fluctuations affect the stability of neural mass models and, hence, how our mathematical model analyses have to be modified. To this end, Axel Hutt and colleagues have performed a stochastic center manifold analysis in a delayed stochastic neural mass model [5] and have found conditions for the stability shift. A first application to delayed stochastic neural fields has revealed how additive random fluctuations may affect EEG-signals [19], [6], however additional detailed mathematical studies and the comparison to experimental data are necessary to affirm the importance of the stochastic effect. Essentially, this work emphasizes to take into account nonlinear noise effects in neural mass and neural field models.

Neural mass models do not consider the spatial extension of neural populations and consequently neglect transmission or interaction delay between neurons at different spatial locations. Taking into account the spatial extension and axonal transmission delay, Axel Hutt and colleagues have shown mathematically [7] how travelling activity fronts propagate through neural tissue and how the fronts properties, such as speed, depend on the neural field properties.

The latter neural field model is embedded in a one-dimensional space. Since biological neural populations in the neocortex are organized in two-dimensional layers or sheets, it is necessary to employ neural field models in two spatial dimensions. This causes both theoretically and numerically problems in the presence of axonal transmission delay. Eric Nichols and colleagues has implemented a recent numerical integration algorithm [8] in the visualization software NeuralFieldSimulator, cf. section5.1. This software is the basis of numerical bifurcation studies of two-dimensional neural field models [12], [20]. First analytical results [10] show good accordance to numerical results obtained by the NeuralFieldSimulator.

The latter neural field models assume homogeneous spatial interactions, i.e., neural interactions whose strength just depends on the distance between the two neurons. This assumption is strong and not biologically realistic in certain brain areas. In addition, this assumption constrains the model description of recurrent sequences of EEG patterns, which have been found experimentally, e.g., during the emergence from general anaesthesia. Consequently to be able to describe such recurrent EEG-pattern sequences, it is necessary to improve the mathematical description of EEG-patterns. A promising new model has been derived by Axel Hutt and collagues based on heterogeneous neural fields [1]. In order to extract the recurrence EEG-patterns from data, we have extended a recent recurrence analysis technique [2]. The next step will consist in the combination of the heterogeneous neural field model and the results from the recurrence analysis.

Recurrence analysis extracts temporally reccurrent time windows in multi-dimensional datasets. Typical EEG-signals obtained durin surgery under anaesthesia include one electrode and hence a single time series only. To extract recurrence structures of such one-dimensional signals, Mariia Fedotenkova computes the multi-dimensional time-frequency representation of the signal and has worked out the best analysis technique for this step [9]. In the next step she will compute the recurrence plot for a large dataset of 110 patients under surgery (data obtained from University of Auckland).

In order to understand immobility during anaesthesia and how to supervise unconscious patients automatically in hospital emergency rooms, Cecilia Lindig-Leon studies motor imagery and its detection by BCI techniques. Limb movement execution or imagination induce sensorimotor rhythms that can be detected in EEG recordings. Her recent work considers signal power changes in two frequency bands to detect the elicited EEG rebound, i.e. the increasing of synchronization, at the end of motor imageries. The analysis is based on the database 2a of the BCI competition IV and shows that rebound can be stronger over the alpha frequency band (8-12Hz) than the beta frequency band (12-20Hz). She can demonstrate that the analysis of the alpha frequency band improves the detection of the end of motor imageries. In this context, Cecilia has compared intrinsic multi-class classifiers (i.e., one-step methods) with ensembles of two-class classifiers on dataset 2a of the BCI competition IV for motor imagery. Subsequently, she has compared the classical Common Spatial Pattern (CSP) approach and the CSP by Joint Approximate Diagonalization in order to identify whether the latter method represents an outperforming alternative.

Sleep is strongly related to anaesthesia and we have started working on the improvement of sleep monitors. The basic idea is to consider not only EEG-signals but multiple different physiological signals (e.g. heart pulses, electrocardiogram, EEG, respiration cycle, body movements) to classify sleep stages. By virtue of the different signal natures of different physiological signals, it is challenging to put together these so-called multi-modal signals in a single analysis method. To this end, Tamara Tosic and colleagues employ recurrence analysis techniques which allow to estimate time windows exhibiting temporal synchronization between physiological signals [11]. They have developed a method that is based on artificial data sets and Local Field Potentials measured under anaesthesia. In the next step, applications to sleep data (obtained from CHU Nancy) will allow to extract sleep stages and will evaluate the method.

