



Activity Report 2013

Team MNEMOSYNE

Mnemonic Synergy

RESEARCH CENTER
Bordeaux - Sud-Ouest

THEME
**Computational Neuroscience and
Medicine**

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Team MNEMOSYNE

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Common Project-Team with the LaBRI, hosted by Institut des Maladies Neurodégénératives, IMN, Bordeaux NeuroCampus

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2. Overall Objectives

2.1. Summary

At the frontier between integrative and computational neuroscience, we propose to model the brain as a system of active memories in synergy and in interaction with the internal and external world and to simulate it *as a whole and in situation*.

In integrative and cognitive neuroscience (*cf.* § 3.1), on the basis of current knowledge and experimental data, we develop models of the main cerebral structures, taking a specific care of the kind of mnemonic function they implement and of their interface with other cerebral and external structures. Then, in a systemic approach, we build the main behavioral loops involving cerebral structures connecting a wide spectrum of actions to various kinds of sensations. We observe at the behavioral level the properties emerging from the interaction between these loops.

We claim that this approach is particularly fruitful for investigating cerebral structures like the basal ganglia and the prefrontal cortex, difficult to comprehend today because of the rich and multimodal information flows they integrate. We expect to cope with the high complexity of such systems, inspired by behavioral and developmental sciences, explaining how behavioral loops gradually incorporate in the system various kinds of information and associated mnemonic representations. As a consequence, the underlying cognitive architecture, emerging from the interplay between these sensations-actions loops, results from a *mnemonic synergy*.

In computational neuroscience (*cf.* § 3.2), we concentrate on the efficiency of local mechanisms and on the effectiveness of the distributed computations at the level of the system. We also take care of the analysis of their dynamic properties, at different time scales. These fundamental properties are of high importance to allow the deployment of very large systems and their simulation in a framework of high performance computing (*cf.* § 5.1). Running simulations at a large scale is particularly interesting to evaluate over a long period a consistent and relatively complete network of cerebral structures in realistic interaction with the external and internal world. We face this problem in the domain of autonomous robotics (*cf.* § 3.4) and ensure a real autonomy by the design of an artificial physiology and convenient learning protocols.

We are convinced that this original approach also permits to revisit and enrich algorithms and methodologies in machine learning (*cf.* § 3.3) and in autonomous robotics (*cf.* § 3.4), in addition to elaborate hypotheses to be tested in neuroscience and medicine, while offering to these latter domains a new ground of experimentation similar to their daily experimental studies.

3. Research Program

3.1. Integrative and Cognitive Neuroscience

The human brain is often considered as the most complex system dedicated to information processing. This multi-scale complexity, described from the metabolic to the network level, is particularly studied in integrative neuroscience, the goal of which is to explain how cognitive functions (ranging from sensorimotor coordination to executive functions) emerge from (are the result of the interaction of) distributed and adaptive computations of processing units, displayed along neural structures and information flows. Indeed, beyond the astounding complexity reported in physiological studies, integrative neuroscience aims at extracting, in simplifying models, regularities in space and functional mechanisms in time. From a spatial point of view, most neuronal structures (and particularly some of primary importance like the cortex, cerebellum, striatum, hippocampus) can be described through a regular organization of information flows and homogenous learning rules, whatever the nature of the processed information. From a temporal point of view, the arrangement in space of neuronal structures within the cerebral architecture also obeys a functional logic, the sketch of which is captured in models describing the main information flows in the brain, the corresponding loops built in interaction with the external and internal (bodily and hormonal) world and the developmental steps leading to the acquisition of elementary sensorimotor skills up to the most complex executive functions.

Three important characteristics are worth mentioning concerning these loops. Firstly, each of them sets a closed relation between the central nervous system and the rest of the world. This includes the external world (possibly including other intelligent agents), but also the internal world, with hormonal, physiological and bodily dimensions. Secondly, each of these loops can be described as a loop relating sensations to actions, in the wide sense of these terms: effectively, action can refer to acting in the real world, but also to modifying physiological parameters or controlling neuronal activation. These loops have different constants of time, from immediate reflexes and sensorimotor adjustments to long term selection of motivation for action, the latter depending on hormonal and social parameters. Thirdly, each of the loops performs a learning reinforced by a primary (physiologically significant) or pseudo reward (sub-goal to be learned). As an illustration, we can mention respondent conditioning detecting stimuli anticipatory of primary rewards, episodic learning detecting multimodal events, and also more local phenomena like self-organization of topological structures. The gradual establishment of these loops and their mutual interactions give an interpretation of the resulting cognitive architecture as a synergetic system of memories.

In summary, integrative neuroscience builds, on an overwhelming quantity of data, a simplifying and interpretative grid suggesting homogenous local computations and a structured and logical plan for the development of cognitive functions. They arise from interactions and information exchange between neuronal structures and the external and internal world and also within the network of structures.

