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Project-Team CORTEX

Computational Neuroscience

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CORTEX is a project-team of the LORIA (UMR 7503) common to CNRS, INRIA, University Henri Poincaré Nancy 1 (UHP), University Nancy 2 and National Polytechnic Institute of Lorraine.

1. Team

Research Scientist

Frédéric Alexandre [Research Director (DR) INRIA, Team Leader, HdR]
Axel Hutt [CR]
Nicolas Rougier [CR]
Thierry Viéville [DR (half time in the project-team), HdR]
Thomas Voegtlin [CR]
Dominique Martinez [CR]

Faculty Member

Yann Boniface [Maître de conférences, U. Nancy 2]
Laurent Bougrain [Maître de conférences, UHP]
Bernard Girau [Professeur des Universités, UHP, HdR]

External Collaborator

Hervé Frezza-Buet [Enseignant-Chercheur à Supélec Campus de Metz]

Technical Staff

Baptiste Payan [Junior technical staff, ADT LOIC (from october 2009)]
Marie Tonnelier [Junior technical staff, COMAC (from november 2009)]

PhD Student

Lucian Aleçu [Supelec]
Maxime Ambard [NoE Gospel (until june 2009)]
Hana Belmabrouk [ANR Pherosys]
Mauricio Cerda [Cordi]
Thomas Girod [MESR]
Elham Ghassemi [Cordi/Région]
Randa Kassab [Syria (until june 2009)]
Mathieu Lefort [MESR]
Maxime Rio [Cordi]
Horacio Rostro [CONACIT, co-advised with NEUROMATHCOMP]
Carolina Saavedra [Chile (from october 2009)]
Wahiba Taouali [MESR (from october 2009)]

Post-Doctoral Fellow

Nanying Liang [(until april 2009)]
Jean-Charles Quinton [(from november 2009)]

Administrative Assistant

Martine Kuhlmann [part time in the project-team]

2. Overall Objectives

2.1. Overall Objectives

The goal of our research is to study the properties and computational capacities of distributed, numerical and adaptative networks, as observed in neuronal systems. In this context, we aim to understand how complex high level properties may emerge from such complex systems including their dynamical aspects. In close reference to our domain of inspiration, Neuroscience, this study is carried out at three scales, namely neurons, population, cerebral region.

1. **Neurons:** At the microscopic level, our approach relies on precise and realistic models of neurons and of the related dynamics, analyzing the neural code in small networks of spiking neurons (*cf.* § 3.2).
2. **Population of neurons:** At the mesoscopic level, the characteristics of a local circuit are integrated in a high level unit of computation, i.e. a dynamic neural field (*cf.* § 3.3). This level of description allows us to study larger neuronal systems, such as cerebral maps, as observed in sensori-motor loops.
3. **Higher level functions:** At the macroscopic level, the analysis of physiological signals and psychometric data is to be related to more behavioral hints. This is for instance the case with electroencephalographic (EEG) recordings, allowing to measure brain activity, including in brain computer interface paradigms (*cf.* § 3.4).

Very importantly, these levels are not studied independently and we target progresses at the interface between levels. The microscopic/mesoscopic interface is the place to consider both the analog and asynchronous/event-based mechanisms and derive computational principles coherent across scales. The mesoscopic/macroscopic interface is the place to understand the emergence of functions from local computations, by means of information flow analysis and study of interactions.

Learning is a central issue at each level. At the microscopic level, the pre/post synaptic interactions are studied in the framework of Spike Time Dependent Plasticity (STDP). At the mesoscopic level, spatial and temporal patterns of activity in neural population are the cues to be memorized (e.g. via the BCM rule). At the macroscopic level, behavioral skills are acquired along time, through incremental strategies, e.g. using conditioning, unsupervised or reinforcement learning.

Our research is linked to several scientific domains (*cf.* § 3.1). In the domain of computer science, we generate novel paradigms of distributed spatial computation and we aim at explaining their properties, intrinsic (e.g. robustness) as well as functional (e.g. self-organization). In the domain of cognitive science, our models are used to emulate various functions (e.g. attention, memory, sensori-motor coordination) which are consequently fully explained by purely distributed asynchronous computations. In the domain of neuroscience, we share with biologists, not only data analysis, but also frameworks for the validation of biological and computational assumptions in order to validate or falsify existing models. This is the best way to increase knowledge and improve methods in both fields.

In order to really explore these kinds of bio-inspired computations, the key point is to remain consistent with biological and ecological constraints. Among computational constraints, computations have to be really distributed, without central clock or common memory. The emerging cognition has to be situated (*cf.* § 3.6), i.e. resulting from a real interaction in the long term with the environment. As a consequence, our models are particularly well validated with parallel architectures of computations (e.g. FPGA, clusters, *cf.* § 3.5) and embodied in systems (robots) that interact with their environment (*cf.* § 3.6).

Accordingly, four topics of research have been carried out this year.

- Microscopic level (*cf.* § 6.1): neural code; time coding and synchronization; simulation; application to olfaction.
- Mesoscopic level (*cf.* § 6.2): motion perception; visual attention; motor anticipation; neural field implementation.
- Macroscopic level (*cf.* § 6.3): neural information processing; brain computer interface.

with a transversal topic related to:

- Embodied and embedded systems (*cf.* § 6.4): dedicated architectures.

3. Scientific Foundations

3.1. Computational neuroscience

With regards to the progress that has been made in anatomy, neurobiology, physiology, imaging, and behavioral studies, computational neuroscience offers a unique interdisciplinary cooperation between experimental and clinical neuroscientists, physicists, mathematicians and computer scientists. It combines experiments with data analysis and functional models with computer simulation on the basis of strong theoretical concepts and aims at understanding mechanisms that underlie neural processes such as perception, action, learning, memory or cognition.

Today, computational models are able to offer new approaches of the complex relations between the structural and the functional level of the brain thanks to models built at several levels of description. In very precise models, a neuron can be divided in several compartments and its dynamics can be described by a system of differential equations. The spiking neuron approach (*cf.* § 3.2) proposes to define simpler models concentrated on the prediction of the most important events for neurons, the emission of spikes. This allows to compute networks of neurons and to study the neural code with event-driven computations.

Larger neuronal systems can be considered when the unit of computation is defined at the level of the population of neurons and when rate coding is supposed to bring enough information. Studying Dynamic Neural Fields (*cf.* § 3.3) consequently lays emphasis on information flows between populations of neurons (feed-forward, feed-back, lateral connectivity) and is well adapted to defining high-level behavioral capabilities related for example to visuomotor coordination.

Furthermore, these computational models and methods have strong implications for other sciences (e.g. computer science, cognitive science, neuroscience) and applications (e.g. robots, cognitive prosthesis) as well (*cf.* § 4.1). In computer science, they promote original modes of distributed computation (*cf.* § 3.5); in cognitive science, they have to be related to current theories of cognition (*cf.* § 3.6); in neuroscience, their predictions have to be related to observed behaviors and measured brain signals (*cf.* § 3.4).

3.2. Computational neuroscience at the microscopic level: spiking neurons and networks

Computational neuroscience is also interested in having more precise and realistic models of the neuron and especially of its dynamics. We consider that the latter aspect can not be treated at the single unit level only; it is also necessary to consider interactions between neurons at the microscopic scale.