7. Partnerships and Cooperations

7.1. Regional Initiatives

In the *Contrat de Projet État Région (CPER) Action Modeling, Simulation and Interaction* (2009-2014), we are contributing to the axis *Situed Informatic* through the project CoBras for controlling a jaco robotic arm using EEG. Contact in Neurosys is Laurent Bougrain.

7.2. National Initiatives

7.2.1. ANR

We participate in the project *Keops:* Algorithms for modeling the visual system: From natural vision to numerical applications (2011-2014).
A recent description in the retina of non-standard ganglion cells types, beside a complex repertoire of standard ganglion cells, responses in front of natural stimulus and conveys important questions about the real, early processing capacity of the retina. This leads to revisit both the neural coding of the information the eye is sending to the brain, and also sheds light to engineering applications from the understanding of such encoding, as detailed in the sequel. At the modeling level, retinal cells are mainly formalized using a LN (Linear spatio-temporal filtering followed by a static Non-linear transduction), while an important fraction of non-standard cells response cannot be represented in such a model class. This is a challenge to develop an innovative formalism that takes such complex behaviors into account, with such immediate applications as new dynamical early-visual modules. Proposing new innovative bioinspired formalisms in order to perform dynamical visuo-perceptual tasks adapted to natural environment is a main goal of this project, with a special focus to scenes including complex visual motion interacting with light.
The project is a cooperation between the University of Nice (France), the University of Valparaiso (Chile), the Pontifical Catholic University of Chile in Santiago de Chile, the Inria teams NeuroMathComp, Mnemosyne, Cortex and Neurosys.

7.2.2. Others

- Inria Technological development action (ADT): OpenViBE-NT
  This is a three-year multi-site project (2012–2015) to develop OpenViBE further on several fronts such as usability, new algorithms and scope of applicability. Teams of the ADT are Hybrid(Rennes), Athena (Sophia), Potioc (Bordeaux) and Neurosys. Coordinator is Laurent Bougrain.
- Multidisciplinary Exploratory Project (PEPS 2014) Bio-Maths-Info (BMI): *Characterising the laminar profile of motor cortical oscillatory synchronization during visuomotor behavior with new analysis tools.*
  Oscillations are omnipresent in the brain, but their function is still disputed. In motor cortex, beta and gamma oscillations are often observed, but their proposed roles in sensorimotor behavior are largely overlapping. While much is known on the laminar distribution of oscillations in sensory areas, the very sparse data on the laminar profile of motor cortical oscillations largely limits their functional interpretations. The 2-years project studies the layer specificity of monkey motor cortical oscillations and oscillatory interactions between the motor areas M1 and PMd during visuomotor behavior. Extending conventional tools, such as coherency analysis, Neurosys develops a new method to quantify short-lasting partial amplitude and phase synchronization in single-trial data, based on wavelets, exploiting the predefined vicinity of contacts on the laminar probes. The application of this new method to the data recorded in Marseille will reveal instantaneous amplitude and phase

synchronization between cortical layers and between the brain areas $M1$ and PMd, providing novel insights into the functional roles of beta and gamma oscillations in visuomotor behavior. The experimental partner at the *Institut de Neurosciences de la Timone* in Marseille is Bjork Kilavik. The contact in Neurosys is Axel Hutt.

7.3. European Initiatives

7.3.1. FP7 & H2020 Projects

The *ITN*-project *Neural Engineering Transformative Technologies (NETT)* (2012-2016) is a Europe-wide consortium of 18 universities, research institutes and private companies which together hosts 17 PhD students and 3 postdoctoral researchers over the next 4 years. Neural Engineering brings together engineering, physics, neuroscience and mathematics to design and develop brain-computer interface systems, cognitive computers and neural prosthetics. Neurosys will host a PhD-student from University of Barcelona for three months in fall 2015. Contact is Axel Hutt.