This domain is today very active and stimulating because it proposes, of course at the price of simplifications, global views of cerebral functioning and more local hypotheses on the role of subsets of neuronal structures in cognition. In the global approaches, the integration of data from experimental psychology and clinical studies leads to an overview of the brain as a set of interacting memories, each devoted to a specific kind of information processing [47]. It results also in longstanding and very ambitious studies for the design of cognitive architectures aiming at embracing the whole cognition. With the notable exception of works initiated by [43], most of these frameworks (e.g. Soar, ACT-R), though sometimes justified on biological grounds, do not go up to a *connectionist* neuronal implementation. Furthermore, because of the complexity of the resulting frameworks, they are restricted to simple symbolic interfaces with the internal and external world and to (relatively) small-sized internal structures. Our main research objective is undoubtedly to build such a general purpose cognitive architecture (to model the brain *as a whole* in a systemic way), using a connectionist implementation and able to cope with a realistic environment.

3.2. Computational Neuroscience

From a general point of view, computational neuroscience can be defined as the development of methods from computer science and applied mathematics, to explore more technically and theoretically the relations between structures and functions in the brain [49], [36]. During the recent years this domain has gained an increasing interest in neuroscience and has become an essential tool for scientific developments in most fields in neuroscience, from the molecule to the system. In this view, all the objectives of our team can be described as possible progresses in computational neuroscience. Accordingly, it can be underlined that the systemic view that we promote can offer original contributions in the sense that, whereas most classical models in computational neuroscience focus on the better understanding of the structure/function relationship for isolated specific structures, we aim at exploring synergies between structures. Consequently, we target interfaces and interplay between heterogenous modes of computing, which is rarely addressed in classical computational neuroscience.

We also insist on another aspect of computational neuroscience which is, in our opinion, at the core of the involvement of computer scientists and mathematicians in the domain and on which we think we could particularly contribute. Indeed, we think that our primary abilities in numerical sciences imply that our developments are characterized above all by the effectiveness of the corresponding computations: We provide biologically inspired architectures with effective computational properties, such as robustness to noise, self-organization, on-line learning. We more generally underline the requirement that our models must also mimic biology through its most general law of homeostasis and self-adaptability in an unknown and changing environment. This means that we propose to numerically experiment such models and thus provide effective methods to falsify them.

Here, computational neuroscience means mimicking original computations made by the neuronal substratum and mastering their corresponding properties: computations are distributed and adaptive; they are performed without an homunculus or any central clock. Numerical schemes developed for distributed dynamical systems and algorithms elaborated for distributed computations are of central interest here [33], [42] and were the basis for several contributions in our group [48], [45], [50]. Ensuring such a rigor in the computations associated to our systemic and large scale approach is of central importance.

Equally important is the choice for the formalism of computation, extensively discussed in the connectionist domain. Spiking neurons are today widely recognized of central interest to study synchronization mechanisms and neuronal coupling at the microscopic level [34]; the associated formalism [39] can be possibly considered for local studies or for relating our results with this important domain in connectionism. Nevertheless, we remain mainly at the mesoscopic level of modeling, the level of the neuronal population, and consequently interested in the formalism developed for dynamic neural fields [31], that demonstrated a richness of behavior

[35] adapted to the kind of phenomena we wish to manipulate at this level of description. Our group has a long experience in the study and adaptation of the properties of neural fields [45], [46] and their use for observing the emergence of typical cortical properties [38]. In the envisioned development of more complex architectures and interplay between structures, the exploration of mathematical properties such as stability and boundedness and the observation of emerging phenomena is one important objective. This objective is also associated with that of capitalizing our experience and promoting good practices in our software production (*cf.* § 5.1). In summary, we think that this systemic approach also brings to computational neuroscience new case studies where heterogenous and adaptive models with various time scales and parameters have to be considered jointly to obtain a mastered substratum of computation. This is particularly critical for large scale deployments, as we will discuss in § 5.1).

3.3. Machine Learning

The adaptive properties of the nervous system are certainly among its most fascinating characteristics, with a high impact on our cognitive functions. Accordingly, machine learning is a domain [41] that aims at giving such characteristics to artificial systems, using a mathematical framework (probabilities, statistics, data analysis, etc.). Some of its most famous algorithms are directly inspired from neuroscience, at different levels. Connectionist learning algorithms implement, in various neuronal architectures, weight update rules, generally derived from the hebbian rule, performing non supervised (e.g. Kohonen self-organizing maps), supervised (e.g. layered perceptrons) or associative (e.g. Hopfield recurrent network) learning. Other algorithms, not necessarily connectionist, perform other kinds of learning, like reinforcement learning. Machine learning is a very mature domain today and all these algorithms have been extensively studied, at both the theoretical and practical levels, with much success. They have also been related to many functions (in the living and artificial domains) like discrimination, categorisation, sensorimotor coordination, planning, etc. and several neuronal structures have been proposed as the substratum for these kinds of learning [37], [30]. Nevertheless, we believe that, as for previous models, machine learning algorithms remain isolated tools, whereas our systemic approach can bring original views on these problems.