On one hand, compartmental models describe the neuron at the inner scale, through various compartments (axon, synapse, cellular body) and coupled differential equations, allowing to numerically predict the neural activity at a high degree of accuracy. This, however, is intractable if analytic properties are to be derived, or if neural assemblies are considered. We thus focus on phenomenological punctual models of spiking neurons, in order to capture the dynamic behavior of the neuron isolated or inside a network. Generalized conductance based leaky integrate and fire neurons (emitting action potential, i.e. spike, from input integration) or simplified instantiations are considered in our group.

On the other hand, one central issue is to better understand the precise nature of the neural code. From rate coding (the classical assumption that information is mainly conveyed by the firing frequency of neurons) to less explored assumptions such as high-order statistics, time coding (the idea that information is encoded in the firing time of neurons) or synchronization aspects. At the biological level, a fundamental example is the synchronization of neural activities, which seems to play a role in olfactory perception: it has been observed that abolishing synchronization suppresses the odor discrimination capability. At the computational level, recent theoretical results show that the neural code is embedded in periodic firing patterns, while, more generally, we focus on tractable mathematical analysis methods coming from the theory of nonlinear dynamical systems.

For both biological simulations and computer science emerging paradigms, the rigorous simulation of large neural assemblies is a central issue. Our group is at the origin, up to our best knowledge, of the most efficient event-based neural network simulator, based on well-founded discrete event dynamic systems theory, and now extended to other simulation paradigms, thus offering the capability to push the state of the art on this topic.

3.3. Computational neuroscience at the mesoscopic level: dynamic neural field

Our research activities in the domain of computational neurosciences are also interested in the understanding of higher brain functions using both computational models and robotics. These models are grounded on a computational paradigm that is directly inspired by several brain studies converging on a distributed, asynchronous, numerical and adaptive processing of information and the continuum neural field theory (CNFT) provides the theoretical framework to design models of population of neurons.

This mesoscopic approach underlines that the number of neurons is very high, even in a small part of tissue, and proposes to study neuronal models in a continuum limit where space is continuous and main variables correspond to synaptic activity or firing rates in population of neurons. This formalism is particularly interesting because the dynamic behavior of a large piece of neuronal tissue can be studied with differential equations that can integrate spatial (lateral connectivity) and temporal (speed of propagation) characteristics and display such interesting behavior as pattern formation, travelling waves, bumps, etc.

The main cognitive tasks we are currently interested in are related to the autonomous navigation of a robot in an unknown environment (perception, sensorimotor coordination, planning). The corresponding neuronal structures we are modeling are part of the cortex (perceptive, associative, frontal maps) and the limbic system (hippocampus, amygdala, basal ganglia). Corresponding models of these neuronal structures are defined at the level of the population of neurons and functioning and learning rules are built from neuroscience data to emulate the corresponding information processing (filtering in perceptive maps, multimodal association in associative maps, temporal organization of behavior in frontal maps, episodic memory in hippocampus, emotional conditioning in amygdala, selection of action in basal ganglia). Our goal is to iteratively refine these models, implement them on autonomous robots and make them cooperate and exchange information, toward a completely adaptive, integrated and autonomous behavior.

3.4. Brain Signal Processing

The observation of brain activity and its analysis with appropriate data analysis techniques allow to extract properties of underlying neural activity and to better understand high level functions. This study needs to investigate and integrate, (i) in a single trial, information (ii) spread in several cortical areas and (iii) available at different scales (MUA, LFP, ECoG, EEG).

One major problem is how to be able to deal with the variability between trials. Thus, it is necessary to develop robust techniques based on stable features. Specific modeling techniques should be able to extract features investigating the time domain and the frequency domain. In the time domain, template-based unsupervised models allows to extract graphic-elements. Both the average technique to obtain the templates and the distance used to match the signal with the templates are important, even when the signal has a strong distorted shape. The study of spike synchrony is also an important challenge. In the frequency domain, features such as phases, frequency bands and amplitudes contain different pieces of information that should be properly identified using variable selection techniques. In both cases, compression techniques such as PCA can reduce the fluctuations of the cortical signal. Then, the developed models have to be able to track the drift of these features over the time.

Another problem is how to integrate information spreads in different areas and relate this information in a proper time window of synchronization to behavior. For example, feedbacks are very important to better understand a closed-loop control of hand grasp. But between the preparatory signal, the execution of the movement and the visual and somatosensory feedbacks a delay exists. Here, it is also necessary to use stable features to build a mapping between areas using supervised models taking into account a time window shift.

Several recoding techniques exist providing different kinds of information. Some of them provide very local information such as multiunit activities (MUA) and local field potential (LFP) in one or several well-chosen cortical areas. Other ones provide global information about close regions such electrocorticography (ECoG) or the whole scalp such as electroencephalography (EEG). If surface electrodes allow to easily obtain brain imaging, it is more and more necessary to better investigate the neural code.

3.5. Connectionist parallelism

Connectionist models, such as neural networks, are the first models of parallel computing. Artificial neural networks now stand as a possible alternative with respect to the standard computing model of current computers. The computing power of these connectionist models is based on their distributed properties: a very fine-grain massive parallelism with densely interconnected computation units.

The connectionist paradigm is the foundation of the robust, adaptive, embeddable and autonomous processings that we develop in our team. Therefore their specific massive parallelism has to be fully exploited. Furthermore, we use this intrinsic parallelism as a guideline to develop new models and algorithms for which parallel implementations are naturally made easier.

Our approach claims that the parallelism of connectionist models makes them able to deal with strong implementation and application constraints. This claim is based on both theoretical and practical properties of neural networks. It is related to a very fine parallelism grain that fits parallel hardware devices, as well as to the emergence of very large reconfigurable systems that become able to handle both adaptability and massive parallelism of neural networks. More particularly, digital reconfigurable circuits (e.g. FPGA, Field Programmable Gate Arrays) stand as the most suitable and flexible device for fully parallel implementations of neural models, according to numerous recent studies in the connectionist community. We carry out various arithmetical and topological studies that are required by the implementation of several neural models onto FPGAs, as well as the definition of hardware-targetted neural models of parallel computation.

This research field has evolved within our team by merging with our activities in behavioral computational neuroscience. Taking advantage of the ability of the neural paradigm to cope with strong constraints, as well as taking advantage of the highly complex cognitive tasks that our behavioral models may perform, a new research line has emerged that aims at defining a specific kind of brain-inspired hardware based on modular and extensive resources that are capable of self-organization and self-recruitment through learning when they are assembled within a perception-action loop.

3.6. The embodiment of cognition

Recent theories from cognitive science stress that human cognition emerges from the interactions of the body with the world. Through motor actions, the body can orient toward objects to better perceive and analyze them. The analysis is performed on the basis of physical measurements and more or less elaborated emotional reactions of the body, generated by the stimuli. This will elicit other orientation activities of the body (approach and grasping or avoidance). This elementary behavior is made possible by the capacity, at the cerebral level, to coordinate the perceptive representation of the outer world (including the perception of the body itself) with the behavioral repertoire that it generates either on the physical body (external actions) or on a more internal aspect (emotions, motivations, decisions). In both cases, this capacity of coordination is acquired from experience and interaction with the world.

The theory of the situatedness of cognition proposes to minimize representational contents (opposite to complex and hierarchical representations) and privileges simple strategies, more directly coupling perception and action and more efficient to react quickly in the changing environment.

A key aspect of this theory of intelligence is the Gibsonian notion of affordance: perception is not a passive process and, depending on the current task, objects are discriminated as possible “tools” that could be used to act in the environment. Whereas a scene full of details can be memorized in very different and costly ways, a task-dependent description is a very economical way that implies minimal storage requirements. Hence, remembering becomes a constructive process.