7.3.2. Collaborations in European Programs, except FP7 & H2020

Program: ERC Starting Grant

Project acronym: MATHANA

Project title: Mathematical Modeling of Anaesthesia

Duration: January 2011 – December 2015

Coordinator: Axel Hutt

Abstract: MATHANA aims to study mathematically spatially extended neural systems and reveal their spatio-temporal dynamics during general anaesthesia.

7.3.3. Collaborations with Major European Organizations

Lifestyle Research Association (LIRA): Philips (Netherlands), Fraunhofer (Germany), Inria

Sleep is an essential part of a healthy life, but many people have trouble getting enough uninterrupted sleep. Special sensors installed in a mobile phone or bed can analyze activities, stress patterns and sleep sequences and provide ideas for new strategies and, eventually, products that support a healthier night's sleep. NEUROSYS has a Postdoc project running merging all sensor signals in a single data analysis technique to improve existing sleep monitors.

7.4. International Initiatives

7.4.1. Inria International Partners

7.4.1.1. Informal International Partners

- We collaborate with Jamie Sleigh (University of Auckland, New Zealand), who provides us with experimental EEG-data obtained in humans during anaesthesia (A. Hutt).
- In the collaboration with Flavio Frohlich (University of North Carolina - Chapel Hill), we receive experimental data measured intracranially in ferrets and analyse them on spectral properties (A. Hutt).
- In the collaboration with Jérémy Lefebvre (University of Lausanne), we have been working out together a stochastic delayed neural field analysis leading to new insights into the effects of additive noise (A. Hutt).
- The collaboration with Peter beim Graben (Humboldt University Berlin) on recurrence data analysis has led to analysis techniques to detect meta-stable states in EEG-signals (A. Hutt).

- We have an ongoing collaboration with Pr. Motoharu Yoshida at the Ruhr University Bochum, Germany, aiming to study the role of persistent firing neurons in memory and more specifically in neural network synchronization. M. Yoshida provides us with biological data that we combine with simulations to test hypotheses on memory formation (L. Buhry).
- We also collaborate with Pr. John Rinzel (New York University, USA) and Pr. LieJune Shiau (University of Houston, Texas, USA) on more theoretical approaches concerning the role of intrinsic neuronal dynamics in network synchronization and brain oscillations (L. Buhry).

7.5. International Research Visitors

7.5.1. Visits of International Scientists

We have hosted the visiting professor LieJune Shiau (University of Houston, June) to discuss future collaborations on the modeling of neural populations based on single neuron properties in the presence of anaesthetic drugs. In addition, Motoharu Yoshida (Ruhr-Universität Bochum, Germany) visited our lab, gave a seminar and we discussed our current collaboration about memory and persistent firing cells of the hippocampus.

7.5.2. Visits to International Teams

7.5.2.1. Research stays abroad

Axel Hutt has stayed for 1 month at the Humboldt University Berlin to enforce the collaboration with Peter beim Graben (October - November).

8. Dissemination

8.1. Promoting Scientific Activities

8.1.1. Scientific events organisation

8.1.1.1. Organizing committee membership:

- openVibe Workshop as a satellite event of the international conference on Brain-Computer Interfaces on September 15th, 2014 in Graz (with BrainProduct, TMSi, g.tec) (L. Bougrain & G. Serrière)
- BCI competition, IEEE Neural Engineering Conference , Montpellier, 2015 (L. Bougrain).

8.1.2. Scientific events selection

8.1.2.1. Conference program committee membership:

IEEE International Conference on Systems, Man, and Cybernetics (SMC2014 [6]) special sessions on Brain-Machine Interfaces, October 5-8, San Diego (L. Bougrain)

8.1.2.2. Reviewer:

Programme H2020 (L. Buhry)

8.1.3. Journal

8.1.3.1. Editorial board membership:

Journal of Proteomics & Computational Biology (A. Hutt)