At the cognitive level, most of the problems we face do not rely on only one kind of learning and require instead skills that have to be learned in preliminary steps. That is the reason why cognitive architectures are often referred to as systems of memory, communicating and sharing information for problem solving. Instead of the classical view in machine learning of a flat architecture, a more complex network of modules must be considered here, as it is the case in the domain of deep learning. In addition, our systemic approach brings the question of incrementally building such a system, with a clear inspiration from developmental sciences. In this perspective, modules can generate internal signals corresponding to internal goals, predictions, error signals, able to supervise the learning of other modules (possibly endowed with a different learning rule), supposed to become autonomous after an instructing period. A typical example is that of episodic learning (in the hippocampus), storing declarative memory about a collection of past episodes and supervising the training of a procedural memory in the cortex.

At the behavioral level, as mentioned above, our systemic approach underlines the fundamental links between the adaptive system and the internal and external world. The internal world includes proprioception and interoception, giving information about the body and its needs for integrity and other fundamental programs. The external world includes physical laws that have to be learned and possibly intelligent agents for more complex interactions. Both involve sensors and actuators that are the interfaces with these worlds and close the loops. Within this rich picture, machine learning generally selects one situation that defines useful sensors and actuators and a corpus with properly segmented data and time, and builds a specific architecture and its corresponding criteria to be satisfied. In our approach however, the first question to be raised is to discover what is the goal, where attention must be focused on and which previous skills must be exploited, with the help of a dynamic architecture and possibly other partners. In this domain, the behavioral and the developmental sciences, observing how and along which stages an agent learns, are of great help to bring some structure to this high dimensional problem.

At the implementation level, this analysis opens many fundamental challenges, hardly considered in machine learning : stability must be preserved despite on-line continuous learning; criteria to be satisfied often refer to behavioral and global measurements but they must be translated to control the local circuit level; in an incremental or developmental approach, how will the development of new functions preserve the integrity and stability of others? In addition, this continuous re-arrangement is supposed to involve several kinds of learning, at different time scales (from msec to years in humans) and to interfere with other phenomena like variability and meta-plasticity.

In summary, our main objective in machine learning is to propose on-line learning systems, where several modes of learning have to collaborate and where the protocols of training are realistic. We promote here a *really autonomous* learning, where the agent must select by itself internal resources (and build them if not available) to evolve at the best in an unknown world, without the help of any *deus-ex-machina* to define parameters, build corpus and define training sessions, as it is generally the case in machine learning. To that end, autonomous robotics (*cf.* § 3.4) is a perfect testbed.

3.4. Autonomous Robotics

Autonomous robots are not only convenient platforms to implement our algorithms; the choice of such platforms is also motivated by theories in cognitive science and neuroscience indicating that cognition emerges from interactions of the body in direct loops with the world and develops interesting specificities accordingly. For example, internal representations can be minimized (opposite to building complex and hierarchical representations) and compensated by more simple strategies [32], more directly coupling perception and action and more efficient to react quickly in the changing environment (for example, instead of memorizing details of an object, just memorizing the eye movement to foveate it: the world itself is considered as an external memory). In this view for the *embodiment of cognition*, learning is intrinsically linked to sensorimotor loops and to a real body interacting with a real environment.

A real autonomy can be obtained only if the robot is able to define its goal by itself, without the specification of any high level and abstract cost function or rewarding state. To ensure such a capability, we propose to endow the robot with an artificial physiology, corresponding to perceive some kind of pain and pleasure. It may consequently discriminate internal and external goals (or situations to be avoided). This will mimic circuits related to fundamental needs (e.g. hunger and thirst) and to the preservation of bodily integrity. An important objective is to show that more abstract planning capabilities can arise from these basic goals.

A real autonomy with an on-line continuous learning as described in § 3.3 will be made possible by the elaboration of protocols of learning, as it is the case, in animal conditioning, for experimental studies where performance on a task can be obtained only after a shaping in increasingly complex tasks. Similarly, developmental sciences can teach us about the ordered elaboration of skills and their association in more complex schemes. An important challenge here is to translate these hints at the level of the cerebral architecture.

As a whole, autonomous robotics permits to assess the consistency of our models in realistic condition of use and offers to our colleagues in behavioral sciences an object of study and comparison, regarding behavioral dynamics emerging from interactions with the environment, also observable at the neuronal level.

In summary, our main contribution in autonomous robotics is to make autonomy possible, by various means corresponding to endow robots with an artificial physiology, to give instructions in a natural and incremental way and to prioritize the synergy between reactive and robust schemes over complex planning structures.