For example with such a strategy, the organism can keep track of relevant visual targets in the environment by only storing the movement of the eye necessary to foveate them. We do not memorize details of the objects but we know which eye movement to perform to get them: The world itself is considered as an external memory.

Our agreement to this theory has several implications for our methodology of work. In this view, learning emerges from sensorimotor loops and a real body interacting with a real environment are important characteristics for a learning protocol. Also, in this view, the quality of memory (a flexible representation) is preferred to the quantity of memory.

4. Application Domains

4.1. Overview

Our application domain is twofold:

On one hand, neuro-scientists are end-users of our research. Data analysis is one issue, but the main outcomes concern the validation of biological assumptions either at a theoretical level or via numerical experiments and simulation of bio-processes. This includes algorithmic expertises and dedicated softwares.

On the other hand, science and technology of information processing is impacted. This concerns embedded systems such as in-silico implementations of bio-inspired processes, focusing on spatial and distributed computing. This also concerns embodied systems such as robotic implementation of sensori-motor loops, the bio-inspiration yielding such interesting properties as adaptivity and robustness.

5. Software

5.1. Spiking neural networks simulation

Participants: Dominique Martinez, Thierry Viéville.

A spiking neuron is usually modeled as a differential equation describing the evolution over time of its membrane potential. Each time the voltage reaches a given threshold, a spike is sent to other neurons depending on the connectivity. A spiking neural network is then described as a system of coupled differential equations. For the simulation of such a network we have written two simulation engines : (i) mvaspike based on an event-driven approach and (ii) sirene based on a time-driven approach.

- Mvaspike : The event-driven simulation engine was developed in C++ by O. Rochel during his PhD thesis and is available on http://gforge.inria.fr/projects/mvaspike. Mvaspike is a general event-driven purpose tool aimed at modeling and simulating large, complex networks of biological neural networks. It allows to achieve good performance in the simulation phase while maintaining a high level of flexibility and programmability in the modeling phase. A large class of spiking neurons can be used ranging from standard leaky integrate-and-fire neurons to more abstract neurons, e.g. defined as complex finite state machines.
- Sirene : The time-driven simulator engine was written in C and developed for the simulation of biologically detailed models of neurons —such as conductance-based neurons— and synapses. Its high flexibility allows the user to implement easily any type of neuronal or synaptic model and use the appropriate numerical integration routine (e.g. Runge-Kutta at given order).

5.2. DANA: Implementation of computational neuroscience mechanisms

Participants: Nicolas Rougier, Thomas Girod, Mathieu Lefort.

Computational neuroscience is a vast domain of research going from the very precise modeling of a single spiking neuron, taking into account ion channels and/or dendrites spatial geometry up to the modeling of very large assemblies of simplified neurons that are able to give account of complex cognitive functions. DANA attempts to address this latter modeling activity by offering a python computing framework for the design of very large assemblies of neurons using numerical and distributed computations. However, there does not exist something as a unified model of neuron: if the formal neuron has been established some sixty years ago, there exists today a myriad of different neuron models that can be used within an architecture. Some of them are very close to the original definition while some others tend to refine it by providing extra parameters or variables to the model in order to take into account the great variability of biological neurons. DANA makes the assumption that a neuron is essentially a set of numerical values that can vary over time due to the influence of other neurons and learning. DANA aims at providing a constrained and consistent python framework that guarantee this definition to be enforced anywhere in the model, i.e., no symbol, no homonculus, no central executive.

5.3. ENAS: Event Neural Assembly Simulation

Participants: Frédéric Alexandre, Axel Hutt, Nicolas Rougier, Thierry Viéville.

EnaS (that stands for “Event Neural Assembly Simulation”) is a middleware implementing our last numerical and theoretical developments, allowing to simulate and analyze so called "event neural assemblies". The recent achievements include (in collaboration with the Neuromathcomp EPI): spike trains statistical analysis via Gibbs distributions, 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. It has been designed as plug-in for our simulators (e.g. DANA or MVASpike) as other existing simulators (via the NeuralEnsemble meta-simulation platform) and additional modules for computations with neural unit assembly on standard platforms (e.g. Python or the Scilab platform).

5.4. GINNet-DynNet: Decision-making platform

Participant: Laurent Bougrain.

GINNet (Graphical Interface for Neural Networks) is a decision-aid platform written in Java, intended to make neural network teaching, use and evaluation easier, by offering various parametrizations and several data pre-treatments. GINNet is based upon a local library for dynamic neural network developments called DynNet. DynNet (Dynamic Networks) is an object-oriented library, written in Java and containing base elements to build neural networks with dynamic architecture such as Optimal Cell Damage and Growing Neural Gas. Classical models are also already available (multi-layer Perceptron, Kohonen self-organizing maps, ...). Variable selection methods and aggregation methods (bagging, boosting, arcing) are implemented too.

The characteristics of GINNet are the following: Portable (100% Java), accessible (model creation in few clicks), complete platform (data importation and pre-treatments, parametrization of every models, result and performance visualization). The characteristics of DynNet are the following: Portable (100% Java), extensible (generic), independent from GINNet, persistent (results are saved in HML), rich (several models are already implemented), documented.

This platform is composed of several parts:

1. Data manipulation: Selection (variables, patterns), descriptive analysis (stat., PCA..), detection of missing, redundant data.
2. Corpus manipulation: Variable recoding, permutation, splitting (learning, validation, test sets).
3. Supervised networks: Simple and multi-layer perceptron.
4. Competitive networks: Kohonen maps, Neural Gas, Growing Neural Gas.
5. Metalearning: Arcing, bagging, boosting.
6. Results: Error curves, confusion matrix, confidence interval.

DynNet and GINNet are free softwares, registrated to the APP and distributed under CeCILL license, Java 1.4 compatible (http://ginnet.gforge.inria.fr). GINNet is available as an applet. For further information, see http://gforge.inria.fr/projects/ginnet (news, documentations, forums, bug tracking, feature requests, new releases...)

5.5. EEG acquisition module for OpenViBE

Participants: Laurent Bougrain, Baptiste Payan.

In the domain of Brain-Computer Interface (BCI), we developed an acquisition module to interface the OpenViBE plateform (http://www.irisa.fr/bunraku/OpenViBE) to an EEG (electroencephalographic) amplifier by TMSi. This module allows to send data collected from our experiments to this well-known platform. We aim to compare our algorithms with the ones developed by the other community members.

6. New Results

6.1. Spiking neurons

Participants: Maxime Ambard, Hana Belmabrouk, Yann Boniface, Dominique Martinez, Thierry Viéville, Thomas Voegtlin.

6.1.1. Analysis of experimental data:

We study the encoding of sensory information in the mammal olfactory bulb –in collaboration with P.M. Lledo from the Pasteur Institute, Paris– and in the insect antennal lobe –in collaboration with J.P. Rospars from INRA, Versailles–.

In the collaborative work with the Pasteur Institute, we analysed the correlation between the firing of individual neurons and the network oscillation. Analysis of electrophysiological data, recorded in vitro from rat olfactory bulb slices, shows that mitral cell firing is phase-locked to the fast (gamma range) local field potential oscillation. This phase-locking is largely reduced when the inhibitory synaptic conductance is pharmacologically blocked, hence highlighting the important role of synaptic inhibition. In order to extract the time course of the inhibitory synaptic conductance, we have developed a new method based on the adjustment of a neuron model from experiments with local injections of a synaptic blocker. Using this method, we found that the inhibitory conductance fluctuations are correlated to the local field potential oscillations. A relationship between the received inhibition and the phase of mitral action potentials is also revealed. The probability to fire a phase-locked action potential increases if the neuron receives a large number of inhibitory synaptic events, and if these events are themselves phase-locked [1]. This finding confirms our model prediction.