8.1.3.2. Reviewing activities:

Nonlinearity, Neurocomputing, Neural Computation, Journal of Computational Neuroscience, SIAM Journal of Applied Dynamical Systems, Journal of Mathematical Neuroscience, Frontiers in Neurology, Biological Cybernetics, Physical Review E, Physical Review Letters, Journal of Neuroscience, PLoS One, IEEE Transctions on Biomedical Engineering (A. Hutt); Neural Computation, Journal of Computational Neuroscience, Journal of Neural Engineering, Neurocomputing,CCSP (Circuits, Systems & Signal Processing) (L. Buhry)

[6] http://smc2014.org

8.2. Teaching - Supervision - Juries

8.2.1. Teaching

Engineer school : L. Bougrain, *Artificial Intelligence*, 109h, (3rd year) Telecom Nancy, France

Engineer school : L. Bougrain, *Brain-Computer interfaces*, 4.5h, (3rd year) Supelec, France

Licence: L. Buhry, *Applications en Sciences Cognitives*, 3h en équivalent TD, niveau L1 MIASHS, University of Lorraine

Licence: L. Buhry, *Programmation Python*, 37h en équivalent TD, niveau L1 MIASHS, University of Lorraine

Licence : L. Buhry, *IA et Résolution de problèmes*, 25h en équivalent TD, niveau L3 MIASHS, University of Lorraine

Licence : L. Bougrain, *mobile development*, 35h, Licence of computer science (3st year), University of Lorraine, France

Licence : L. Bougrain, *artificial intelligence*, 35h, Licence of computer science (3st year), University of Lorraine, France

Licence : L. Bougrain, *optimization*, 37.5h, Licence of computer science (3st year), University of Lorraine, France

Master : L. Buhry, *Algoritmique pour l'intelligence artificielle (IA)*, 31h en équivalent TD, niveau Master 1 SCA (Sciences Cognitives et Applications), University of Lorraine

Master : L. Buhry, *IA fondamentale et fouille de données*, 18h en équivalent TD, niveau Master 1 SCA (Sciences Cognitives et Applications), University of Lorraine

Master: L. Buhry, *Formalismes de Représentation et Raisonnement*, 25h en équivalent TD, niveau Master 1 SCA (Sciences Cognitives et Applications), University of Lorraine

Master: L. Buhry, *Memory and Machine Learning* (in English), 38h en équivalent TD, niveau Master 1 SCA (Sciences Cognitives et Applications), University of Lorraine

Master : L. Buhry, *Neurosciences Computationnelles*, 25h en équivalent TD, niveau Master 2 SCMN, University of Lorraine

Master : L. Bougrain, *Machine learning*, 18h, Master of computer science (2st year), University of Lorraine, France

Master : L. Bougrain, *Human factors*, 30h, Master of computer science (1st year), University of Lorraine, France

Master : A. Hutt, *Pépites Algorithmiques*, 9h, niveau M1, École des Mines Nancy

8.2.2. Supervision

PhD in progress : Meysam Hashemi, *A cortico-thalamic model to describe the power spectrum of EEG under anaesthesia*, May 2012, A. Hutt

PhD in progress : Mariia Fedotenkova, *Detection of EEG-signal features for pain under general anaesthesia*, November 2013, A. Hutt

PhD in progress : Cecilia Lindig-Leon, *Multilabel classification for a 3D control of a robotic arm using band-specific EEG markers associated with a motor task*, November 2013, L. Bougrain and A. Hutt

PhD in progress : Francesco Giovannini, *Mathematical modelling of the memory system under general anesthesia*, October 2014, L. Buhry and A. Hutt

Spring-Summer 2014 internship: Francesco Giovannini (Laure Buhry)

Summer 2014 internship: Sébastien Rimbert, *Immobility and anesthesia* (L. Bougrain)

Summer 2014 internship: Thomas Tassone *Client-server solution using ØMQ to allow a communication between OpenViBE and the API of the JACO robotic arm* (L. Bougrain)

8.2.3. Juries

- PhD defense of Cornelia Petrovic, University of Muenster, January 31 2014, reviewer and committee member (Axel Hutt)
- Recruitment of permanent Inria junior researchers (CR2) at Inria Sophia-Antipolis (Axel Hutt).