4. Application Domains

4.1. Overview

One of the most original specificity of our team is that it is part of a laboratory in Neuroscience (with a large spectrum of activity from the molecule to the behavior), focused on neurodegenerative diseases and

consequently working in tight collaboration with the medical domain. As a consequence, neuroscientists and the medical world are considered as the primary end-users of our researches. Beyond data and signal analysis where our expertise in machine learning may be possibly useful, our interactions are mainly centered on the exploitation of our models. They will be classically regarded as a way to validate biological assumptions and to generate new hypotheses to be investigated in the living. Our macroscopic models and their implementation in autonomous robots will allow an analysis at the behavioral level and will propose a systemic framework, the interpretation of which will meet aetiological analysis in the medical domain and interpretation of intelligent behavior in cognitive neuroscience.

The study of neurodegenerative diseases is targeted because they match the phenomena we model. Particularly, the Parkinson disease results from the death of dopaminergic cells in the basal ganglia, one of the main systems that we are modeling. The Alzheimer disease also results from the loss of neurons, in several cortical and subcortical regions. The variety of these regions, together with large mnemonic and cognitive deficits, require a systemic view of the cerebral architecture and associated functions, very consistent with our approach.

Of course, numerical sciences are also impacted by our researches, at several levels. At a global level, we will propose new control architectures aimed at providing a higher degree of autonomy to robots, as well as machine learning algorithms working in more realistic environment. More specifically, our focus on some cognitive functions in closed loop with a real environment will address currently open problems. This is obviously the case for planning and decision making; this is particularly the case for the domain of affective computing, since motivational characteristics arising from the design of an artificial physiology allow to consider not only cold rational cognition but also hot emotional cognition. The association of both kinds of cognition is undoubtedly an innovative way to create more realistic intelligent systems but also to elaborate more natural interfaces between these systems and human users.

At last, we think that our activities in well-founded distributed computations and high performance computing are not just intended to help us design large scale systems. We also think that we are working here at the core of informatics and, accordingly, that we could transfer some fundamental results in this domain.

5. Software and Platforms

5.1. Positioning

Our previous works in the domain of well-defined distributed asynchronous adaptive computations [48], [45], [50] have already made us define a library (DANA [44]), closely related to both the notion of artificial neural networks and cellular automata. From a conceptual point of view, the computational paradigm supporting the library is grounded on the notion of a unit that is essentially a (vector of) potential that can vary along time under the influence of other units and learning. Those units can be organized into layers, maps and networks.

We also gather in the middleware EnaS (that stands for *Event Neural Assembly Simulation*; cf. <http://forge.inria.fr/projects/enas>) our numerical and theoretical developments, allowing to simulate and analyze so called "event neural assemblies". In 2013, we have also integrated in this C/C++ middleware early-vision perception routines developed within the scope of the KEOpS project.

We will also have to interact with the High Performance Computing (HPC) community, since having large scale simulations at that mesoscopic level is an important challenge in our systemic view of computational neuroscience. Our approach implies to emulate the dynamics of thousands, or even millions, of integrated computational units, each of them playing the role of a whole elementary neural circuit (e.g. the microcolumn for the cortex). Mesoscopic models are considered in such an integrative approach, in order to exhibit global dynamical effect that would be hardly reachable by compartment models involving membrane equations or even spiking neuron networks.

The vast majority of high performance computing softwares for computational neuroscience addresses sub-neural or neural models [34], but coarser grained population models are also demanding for large scale simulations, with fully distributed computations, without global memory or time reference, as it is specified in (cf. § 3.2).

5.2. Dana

Participant: Nicolas Rougier.

DANA [44] is a python framework (<http://dana.loria.fr>) whose computational paradigm is grounded on the notion of a unit that is essentially a set of time dependent values varying under the influence of other units via adaptive weighted connections. The evolutions of a unit's value are defined by a set of differential equations expressed in standard mathematical notation which greatly ease their definition. The units are organized into groups that form a model. Each unit can be connected to any other unit (including itself) using a weighted connection. The DANA framework offers a set of core objects needed to design and run such models. The modeler only has to define the equations of a unit as well as the equations governing the training of the connections. The simulation is completely transparent to the modeler and is handled by DANA. This allows DANA to be used for a wide range of numerical and distributed models as long as they fit the proposed framework (e.g. cellular automata, reaction-diffusion system, decentralized neural networks, recurrent neural networks, kernel-based image processing, etc.).

5.3. ENAS: Event Neural Assembly Simulation

Participants: Frédéric Alexandre, 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 programming 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. On the mnemosyne side, this middleware includes since 2013 functional simulations of the non-standard perceptive behavior of the retina (detection of visual events) based on intensity and local spatial intensity cues, while in 2014 we are going to extend these new developments to motion cues. We have also made a strong effort in terms of interoperability on our side, since main functions are now usable from other languages (especially the python wrapper, actually in use), while we still maintain the interoperability with . This development is a complement of what has been developed on the Neuromathcomp side where colleagues have invested in a GUI for their routines.

5.4. Virtual Enaction

Participants: Frédéric Alexandre, André Garenne, Nicolas Rougier, Thierry Viéville.