In the collaborative work with INRA, we analysed the spike timing precision of pheromone sensitive neurons in the antennal lobe of the moth Agrotis ipsilon. Spike train activity from several neurons was first recorded in vivo in responsive areas of the macroglomerular complex and individual spike trains were identified using spike sorting. A statistical tool was then developed to segment and characterize individual spike trains. It reveals that antennal lobe neurons have a stereotyped and synchronized response in the presence of pheromones. From repeated measurements, we show that the response is both precise (temporal jitter of spikes over trials $<$ 4ms) and robust (probability of loosing spikes over trials < 0.1) [25]. The stereotyped response and its extreme precision leads to certain hypotheses concerning intrinsic properties of these neurons.

6.1.2. Modeling at the neuronal level:

A major paradigm in computational neuroscience is that information is encoded in the precise timing of individual spikes, rather than in the mean firing rate. In order to understand the neural code, it seems therefore important to focus on the response of a neuron to an incoming current. This response depends on its internal state, in a way that is described by a Phase Response Curve. We have developed a theory of temporal coding based on this principle. The idea is that the meaning of a spike arriving at a synapse depends on the post-synaptic neuron's dynamic state. If the post-synaptic neuron is in a highly excitable state, and responds well to incoming currents, then an incoming spike will code for a high value. Therefore the time at which this neuron is excitable can be used to encode high values. Conversely, low values correspond to times when the neuron is less excitable. We have derived a learning algorithm for spiking neural networks, based on this principle, that generalizes single-layer and multi-layer perceptron learning in spiking neurons [12]. Another development of this theory uses Spike Timing Dependent Plasticity, a biologically plausible learning mechanism, in order to extract the principal components of the distribution of a time-coded random input vector [15].

Following this line of research, we carried on with a study that focuses on synchronized firings across neurons and phase-locking to the network oscillation. More precisely, we investigated the formation of synchronized neural assemblies in inhibitory networks. First, a mathematical analysis revealed that oscillatory synchronization requires precise and balanced inhibition. This model prediction was further tested on experimental data from olfactory bulb slices (see above, section about data analysis). Second, we studied the role of inhibitory, noisy interactions in producing stimulus-specific synchrony. From theoretical analysis and computer simulations, we found that slow inhibition plays a key role in desynchronizing neurons. Depending on the balance between fast and slow inhibitory inputs, particular neurons may either synchronize or desynchronize themselves. The complementary roles of the two synaptic time scales in the formation of neural assemblies suggest a wiring scheme that produces stimulus-specific inhibitory interactions and endows inhibitory sub-circuits with properties of binary memories. The relative number between fast GABA-A and slow GABA-B inputs regulates synchrony and determines whether particular projection neurons engage in the neural assembly.

6.1.3. Mathematical analysis of spiking networks

6.1.3.1. Overview of facts and issues about neural coding by spikes: introducing numerical bounds to explain spiking neural networks limits and improve event-based neural network simulation.

In the present colloborative work, we have clarified some aspects of coding with spike-timing, through a simple review of well-understood technical facts regarding spike coding. Our goal is a better understanding of the extent to which computing and modeling with spiking neuron networks might be biologically plausible and computationally efficient [4].

We intentionally restrict ourselves to a deterministic implementation of spiking neuron networks and we consider that the dynamics of a network is defined by a non-stochastic mapping. By staying in this rather simple framework, we are able to propose results, formula and concrete numerical values, on several topics: (i) general time constraints, (ii) links between continuous signals and spike trains, (iii) spiking neuron networks parameter adjustment. Beside an argued review of several facts and issues about neural coding by spikes, we propose new results, such as a numerical evaluation of the most critical temporal variables that schedule the progress of realistic spike trains [51].

When implementing spiking neuron networks, for biological simulation or computational purpose, it is important to take into account the indisputable facts here unfolded [6]. This precaution could prevent one from implementing mechanisms that would be meaningless relative to obvious time constraints, or from artificially introducing spikes when continuous calculations would be sufficient and more simple. It is also pointed out that implementing a large-scale spiking neuron network is finally a simple task.

6.1.3.2. Reverse-engineering of spiking neural networks parameters

We consider the deterministic evolution of a time-discretized network of spiking neurons with connection weights having delays, modeled as a discretized neural network of the generalized integrate and fire (gIF) type. The purpose is to study a class of algorithmic methods allowing to calculate the proper parameters to reproduce exactly a given spike train generated by an hidden (unknown) neural network.

This standard problem is known as NP-hard when delays are to be calculated. We propose here a reformulation, now expressed as a Linear-Programming (LP) problem, thus allowing to provide an efficient resolution. This allows us to “back-engineer” a neural network, i.e. to find out, given a set of initial conditions, which parameters (i.e., connection weights in this case), allow to simulate the network spike dynamics.

More precisely we make explicit the fact that the back-engineering of a spike train, is a Linear (L) problem if the membrane potentials are observed and a LP problem if only spike times are observed, with a gIF model. Numerical robustness is discussed. Furthermore, we point out how the L or LP adjustment mechanism is local to each unit and has the same structure as an “Hebbian” rule [42].

A step further, this paradigm has been generalizabled to the design of input-output spike train transformations. This means that we have a practical method to “program” a spiking network, i.e. find a set of parameters allowing us to exactly reproduce the network output, given an input [43].

6.1.3.3. Parametric Estimation of spike train statistics, with Gibbs Distributions and application to Synaptic Adaptation Mechanisms

We consider the evolution of a network of neurons, focusing on the asymptotic behavior of spikes dynamics instead of membrane potential dynamics. The spike response is not sought as a deterministic response in this context, but as a conditional probability: "Reading the code" consists in inferring such a probability.

This probability is computed from empirical raster plots, by using the framework of thermodynamic formalism in ergodic theory. This gives us a parametric statistical model where the probability has the form of a Gibbs distribution. In this respect, this approach generalizes the seminal and profound work of Schneidman, Bialek and collaborators [40].

A minimal presentation of the formalism is reviewed here, while a general algorithmic estimation method is proposed, minimizing the relative entropy, yielding fast convergent implementations. It is also made explicit how several spike observables (entropy, rate, synchronizations, correlations) are given in closed-form from the parametric estimation [41].

This paradigm does not only allow us to estimate the spike statistics, given a design choice, but also to compare different models, thus answering comparative questions about the neural code such as : are correlations (or time synchrony or a given set of spike patterns, ..) significant with respect to rate coding ?

A numerical validation of the method is proposed and the perspectives regarding spike-train code analysis are also discussed [44].

A step further, we use this mechanism to help Bruno Cessac (from NeuroMathComp EPI) to study the effects of synaptic plasticity on these statistics and introduce a framework in which spike trains are associated to a coding of membrane potential trajectories, and actually, constitute a symbolic coding in important explicit examples (the so-called gIF models). For instance, it has been shown that Gibbs distributions naturally arise when considering "slow" synaptic plasticity rules where the characteristic time for synapse adaptation is quite longer than the characteristic time for neurons dynamics [5].

6.1.4. Simulation tools :

We have developed two simulators for the numerical simulation of spiking neural network models. In SIRENE, a time-stepping method (Runge-Kutta) approximates the membrane voltage of neurons on a discretized time. In MVASpike, computation of the firing times is driven by local or global events.