8.2.4. Commitees

- Member of the CDT (Commission de Développement Technologique) at Inria Nancy–Grand-Est (Laure Buhry)
- Member of the IES committee (Commission Information et Edition Scientifique) at Inria Nancy–Grand-Est (Laurent Bougrain)
- Member of Inria committee COST-GTRI to evaluate Inria Associate Teams (Axel Hutt).

8.3. Popularization

- TV interview for France 3 Lorraine, April 7 2014 (L. Buhry)
- Interview for the "Interstices" podcast, May 22 2014 (L. Buhry)
- Brain week: Comment lire dans les pensées d'autrui ? 12 March 2014, central hospital, Nancy (L. Bougrain)
- Exhibit on *controlling a robotic arm using EEG* at Researchers' Film Festival, June 10-15, 2014, Parc de la Pépinière, Nancy (L. Bougrain)
- Computational neuroscience, Inria Scientific Days, June 2014 (Laure Buhry)
- OpenViBE, Inria Scientific Day, June 2014, Lille (L. Bougrain)
- Is it really statistically significant? « Dynamics of neural circuits » NETT workshop, March 2014, Florence (L. Bougrain)
- Multiclass approaches to identify motor imageries, LAGIS sem., Jun. 2014, Lille (L. Bougrain)
- *Additive noise in neural populations on multiple scales*, Bernstein Center for Computational Neuroscience, Berlin, July 2014 (A. Hutt)
- *Modelling neural population activity under anaesthesia*, Humboldt University Berlin, July 2014 (A. Hutt)
- *Pattern storage and transient dynamics in heterogeneous neural fields in the context of cognition*, 3rd International Conference on Neural Field Theory (ICNFT), Reading, June 2014 (A. Hutt)
- *Additive noise tunes the stability in nonlinear delqyed systems*, Conference on Random Dynamics and Stochastic Numerics, Mannheim, June 2014 (A. Hutt)
- *Additive noise tunes the stability in nonlinear systems*, Inhomogeneous random systems, Paris, January 2014 (A. Hutt)
- *Additive noise in neural populations on multiple scales*, Fluctuations in Population Biology, Epidemiology and Evolution, Leiden, August 2014 (A. Hutt)

9. Bibliography

Publications of the year

Articles in International Peer-Reviewed Journals

[1] P. BEIM GRABEN, A. HUTT. *Attractor and saddle node dynamics in heterogeneous neural fields*, in "EPJ Nonlinear Biomedical Physics", May 2014, vol. 2, 4 p. [*DOI :* 10.1140/EPJNBP17], https://hal.inria.fr/hal-00987789

[2] P. BEIM GRABEN, A. HUTT. *Detecting event-related recurrences by symbolic analysis: Applications to human language processing*, in "Philosophical Transactions A: Mathematical, Physical and Engineering Sciences", 2014, vol. 373, 20140089 p. [*DOI :* 10.1063/1.1819625], https://hal.inria.fr/hal-01077055

[3] M. HASHEMI, A. HUTT, J. SLEIGH. *Anesthetic action on extra-synaptic receptors: effects in neural population models of EEG activity*, in "Frontiers in Systems Neuroscience", November 2014, pp. 1-19, https://hal.inria.fr/hal-01088062

[4] A. HUTT, L. BUHRY. *Study of GABAergic extra-synaptic tonic inhibition in single neurons and neural populations by traversing neural scales: application to propofol-induced anaesthesia*, in "Journal of Computational Neuroscience", 2014, https://hal.inria.fr/hal-00916420

[5] A. HUTT, J. LEFEBVRE. *Stochastic center manifold analysis in scalar nonlinear systems involving distributed delays and additive noise*, in "Markov Processes and Related Fields", December 2014, forthcoming, https://hal.inria.fr/hal-01006388

[6] J. LEFEBVRE, A. HUTT, J.-F. KNEBEL, W. KEVIN, M. MURRAY. *Stimulus statistics shape oscillations in non-linear recurrent neural networks*, in "Journal of Neuroscience", February 2015, https://hal.inria.fr/hal-01091816

[7] L. ZHANG, A. HUTT. *Traveling wave solutions of nonlinear scalar integral differential equations arising from synaptically coupled neuronal networks*, in "Journal of Applied Analysis and Computation", February 2014, vol. 4, n^{o} 1, pp. 1-68, https://hal.inria.fr/hal-00933715