The computational models studied in this project have applications that extend far beyond what is possible to experiment yet in human or non-human primate subjects. Real robotics experimentations are also impaired by rather heavy technological constraints; for instance, it is not easy to dismantle a given embedded system in the course of emerging ideas. The only versatile environment in which such complex behaviors can be studied both globally and at the level of details of the available modeling is a virtual environment, as in video games. Such a system can be implemented as "brainy-bot" (a programmed player based on our knowledge of the brain architecture) which goal is to survive in a complete manipulable environment.

In order to attain this rather ambitious objective we are going to both (i) deploy an existing open-source video game middleware in order to be able to shape the survival situation to be studied and (ii) revisit the existing models in order to be able to integrate them as an effective brainy-bot. It will consist of a platform associated to a scenario that would be the closest possible to a survival situation (foraging, predator-prey relationship, partner approach to reproduction) and in which it would be easy to integrate an artificial agent with sensory inputs (visual, touch and smell), emotional and somatosensory cues (hunger, thirst, fear, ..) and motor outputs (movement, gesture, ..) connected to a "brain" whose architecture will correspond to the major anatomical regions involved in the issues of learning and action selection (cortex areas detailed here, basal ganglia, hippocampus, and areas dedicated to sensorimotor processes). The internal game clock will be slowed down enough to be able to run non trivial brainy-bot implementations. This platform has already being used by two students of the team and is now a new deliverable of the KEOpS project.

6. New Results

6.1. Overview

Though our view is systemic, our daily research activities are concerned with the design, at a given scale of description, of models of neuronal structures, each concerned with a specific learning paradigm. Of course, a major challenge is to keep in mind the systemic view, to put a specific emphasis on the way each neuronal structure communicates with the rest of the system and to highlight how the learning paradigm interplays with other memory systems.

Among the numerous loops involving the brain, the body and the environment, a basic grid of description corresponds to distinguish “Perception Loops”, the goal of which is to extract from the inner and outer world sensory invariants helpful to identify and evaluate the current state and to make predictions from previous learning, and “Action Loops”, the goal of which is to rely on this sensory, emotional and motivational information to decide, plan and trigger actions for the benefit of the body.

Presently, our team is engaged on the following topics: Concerning perception loops, we are firstly considering the role of the hippocampus and of the posterior cortex in learning high level sensory cues that contribute to pavlovian conditioning in the amygdala. Secondly, we are investigating the role of the thalamus in attentional shifts in the cortex. This latter topic relies on recent advances we made in the Keops ANR project (*cf.* § 7.1) on a model of the retina that we also sum up here. Concerning Action loops, we are preparing a critical analysis of the current views of the interactions between the prefrontal cortex and the basal ganglia. Finally, we also report here more methodological achievements.

6.2. Pavlovian conditioning

The fundamental role of the amygdala in pavlovian conditioning is widely acknowledged, both on the motor, autonomic and hormonal expression of pavlovian responses and on the learning of the associations between conditional and unconditioned stimuli. This year, we have proposed models showing in a systemic view how errors of prediction in the amygdala might trigger, by cholinergic hormonal expression, episodic learning in the hippocampus [17] and semantic learning and attentional shift in the posterior cortex [8]. On this basis, we are currently studying how emotional values of sensory information are dynamically encoded in the basolateral nucleus of the amygdala [11], to fit with the multiple requirements for this kind of information in the brain.

6.3. The thalamus is more than a relay

Many recent results in neuroscience indicate that the role of the thalamus in the brain is certainly more important than it used to be considered, particularly concerning its relation with the cortex. Interestingly, we considered this question as a side effect of our work in the Keops project (*cf.* § 7.1) with our chilean neuroscientist colleagues studying non standard ganglion cells in the retina. Our modeling [6] and bibliographic studies led us to propose a biologically-founded algorithm [13] for the interplay between the modulatory and driving connections between the thalamus and the cortex, in the case of the projection of these ganglion cells on the thalamus [14]. This study has been carried out with the strong constraint of proposing a system working on a real visual flow. In the near future, we aim at developing this original view of the thalamus in the more general case of its pulvinar associative nucleus, learning to route to the cortex multimodal information flows.

6.4. Eyes are really smarter than believed

While it is known that the retina has not only standard ganglion cells devoted to contrast (parvo) or motion (magno) cues, but is able to perform sophisticated detection of spatial or temporal events in the visual scene (konio) [40], it was still to understand how such computation could be implemented as a robust effective processing of realistic natural image sequence and not only as a toy model of cartoonish stimuli. It has been shown in our group [19] that biologically plausible variational models of non-linear filtering coupled with optimized simple threshold mechanisms as derived from statistical learning mechanisms provides an efficient and realistic simulation of such non-standard retina output as observable at the level of konio-cells [14].

6.5. On the computational efficiency of Basal Ganglia models

Many valuable models have been proposed to capture the richness of the fundamental relations between the basal ganglia and prominent brain structures including the prefrontal cortex, the hippocampus and the superior colliculus. To choose among them the mechanisms on which to build the design of the motor pole of our brain-inspired system, a fundamental issue is to evaluate the efficiency of these models in more realistic cases than the ones which are generally considered by the authors. For this reason, we are presently preparing a comparative study of models, including a model developed in our lab with neuroscientist colleagues [2], in the more realistic case of large sensory and motor flows.