- Global event-driven: In a pure event-driven strategy, an event corresponds to the reception or the emission of a spike. The spike timings are analytically given and are calculated with an arbitrary precision (up to the machine precision). This scheme allows an exact simulation where no spike is missed. However only a limited class of simplified neuron models of integrate-and-fire type is amenable to exact simulations.
- Local event-driven: we have recently proposed a novel integration scheme, called voltage-stepping, that discretizes the voltage state-space [16]. Voltage stepping produces new events: the events are not only firing times or spike receptions but also the times when the current voltage reaches a new

voltage interval. Local events correspond to a significant variation of the potential of the neuron. Voltage-stepping defines an implicit and adaptive time-step tuned to the dynamics of the membrane potential. We have demonstrated some advantages of voltage-stepping over classical time-stepping methods and global-event driven methods [16]. Voltage-stepping actually combines the advantages of the two approaches, the accuracy of an event driven strategy with the genericity of a time-stepping scheme.

6.2. Dynamic Neural Fields

Participants: Frédéric Alexandre, Yann Boniface, Laurent Bougrain, Mauricio Cerda, Hervé Frezza-Buet, Bernard Girau, Thomas Girod, Axel Hutt, Mathieu Lefort, Nicolas Rougier, Wahiba Taouali, Thierry Viéville, Thomas Voegtlin.

The work reported this year represents both extensions of previous works and new results linked to the notion of neural population, considered at (i) a formal level (theorical studies of neural fields), (ii) a numerical level (interface with the spike level) and (iii) a more embodied one (implementations).

6.2.1. Formal Level

6.2.1.1. Synchronous and Asynchronous Computations

Several artificial neuron models are best described by a set of continuous differential equations that define the evolution of some variables over time, e.g. the membrane potential of the neuron. When these models are connected together, we obtain a differential equation system with complex inter-dependent interactions. To gain the solution of such a system, in general it requires a numerical integration since in the vast majority of cases there is no analytical solution. Regardless of the numerical method used, we emphasize the fact that all these numerical methods actually require a central clock to synchronize computations. In this context, we would like to study the extent to which we can remove this central clock and implement asynchronous computations. We have thus studied this phenomenon in some details and characterized the relation between noise, synchronous evaluation (the "regular" mathematical integration) and asynchronous evaluation in the case of a simple dual particle system [33]. More generally, we aim at explaining the behavior of a general differential equation system when it is considered as a set of particles that may or may not be iterated by synchronous computations.

6.2.1.2. Algorithmic adjustment of neural field parameters.

We have completed this study of neural-field calculation maps parameter adjustment in the discrete case. Algorithmic mechanisms allowing to choose a right set of parameters in order to both (i) guaranty the stability of the calculation and (ii) tune the shape of the output map, have been proposed. These results do not "prove" the existence of stable bump solutions, this being already known and extensively verified numerically, but allow to calculate algorithmically the related parameters. The results apply to scalar and vectorial neural-fields thus allowing to bypass the inherent limitations brought by mean frequency models and also take the laminar structure of the cortex or high-level representation of cortical computations into account [50].

6.2.2. Numerical level

6.2.2.1. Learning.

Feed-forward, feed-back and lateral information flows can be extracted in cortically-inspired neural fields. Beyond the question of their respective effects stands the question of the learning rules that can be associated to each of them and of their interactions. We are studying the question with learning rules inspired from the BCM paradigm[1], where a dynamic threshold between LTP and LTD (resp. Long Term Potentiation and Depression) depends on the history of activations. Such learning rules are local and unsupervised, which is very interesting in the framework of neural fields, and have demontrated the ability to learn orientation selectivity from feed-forward and lateral connectivity. In this framework, we have also shown that the feed-back flow could be used as a modulatory influence, for example to signal the interest of some stimuli and accelerate their learning [27].

[1] Bienenstock, E.L. and Cooper, L.N. and Munro, P.W.; Theory for the Development of Neuron Selectivity: Orientation Specificity and Binocular Interaction in Visual Cortex. J Neurosci (2); 1982

6.2.2.2. Qualitatively quantifying neural fields.

In collaboration with Supelec, we have proposed to define the properties of a neural field through a set of behaviors it should display, when facing certain characteristic inputs. Accordingly, we have defined some statistical measurements to quantify the performances of a neural field in such situations. On this basis, we have proposed a new neural field model [18] particularly suited to implement the competitive processing required in a map performing self organization. With the addition of Kohonen-like learning rules on the input information flow, we therefore obtain a self organization process emerging from purely distributed computations, which was not possible with Kohonen-like self-organizing maps. Future works correspond to the implementation of the model on a really distributed architecture and to its extension to multi-maps multimodal learning.

6.2.2.3. Multimodal learning through joint dynamic neural fields

This work relates to the development of a coherent multimodal learning for a system with multiple sensory inputs in order to obtain different maps which are topographically organized (two spatially close neurons respond to close stimuli). We have modified the BCM synaptic rule, a local learning rule, to obtain the self organization of our neuronal inputs maps and we use a CNFT based competition to drive the BCM rule. In practice, we introduce a feedback modulation of the learning rule, representing multimodal constraints of the environment. This feedback is obtained using a relaxation between the different layers of the sensory and associative maps of the system.

6.2.2.4. Dynamic Neural Field using spikes

We've been studying the spiking diffusion of a neural field model that is an extension of lateral inhibition-type neural field models. The major breakthrough of this work is the possibility to use both spiking neurons (instead of regular rate-coding neuron models) and a restricted pattern of lateral connectivity. The suppression of the common global inhibition signal is compensated by a diffusion phenomenon that allows to transport information from one point to another. In the end we obtain a model of fast visual tracking that aimed to be implemented on FPGA hardware allowing real time multi-target tracking.

6.2.3. Embodied level

6.2.3.1. Motion detection.

We develop bio-inspired neural architectures to detect, extract and segment the direction and speed components of the optical flow within sequences of images. The structure of these models derives from the course of the optical flow in the human brain. It begins in the retina and receives various treatments at every stages of its magnocellular pathway through the thalamus and the cortex. Our models mostly handle the properties of three cortical areas called V1 (primary visual area), MT (middle temporal), and MST (middle superior temporal): the MT area detects patterns of movement, while spatio-temporal integration is made at the local level by V1 and at the global level by both MT and MST. This work faces many concrete difficulties, such as specular effects, shadowing, texturing, occlusion and aperture problems. Moreover, the complexity of this task must be dealt with within the implementation constraint of real-time processing. Recent works have focused on two extensions of our initial models.

- We have developped a bio-inspired parallel architecture to perform detection of motion, providing a wide range of operation and avoiding the error propagation associated with the usual serial multiscale approaches [24]. Our architecture is inspired by biological experiments that show that human motion perception seems to follow a parallel multiscale scheme.
- We now address the complex task of recognizing visual motion patterns such as walking, fighting and face gestures among others. Based on experiments in psychophysics, electro-physiological data and functional imaging techniques, we show that several key features of the human recognition of visual motion patterns may be modeled using 2D asymmetric neural fields [34]. Our model implements template-based recognition, that may be related to the existence of units or populations acting as snapshots in the dorsal pathway. To validate our model on real video sequences, we have defined a setup for the acquisition of synchronized 2D and 3D sequences based on Vicon cameras. This work has been performed in relation with our STIC-AmSud BAVI project depicted in § 7.4.