Scientific Books (or Scientific Book chapters)

[8] A. HUTT, N. P. ROUGIER. *Numerical simulation scheme of one-and two-dimensional neural fields involving space-dependent delays*, in "Neural Field Theory", P. B. GRABEN, S. COOMBES, R. POTTHAST, J. WRIGHT (editors), Springer, 2014, https://hal.inria.fr/hal-00872132

Research Reports

[9] M. FEDOTENKOVA, A. HUTT. *Research report: Comparison of different time-frequency representations.*, Inria Nancy, December 2014, https://hal.inria.fr/hal-01092552

[10] G. KEVIN, A. HUTT. *Analysis of a 2D neural field equation with finite transmission speed*, June 2014, https://hal.inria.fr/hal-01007667

[11] T. TOSIC, A. HUTT. *Technical report: Multivariate signal analysis by recurrence plots*, Inria Nancy, Neurosys, December 2014, https://hal.inria.fr/hal-01095315

Scientific Popularization

[12] E. NICHOLS, A. HUTT. *Two-dimensional neural field simulator with parameter interface and 3D visualization*, June 2014, 3rd International Conference on Neural Field Theory, https://hal.inria.fr/hal-01064205

Other Publications

[13] P. GARCIA, A. HUTT. *Stability analysis and exit problem formulation in a 2D model for general anesthesia*, June 2014, 3rd International Conference on Neural Field Theory (ICNFT), https://hal.inria.fr/hal-01015038

[14] P. GARCIA-RODRIGUEZ, A. HUTT. *Bursting suppression in propofol-induced general anesthesia as bi-stability in a non-linear neural mass model*, July 2014, Twenty Third Annual Computational Neuroscience (CNS) meeting [*DOI :* 10.1186/1471-2202-15-S1-P139], https://hal.inria.fr/hal-01064130

[15] M. HASHEMI, A. HUTT. *A thalamacortical feedback model to explain EEG during anesthesia*, January 2014, https://hal.inria.fr/hal-00912405

[16] M. HASHEMI, A. HUTT, J. SLEIGH, P. B. GRABEN. *Reproduction of EEG power spectrum over frontal region during the propofol-induced general anesthesia*, July 2014, vol. 15, n^{o} Suppl 1, Twenty Third Annual Computational Neuroscience Meeting: CNS - 2014, P211 [*DOI :* 10.1186/1471-2202-15-S1-P211], https://hal.inria.fr/hal-01026526

[17] M. HASHEMI, A. HUTT, J. SLEIGH. *How the cortico-thalamic feedback affects the EEG power spectrum over frontal and occipital regions during propofol-induced anaesthetic sedation*, December 2014, https://hal.inria.fr/hal-01091503

[18] A. HUTT, M. HASHEMI, P. BEIM GRABEN. *How to render Neural Fields more realistic*, June 2014, https://hal.inria.fr/hal-01007681

[19] J. LEFEBVRE, A. HUTT, K. WHITTINGSTALL, M. MURRAY. *Stochastic modulation of oscillatory neural activity*, July 2014, vol. 15, n^{o} Suppl 1, Twenty Third Annual Computational Neuroscience Meeting: CNS - 2014, P80 [*DOI :* 10.1186/1471-2202-15-S1-P80], https://hal.inria.fr/hal-01026527

[20] E. NICHOLS, K. GREEN, A. HUTT, L. VAN VEEN. *Two-dimensional patterns in neural fields subject to finite transmission speed*, BMC Neuroscience, July 2014, vol. 15, 16 p. , Twenty Third Annual Computational Neuroscience Meeting [*DOI :* 10.1186/1471-2202-15-S1-P16], https://hal.inria.fr/hal-01064153

[21] K. K. SELLERS, D. V. BENNETT, A. HUTT, J. H. WILLIAMS, F. FROHLICH. *Micro- and Mesoscale Impairment of Sensory Processing and Functional Connectivity in Cortex during Anesthesia*, December 2014, https://hal.inria.fr/hal-01091902