6.6. From distributed computing to distributed computing

One of the challenges in our systemic approach is to promote behaviors using distributed adaptive numerical computing that prevents (by definition) the specification of any behavior at a global level (no homunculus). This paradigm has been found to be very close to some class of problems in computer graphics where one tries to achieve a specific effect at the whole image level while the actual implementation is made at the pixel level (fragment). Transposing our expertise in distributed numerical computing, we thus experiment GPU programming (vertex/fragment programming) that offers hardware enforcement of distributed constraints: every fragment get the same program but their combination promotes a global image effect. This has been done for the case of text rendering [4] and dashed line rendering [5].

7. Partnerships and Cooperations

7.1. National Initiatives

7.1.1. ANR

7.1.1.1. ANR project KEOPS

Participants: Frédéric Alexandre, Thierry Viéville.

We are responsible for this “ANR Internal White Project” involving Mnemosyne and Neuromathcomp Inria Project-Teams in France with the U. of Valparaiso, U. Tecnica Frederico Santa-Maria, and U. Chile. The project addresses the integration of non-standard behaviors of retinal neural sensors, observed in natural conditions, into neural coding models and their translation into real, highly non-linear, bio-engineering artificial solutions. This project is now a four year project until the end of 2014, it has been evaluated by the reviewers at the end of 2013. Results concerning the thalamus and the retina evoked in § 6.3 and § 6.4 have been obtained in this project. Furthermore, new collaboration tracks have been conducted, taking benefit of interdisciplinarity of this international collaboration, e.g. at the methodological level [1].

7.2. International Initiatives

7.2.1. Inria Associate Teams

7.2.1.1. Cortina, associate team with Chile

Participants: Frédéric Alexandre, Thierry Viéville.

The goal of this associate team that finished this year is to combine our complementary expertise, from experimental biology and mathematical models (U de Valparaiso and U Federico Santa-Maria) to computational neuroscience (Mnemosyne and Neuromathcomp Project-teams), in order to develop common tools for the analysis and formalization of neural coding and related sensory-motor loops. Recording and modeling spike trains from the retina neural network, an accessible part of the brain, is a difficult task that our partnership can address, what constitute an excellent and unique opportunity to work together sharing our experience and to focus in developing computational tools for methodological innovations.

7.2.2. Inria International Partners

7.2.2.1. Informal International Partners

We have informal relations with the Computational Cognitive Neuroscience (CCN) Lab, University of Colorado, Boulder, USA (Prof. Randall O'Reilly) concerning the computationally-based understanding of the neural circuits involved in affectively-driven decision making, including the basal ganglia (BG) and ventral and medial prefrontal cortex areas.

7.3. International Research Visitors

7.3.1. Visits of International Scientists

7.3.1.1. Invited Professor

Prof. Adrian Palacios, responsible for the Chilean part of our associate team Cortina (*cf.* § 7.2) has been visiting Bordeaux one month in September 2013. He was also partly supported by the Labex BRAIN.

7.3.1.2. Internships

Meropi Topalidou

Subject: Touch and the Body

Date: from Mar 2013 until Sep 2013

Institution: Université Nationale Capodistrienne d'Athènes (Greece)

Román Gorojovsky

Subject: Hierarchical Associative Memories

Date: from Apr 2013 until Oct 2013

Institution: University of Buenos Aires (Argentina)

7.3.2. Visits to International Teams

From mid-July to end of August, Maxime Carrere, a newly-hired PhD student in the team, has visited the CCN lab in Boulder, USA (*cf.* § 7.2) for 6 weeks.

8. Dissemination

8.1. Scientific Animation

8.1.1. Responsibilities

- Thierry Viéville is in charge, at the Inria national level, of the institute science outreach actions and depends on the Direction de la Recherche for this part of his work.
- Member of the scientific committee of the CNRS PEPS program, of the local Inria committee for invited professors (F. Alexandre).
- Expert of the ITMO 'Neurosciences, Sciences Cognitive, Neurologie, Psychiatrie' (F. Alexandre)

8.1.2. Review activities

- Reviewing for journals: Plos One, Frontiers in Neurorobotics, Applied Intelligence, Cognitive Computation, J. Physiol. (F. Alexandre); Neural Networks, Neurocomputing (N. Rougier); Frontiers in Computational Neuroscience (T. Viéville).
- Member of program committees of conferences: CAP, EMBS, TAIMA (F. Alexandre)
- Reviewing for the Fonds Recherche Quebec, the CNRS, the ANR and several French regional and territorial agencies and universities (F. Alexandre)

8.1.3. Workshops, conferences and seminars

Organization of conferences and workshops:

- Member of the organizing committee of the annual symposium of the CNRS GDR "Multi-electrodes", in charge of the tutorial day (F. Alexandre, October)

Invited speaker and seminars:

- Invited talk to the CNRS 'STIC-Santé' GDR day: "Computer Science and the Brain" (N. Rougier, november)
- Invited Talk to the "Robotics and the Living", Conference organized by the Cergy-Pontoise university (N. Rougier, december)
- Invited Talks "Scientific Visualization" for the JDEV 2013 days (N. Rougier, september)

8.2. Teaching - Supervision - Juries

8.2.1. Teaching

Many courses are given in universities and schools of engineers at different levels (LMD) by most team members, in computer science, in applied mathematics, in neuroscience and in cognitive science.