6.2.3.2. Modeling the superior colliculus by mean of a neural field.

In the context of the ANR MAPS project (cf. § 7.2), we have been studying the superior colliculus in tight collaboration with Laurent Goffart from the Institut de Neurosciences Cognitives de la Méditerranée. Considering the cortical magnification induced by the non homogeneous distribution of retina rods and cones on the retina surface, we modeled the superior colliculus using a dynamic neural field that may explain the stereotyped nature of colliculus activity. The process of building experimental setup using monkeys to check model predictions is currently ongoing. In the same context in collaboration with the Maia team, we are studying the cerebellum structure in order to understand how the motor command from the colliculus can be adjusted/modulated through learning.

6.2.3.3. Modeling of neural activity during anaesthesia.

Anaesthesia plays an important role in medical surgery though its neural mechanism is still poorly understood. Besides several different molecular and behavioral phenomena, the administration of anaesthetic agents affects the power spectrum of electro-encephalographic activity (EEG) in a characteristic way. The theoretical study aims to model the power spectrum changes in EEG subject to the concentration of the specific anaesthetic agent propofol. The work developed a neural model involving two neuron types and synapse types while taking into account the synaptic effect of propofol. The mathematical derivation of the power spectrum allows for the investigation of suitable physiological parameters which reproduce the experimental effect of propofol. Several mathematical conditions on physiological parameters have been derived and the EEG-power spectrum during the administration of different concentration levels of propofol has been modeled successfully.

6.3. Higher level functions

Participants: Frédéric Alexandre, Laurent Bougrain, Axel Hutt, Nanying Liang, Randa Kassab, Maxime Rio, Carolina Saavedra.

This year, our activities concerned information analysis and interpretation and the design of numerical distributed and adaptive algorithms in interaction with biology and medical science. To better understand cortical signals, we choose a top-down approach for which data analysis techniques extract properties of underlying neural activity. To this end several unsupervised methods and supervised methods are investigated and integrated to extract features in measured brain signals.

6.3.1. Template-based classifiers to detect evoked potentials

To detect efficiently transient events in multivariate time series, we develop pattern recognition techniques for graphic elements, e.g. event-related potential, auditory evoked potential, k-complex, sleep spindles or vertex waves, which are present in electroencephalographic signals [17]. More specifically, template-based classifiers have been proposed to robustly detect evoked potentials in a single trial from noisy and multi-sources electro-encephalographic (EEG) signals. In this context, we have extended the learning vector quantization (LVQ) algorithm by Kohonen to non-identity assignment to robustly detect evoked potentials in noisy electro-encephalographic (EEG) signals for brain-computer interfaces (BCIs). The improved LVQ is obtained by optimizing its assignment layer using the minimum-norm least-square algorithm, the same scheme used by extreme learning machine (ELM)[2]. The proposed LVQ is evaluated using the Wadsworth P300 speller dataset from BCI competition III. The experimental results show that the proposed algorithm improves the accuracy with less computational units compared to original LVQ and ELM. Based on these results, an international STIC AmSud project started in 2009 on P300 single-trial detection (cf. § 7.4).

6.3.2. Decoding Finger Flexion from ECoG in Brain-Machine Interfaces (BMI)

Over the last two decades, major advances in both multi-electrode recording techniques and the development of decoding algorithms have provided new tools for brain-machine interfaces (BMIs). We developed data analysis techniques to extract properties of underlying neural activity from multi-electrode recordings for direct BMIs

[2] Huang, G.-B., Zhu, Q.-Y. and Siew, C.-K., Extreme learning machine: A new learning scheme of feedforward neural networks, Proceedings of International Joint Conference on Neural Networks, Vol. 2, 985-990, Budapest, Hungary, (2004).

for the control of a skilled hand movement. We won the international BCI competition IV, datasets 4, on the prediction of individual finger flexion from electro-corticogram (ECoG) using amplitude modulation in specific bands. We built a linear decoding scheme based on bandspecific amplitude modulation with a window to the past for predicting finger flexion from ECoG signals. The sensitivity profile of ECoG is clearly band-specific. The gamma band (60-100Hz) seems to provide more useful information. Only a few features are useful. A half-second window through the past improves the prediction [28], [22].

6.3.3. Detection of synchronization in Local Field Potentials

The brain represents a network of brain areas whose interaction is still poorly understood. It is supposed that the interaction mechanism between these areas is based on the synchronization of the dendritic activities in the areas. Since Local Field Potentials (LFPs) reflect this activity, we focus on the study of LFPs obtained experimentally to better understand the inter-area information exchange. In collaboration with the Max Planck Institute for Biological Cybernetics, we investigate the synchronization of LFPs obtained intracranially from various monkey brain areas. The corresponding experiment combines visual attention and motor action and thus allows for the study of the visio-motor feedback loop. The data analysis [49] aims to detect time windows of increased phase synchronization between brain areas and relates these time windows to the monkey behavior.

6.3.4. Detection of event-related components in single trial EEG

In cognitive experiments, electroencephalograpic data (EEG) may be recorded to investigate the brain activity during cognition and to reveal the information processing pathways in the brain. Typically, the experimental task (one trial) is repeated many times and the resulting brain activity is averaged over trials. The main reason for this averaging is the low signal-to-noise ratio (SNR) in the single trials and average increases the SNR dramatically. The average activity allows to extract easily event-related components, which are strongly related to cognitive processes in the brain.
However, this averaging assumes that the brain responds to the external stimuli identically in all trials. However it has been shown in several previous studies that this assumption is not valid. Consequently, to improve the analysis we develop an algorithm to extract event-related components from single trials. This algorithm is part of the PhD-project of Maxime Rio. It is based on a Gaussian mixture model and is implemented in a Bayesian framework.

6.4. Embodied and embedded systems

Participants: Yann Boniface, Hervé Frezza-Buet, Bernard Girau, Mathieu Lefort, Dominique Martinez, Jean-Charles Quinton, Nicolas Rougier.

6.4.1. InterCell

Our research in the field of dedicated architectures and connectionist parallelism mostly focuses on embedded systems (*cf.* §3.5). Nevertheless we are also involved in a new project that considers coarse-grain parallel machines as implementation devices. The core idea of this InterCell project (part of the MIS axis of the CPER (*cf.* §7.1); *cf.* also http://intercell.metz.supelec.fr) is to map fine grain computation (cells) to the actual structure of PC clusters. The latter rather fit coarse grain processing, using relatively few packed communication, which a priori contradicts neural computing. Another fundamental feature of the InterCell project is to promote interaction between the parallel process and the external world. Both features, cellular computing and interaction, allow to consider the use of neural architectures on the cluster on-line, for the control of situated systems, as robots.

This year, the whole setting up of interactive cellular computation has been realized. It consists of the booz library, released by Hervé Frezza-Buet, that allows the design of cellular computation, providing tools for vizualization, savings, step-by-step execution, on-line communication with the external world. From this core library, the implementation of the escabooz suite has been achieved, allowing to solve PDEs by cellular computation. The Intercell cluster is thus available for such a purpose, rather oriented toward physicists. The implementation of cortically inspired neural networks (the bijama model) is at work, as well as interfaces for integrating on the cluster visual units coupled with a video device, for situated robotic experiments mainly.

6.4.2. Embodied/embedded olfactory systems

In the framework of the associate team BioSens, we constructed a micro-electronic nose model using a semiconductor gas sensor array which incorporates spiking neurons encoding sensory information as suggested by the time-to-first-spike paradigm. This study pioneers the translation of neurophysiological findings into hardware for the processing of electronic noses. Another example of bio-inspired processing is our autonomous olfactory robot, for which we have implemented the novel probabilistic technique Infotaxis of Vergassola et al.: we have shown that, although animal behavioral patterns are not pre-programmed or imposed through explicit rules of movement, these behaviors do actually emerge naturally from the underlying model. New improvements of these systems are currently studied.

6.4.3. Specific hardware implementations

In the field of dedicated embeddable neural implementations, we use our expertise in both neural networks and FPGAs so as to propose efficient implementations of applied neural networks on FPGAs.

Recent works in this axis have mainly focused on implementations of spiking neural models with on-chip learning. This work takes advantage of a highly modular and flexible architecture that is able to fit various hardware constraints and parallelism levels. It mainly consists of a population hardware coding module based on bio-inspired gaussian receptive fields [31], and a spiking neural computation module with or without on-chip learning (using the SpikeProp algorithm) [32]. This work has been carried out within the activities of the CorTexMex associate team (*cf.* §7.4).

6.4.4. Brain-inspired hardware

Our activities on dedicated architectures have strongly evolved in the last years. We now focus on the definition of brain-inspired hardware-adapted frameworks of neural computation. The long-term goal is to define and implement modular and extensive resources that are capable of self-organization and self-recruitment through learning when they are assembled within a perception-action loop. This goal gathers our expertise in neural hardware implementations and behavioral models for sensori-motor tasks.

This year, we have mostly carried out upstream studies that still need a hardware development:

- Our works are based here on dynamic neural fields. In order to cope with hardware connectivity requirements, we have defined a model of dynamic spiking neural fields (in the context of visual attention) that only handles local lateral connections within bio-inspired maps of spiking neurons (see §6.2).
- We also address the problem of the costful local storage of lateral kernels by defining hardware-friendly lateral kernels based on non-euclidean norms or random generation of local influences.
- We have carried out upstream studies to define hardware-compatible protocols to assemble various perception-action modalities that are implemented and associated by different bio-inspired neural maps. The hardware plausibility of this model requires simplified local interconnections. We have introduced a new perceptive level that only needs a local feedback interaction from the competitive layer (see the paragraph on “Multimodal learning” in §6.2). We intend to mix this approach with our definition of spiking neural fields (at the competitive level), to be able to satisfy the hardware constraints of the assembling of neural maps.

7. Other Grants and Activities

7.1. Regional initiatives

7.1.1. Action Modeling, Simulation and Interaction of the CPER

Participants: Frédéric Alexandre, Hervé Frezza-Buet, Nicolas Rougier.

In the framework of the Contrat de Projet État Région, we are contributing to the axis MIS (Modeling, Interaction and Simulation) through the project InterCell whose goal is to study massive cellular computations in an interactive framework (*cf.* § 6.4).

7.2. National initiatives

7.2.1. DGE Ministry grant COMAC "Optimized multitechnique control of aeronautic composite structures"

Participants: Laurent Bougrain, Marie Tonnelier.

The goal of this three-years project is to develop a powerful system of control on site, in production and in exploitation, of aeronautical pieces made of composite. It takes up the challenge of the precise, fast and local inspection on composite pieces of aeronautical structures new or in service by using techniques of non-destructive control more effective and faster to increase the lifespans of the structures of planes. This project requires a decision-making system including fast methods of diagnostic based on several optical technics as non-destructive control.

7.2.2. Bio-inspired spatial computing: ARC Amybia

Participant: Bernard Girau.

Our regular collaborations with researchers from the Maia team have shown that we share common computation paradigms based on massively distributed and local models that are inspired by biological systems. This has led us to join our efforts in an original collaboration within the Amybia project led by Nazim Fatès (ARC INRIA), together with Hugues Berry who works on similar models by exploring a bio-inspired approach to propose challenging paradigms for spatial computing within the Alchemy team. This collaboration is also linked with our hardware implementation activities, since it has resulted in an embedded implementation of a biological inspired model for the decentralized gathering of computing agents, as well as in a block-synchronous implementation of the environment of this model to study its phase transition properties [7].

7.2.3. ARC MACCAC

Participants: Frédéric Alexandre, Thierry Viéville.

Since neuronal information processing is related to the brain bio-electrical activity, measured by current neuro imaging techniques at different time and space scales, from neurons to the brain as a whole (e.g. LFP, ECoG, EEG, MEG), the analysis of such complex data coming from these measurements requires the parallel development of suitable models. Namely, these models have to be, on the one hand, close enough to phenomenology, taking into account the various types of bio-electrical activity and their scales relations, in order to propose a coherent representation of information processing in the brain (from neurons to neuronal populations, cortical columns, brain area, etc). On the other hand, these models must be well posed and analytically tractable. This requires a constant interaction between neurobiology, modeling and mathematics. In this spirit, this project, directed by Bruno Cessac (NEUROMATHCOMP), aims to tackle the following questions: (i) Mesoscopic modeling of cortical columns, bifurcations, and imaging. (ii) Statistical analysis of spike trains. The CORTEX team brings its computer science expertise, mainly regarding the question (ii) and the OI modality regarding the question (i). Collaborations with other teams (ALCHEMY (INRIA); CORTEX (INRIA); INCM (CNRS); LJAD (U NiceCNRS); NEUROMATHCOMP (INRIA)) are developed thanks to this initiative.

7.2.4. ANR project PHEROSYS

Participants: Dominique Martinez, Hana Belmabrouk.

This collaborative project in systems Biology (ANR-BBSRC SysBio) with INRA (Paris, FR) and the University of Sussex (UK) explores olfactory coding in the insect pheromone pathway through models and experiments. More information available at http://www.informatics.sussex.ac.uk/research/projects/PheroSys/index.php/.

7.2.5. ANR project MAPS

Participants: Frédéric Alexandre, Yann Boniface, Elham Ghassemi, Nicolas Rougier, Thierry Viéville.

This collaborative project with INCM (Marseille), UMR Perception and Movement (Marseille) and LIRIS (Lyon) aims at re-examining the relationship between structure and function in the brain, taking into account the topological (spatial aspects) and hodological (connectivity) constraints of the neuronal substrate. We think that those constraints are fundamental for the understanding of integrative processes, from the perception level to the motor level and the initiation of coordinated actions.

7.2.6. Project of the CNRS NeuroInformatics program on olfaction

Participant: Dominique Martinez.

The project "Olfactory coding" (2008-2009) from the CNRS program "Neuroinformatics" with the CNRS UMR5020 (Lyon) explores the role of spike timing in olfactory coding.

7.2.7. Project of the CNRS NeuroInformatics program on reinforcement learning

Participants: Frédéric Alexandre, Hervé Frezza-Buet, Nicolas Rougier.

In this collaboration with the MAIA team, Supelec Campus de Metz and the Interative and Cognitive Neuroscience Centre in Bordeaux, we are developing bio-inspired reinforcement learning procedures, on the basis of experimental data from behavioral recordings in rats.

7.2.8. Project of the CNRS NeuroInformatics program on neural coding in the retina

Participants: Frédéric Alexandre, Laurent Bougrain, Axel Hutt, Thierry Viéville.

The new project "Sensory Transduction to Perception " (2009-2010) from the CNRS program "Neuroinformatics" aims to initiate the research cooperation of groups at the University of Nice, the University of Santiago de Chile and the University of Valparaiso in Chile. The aim of the project is the better understanding of the neural coding in the retina in the presence of natural stimuli. To this end, in-vivo experiments are performed in the Chilean laboratories and the French groups analyse and model the data obtained.