Concerning tutorials during conferences, Euroscipy 2013, Matplotlib tutorial, (N.Rougier, August); PRACE Winter school 2013, Scientific Visualisation and Python introduction (N. Rougier, March).

8.2.2. Juries

We participate to many juries each year.

8.3. Popularization

For a multi-disciplinary team as Mnemosyne, science popularization is not a nice and useful contribution to the dissemination of scientific knowledge but also a necessity since we work with colleagues from bio-sciences with whom sharing profound ideas in computer science is mandatory for a real collaboration.

- Thierry Viéville is half-time involved in popularization actions both at a concrete level [21], [23], [22], [9], [10] (including on Mnemosyne subjects [25], [20] and at the methodological level [15], [29], [18]. This explains the rather huge amount of publications on these external subjects in this document.
- "A small history of cyber-criminality" at the Journées pédagogiques sur ISN (N. Rougier, June)
- "About brain modeling", Interstices podcast, (N. Rougier, February)
- Participation to the program "Science Publique", on the french national radio France Culture to a one-hour debate entitled "What can we expect from an artificial human brain?" (F. Alexandre, January).

9. Bibliography

Publications of the year

Articles in International Peer-Reviewed Journals

- [1] K. BORIC, P. ORIO, T. VIÉVILLE, K. WHITLOCK. *Quantitative Analysis of Cell Migration Using Optical Flow*, in "PLoS ONE", July 2013, <http://hal.inria.fr/hal-00850523>
- [2] M. GUTHRIE, A. LEBLOIS, A. GARENNE, T. BORAUD. *Interaction Between Cognitive and Motor Cortico-Basal Ganglia Loops During Decision Making: A Computational Study*, in "Journal of Neurophysiology", March 2013, <http://hal.inria.fr/hal-00828004>
- [3] D. MORETTI, N. LEWIS, A. GARENNE, F. POULLETIER DE GANNES, E. HARO, I. LAGROYE, B. VEYRET, L. PHILIPPE. *In-vitro Exposure of Neuronal Networks to the GSM-1800 Signal*, in "Bioelectromagnetics", May 2013, <http://hal.inria.fr/hal-00828018>

- [4] N. ROUGIER. *Higher Quality 2D Text Rendering*, in "Journal of Computer Graphics Techniques", April 2013, vol. 2, n^o 1, pp. 50-64, <http://hal.inria.fr/hal-00821839>
- [5] N. ROUGIER. *Shader-Based Antialiased Dashed Stroked Polylines*, in "Journal of Computer Graphics Techniques", November 2013, vol. 2, n^o 2, pp. 91-107, <http://hal.inria.fr/hal-00907326>

International Conferences with Proceedings

- [6] C. CARVAJAL, T. VIÉVILLE, F. ALEXANDRE. *Impact of the Konio pathway in the thalamocortical visual system: a modeling study*, in "CNS - 22nd Annual Computational Neuroscience Meeting - 2013", Paris, France, July 2013 [DOI : 10.1186/1471-2202-14-S1-P6], <http://hal.inria.fr/hal-00826704>
- [7] G. DETORAKIS, N. ROUGIER. *A computational view of area 3b of primary somatosensory cortex*, in "Annual Computational Neuroscience Meeting", Paris, France, BMC Neuroscience, July 2013, <http://hal.inria.fr/hal-00908566>

National Conferences with Proceedings

- [8] M. CARRERE, F. ALEXANDRE. *Émergence de catégories par interaction entre systèmes d'apprentissage*, in "Conférence Francophone sur l'Apprentissage Automatique (CAP)", Lille, France, P. PREUX, M. TOMMASI (editors), July 2013, <http://hal.inria.fr/hal-00826554>
- [9] T. VIÉVILLE, F. DUFOUR, P. VIENNE, F. TORT. *Utiliser des proglets pour manipuler des objets numériques*, in "Didapro5 - DidaSTIC : Didactique de l'informatique et des STIC en milieu éducatif", Clermont-Ferrand, France, B. DROT-DELANGE, G.-L. BARON, E. BRUILLARD (editors), Université Blaise Pascal, Université Paris V, ENS Cachan/IFé, July 2013, <http://hal.inria.fr/hal-00843961>
- [10] T. VIÉVILLE, F. TORT. *Donner du sens aux éléments de technologie : l'exemple des URI*, in "Didapro5 - DidaSTIC : Didactique de l'informatique et des STIC en milieu éducatif", Clermont-Ferrand, France, B. DROT-DELANGE, G.-L. BARON, E. BRUILLARD (editors), Université Blaise Pascal, Université Paris V, ENS Cachan/IFé, July 2013, <http://hal.inria.fr/hal-00843963>