7.3. European initiatives

7.3.1. FP7-ICT project NEUROCHEM

Participant: Dominique Martinez.

The european project NEUROCHEM explores biologically inspired computation for chemical sensing, in collaboration with the University of Barcelona, the royal institute of technology (Sweden), INRA (Paris), the university of Manchester, the university Pompeu Fabra (Spain), CNR-IMM (Italy) and the university of Leicester. More information is available at http://www.neurochem-project.org/

7.4. International cooperation

7.4.1. INRIA associate team CorTexMex

Participants: Bernard Girau, Yann Boniface, Mauricio Cerda, Nicolas Rougier.

We are working with the Computer science department of the INAOEP (national institute of astrophysics, optics and electronics of Puebla) and the Cinvestav Tamaulipas research center (both in Mexico) on massively distributed connectionist models for embedded perception, within the INRIA associate team CorTexMex led by Bernard Girau.

Some perceptive tasks cannot be performed satisfactorily by standard algorithms due to the over simplified nature of classical models compared to the intrinsic complexity of the environment. To alleviate this problem, the research line of our team is directed to using brain-inspired models of perception. But the high computational cost of these models usually exceeds the time-multiplexed bounded computational resources of conventional systems. A solution lies in alternative hardware/software based processing architectures, supporting biological realism and providing the large scale computational resources to satisfy application constraints. The CorTexMex associate team focuses on the analysis, methods and techniques for the embedded implementation of bio-inspired connectionist processing for perception tasks on reconfigurable devices under a hardware/software approach. The main goal is to provide methods able to handle the massive distribution and the connection complexity of these models, as well as their specific recurrent differential computations. Another goal is to provide bio-inspired connectionist processing models to be embedded and directly integrated in perception-action loops.

This year, our activities have been mostly oriented towards a preliminary study of the properties of massively distributed elementary computations in bio-inspired models for sensori-motor systems in order to provide efficient implementations into reconfigurable logic devices. Three main subjects have been addressed: embedded spiking connectionist processing, biologically inspired visual perception on FPGAs (based on spiking neural fields), and bio-inspired models on-chip for the perception-action loop (based on Central pattern generators and multimodal neural maps). All these activities are strongly linked with §6.2 and §6.4.

7.4.2. STIC-AmSud project BAVI

Participants: Bernard Girau, Mauricio Cerda.

This collaboration with the Computer science department of the University of Santiago (Chile) and the Laboratory for System Dynamics and Signal Processing, of the National University of Rosario (Argentina), lies in the field of audio-visual information integration. The approach is based on the derivation of distributed models from neurophysiologic studies of motion perception in the human brain, and takes advantage of advanced methods for audio-visual information integration and visual animation. Extracting visual patterns of phoneme-related face motions, and then relating acoustic signals, face motion features and visual animation, we aim at defining a bio-inspired model for audio-visual integration that derives from an implicit cortical sensory (audio/visual)-motor (animation) loop.

7.4.3. STIC-AmSud project BCI

Participants: Frédéric Alexandre, Laurent Bougrain, Carolina Saavedra.

The STIC Amsud project (2009-2010) BCI "Robust single-trial evoked potential detection for brain-computer interfaces using computational intelligence techniques" aims to develop computational intelligence techniques for pattern recognition of graphic elements (e.g. event-related potential, auditory evoked potential, k-complex, spindle) included in electro-encephalographic signals. More precisely, we want to develop adaptive computational intelligence techniques based on artificial neural networks, support vector machines and classical data analysis techniques to robustly detect evoked potentials in a single trial from noisy and multi-sources electro-encephalographic signals. The participants are: the Laboratory of Engineering Rehabilitation and Neuromuscular and Sensorial Research (L.I.R.I.N.S), Facultad de Ingeniería, Universidad Nacional de Entre Ríos, Argentina ; The Department of Biomedical Engineering, Valparaíso University, Valparaiso, Chile ; The Computer Science Department, Federico Santa María University, Valparaiso, Chile ; The Laboratory of Neuro Imaging Research, Autonomous Metropolitan University, Mexico DF, Mexico.

7.4.4. Common project with United Kingdom

Participant: Axel Hutt.

The project partner is the Herriot-Watts University of Edinburgh and the project aims to study stochastic effects in neural networks. To this end the Royal Society of Scotland supported the initial visit in Edinburgh to discuss first mathematical details and software implementations besides a schedule for future common activities.

8. Dissemination

8.1. Leadership within the scientific community

8.1.1. Responsabilities

- Responsible for the axis MIS "Modeling, Interaction Simulation", of the CPER with the Lorraine Region (F. Alexandre).
- Head of the Network Grand-Est for Cognitive Science (F. Alexandre)
- Member of the steering committee of the ARP PIRSTEC (Prospective on cognitive science and technology for the ANR) (F. Alexandre)
- Member of the steering committee of the french association for Artificial Intelligence (AFIA) (F. Alexandre)
- F. Alexandre and T. Viéville are members (and moderators) of the scientific committee of Neuro-Comp, the initiative to gather the french community in Computational Neuroscience (annual conference and web site: http://www.neurocomp.fr/). They were in the scientific committee of Neuro-comp'09.

8.1.2. Review activities

- Reviewing for journals: Mathematical modelling of natural phenomena, SMC-Part B (F. Alexandre); Neurocomputing, Frontiers in Neuroscience, IJCNN,etc.. and several Computer Vision journals (T. Viéville).
- Member of program committees: BioMed'09, CAP'09, ICDL'09, Sinfra'09, TAIMA'09 (F. Alexandre); Reconfig'09 (B. Girau);
- Expertise for the European Commission (FP7; ICT) (F. Alexandre), for grants submitted to Dutch National Science Foundation (A. Hutt)
- Expertise for several programs of the ANR and member of the evaluation committee of the program "Domaines Emergents" (F. Alexandre)
- Expertise for french laboratories and Conseils Régionaux (Aquitaine, Bourgogne) (F. Alexandre)

8.1.3. Workshops, conferences and seminars

- Organization of conferences: organization of a workshop about cognition and computational neuroscience in the program PIRSTEC (F. Alexandre, Paris, 16 june);
- Invited talks: Thierry Viéville, has been invited as speaker by the ASTS-PACA, in partnership with the Institut des Neurosciences Cognitives de la Méditerranée, for a large-public conference on Computational Neuroscience «Peut-on parler d'intelligence mécanique ?» and has been included as teacher in the «Formation Informatique et Objets Numériques» organized by INRIA for high-shool teachers.

8.1.4. International cooperations

- in neurophysiology with MPI for Biological Cybernetics (Tubingen)
- on modeling visual attention with university of Chemnitz (Germany)

8.2. Teaching

- Courses given at different levels (LMD) by most team members, in computer science and in cognitive science;

- T. Viéville: 50h of teaching about Computer Science in sessions of permanent formation of 2ndary schools teachers.
- B. Girau has been the head of the first year of the Master in Computer Science of Nancy University. He is now the head of one of the three specialities (RAR, recognition, learning, reasoning) of the second year of this same Master Programme.
- Member of PhD and HDR defense committees in France and abroad (F. Alexandre, B. Girau, D. Martinez, N. Rougier);

8.3. Miscellaneous

- Thierry Viéville is a member of the Scientific Committee of the University of Nice Sophia-Antipolis; is a member of the ASTI PhD Price board. The other half-time of his activity is dedicated to popularization of science (http://interstices.info (scientific animation from the creation to 2007), http://www.fuscia.info (scientific board animator)).

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