Conferences without Proceedings

- [11] T. BEATI, M. CARRERE, F. ALEXANDRE. *Which reinforcing signals in autonomous systems?*, in "Third International Symposium on Biology of Decision Making", Paris, France, May 2013, <http://hal.inria.fr/hal-00826603>
- [12] L. CAMPAGNOLA, A. KLEIN, C. ROSSANT, N. ROUGIER. *VISPY, A Modern and Interactive Scientific Visualisation*, in "Euroscipy 2013", Brusells, Belgium, August 2013, <http://hal.inria.fr/hal-00907830>
- [13] C. CARVAJAL, T. VIÉVILLE, F. ALEXANDRE. *To flee or not to flee? Neural Field dynamics shape information flows in a model of the thalamocortical visual system*, in "BC - Bernstein Conference - 2013", Tübingen, Germany, September 2013 [DOI : 10.12751/NNCN.BC2013.0002], <http://hal.inria.fr/hal-00858473>
- [14] E. TEFTEF, C. CARVAJAL, T. VIÉVILLE, F. ALEXANDRE. *When early vision in the retina attempts to take decisions about visual motion events : the role of konio cells*, in "Third International Symposium on Biology of Decision Making", Paris, France, Université Pierre et Marie Curie (Paris 6), May 2013, <http://hal.inria.fr/hal-00826099>

- [15] T. VIÉVILLE. *Pourquoi, pour quoi et comment augmenter la culture scientifique ISN de chacune et chacun ?*, in "Cultures numériques, Éducation aux médias et à l'Information", Lyon, France, DGESCO, ENS Lyon, May 2013, <http://hal.inria.fr/hal-00826100>

Research Reports

- [16] F. ALEXANDRE. , *Comprendre les réseaux cérébraux*, Inria, January 2013, n^o RR-8219, 21 p. , <http://hal.inria.fr/hal-00783331>
- [17] R. GOROJOSKY, F. ALEXANDRE. , *Models of Hippocampus for pavlovian learning*, Inria, October 2013, n^o RR-8377, 77 p. , <http://hal.inria.fr/hal-00870700>
- [18] A. ROUSSEAU, A. DARNAUD, B. GOGLIN, C. ACHARIAN, C. LEININGER, C. GODIN, C. HOLIK, C. KIRCHNER, D. RIVES, E. DARQUIE, E. KERRIEN, F. NEYRET, F. MASSEGLIA, F. DUFOUR, G. BERRY, G. DOWEK, H. ROBAK, H. XYPAS, I. ILLINA, I. GNAEDIG, J. JONGWANE, J. EHREL, L. VIENNOT, L. GUION, L. CALDERAN, L. KOVACIC, M. COLLIN, M.-A. ENARD, M.-H. COMTE, M. QUINSON, M. OLIVI, M. GIRAUD, M. DORÉMUS, M. OGOUCHI, M. DROIN, N. LACAUX, N. ROUGIER, N. ROUSSEL, P. GUITTON, P. PETERLONGO, R.-M. CORNUS, S. VANDERMEERSCH, S. MAHEO, S. LEFEBVRE, S. BOLDO, T. VIÉVILLE, V. POIREL, A. CHABREUIL, A. FISCHER, C. FARGE, C. VADEL, I. ASTIC, J.-P. DUMONT, L. FÉJOZ, P. RAMBERT, P. PARADINAS, S. DE QUATREBARBES, S. LAURENT. , *Médiation Scientifique : une facette de nos métiers de la recherche*, March 2013, 34 p. , <http://hal.inria.fr/hal-00804915>
- [19] E. TEFTEF, M.-J. ESCOBAR, A. ASTUDILLO, C. CARVAJAL, B. CESSAC, A. PALACIOS, T. VIÉVILLE, F. ALEXANDRE. , *Modeling non-standard retinal in/out function using computer vision variational methods*, Inria, January 2013, n^o RR-8217, 28 p. , <http://hal.inria.fr/hal-00783091>

Scientific Popularization

- [20] F. ALEXANDRE, C. CARVAJAL, T. VIÉVILLE. *Comprendre le système le plus complexe de notre planète ?*, in "Mathématique pour la planète Terre, Un jour une brève", December 2013, <http://hal.inria.fr/hal-00919818>
- [21] A. ALVAREZ, T. VIÉVILLE. *Dis maman (ou papa), c'est quoi un algorithme dans ce monde numérique ?*, in "Image des Maths", January 2014, <http://hal.inria.fr/hal-00926333>
- [22] A. ALVAREZ, T. VIÉVILLE. *Dis maman (ou papa), comment on cache des secrets dans le monde numérique ?*, in "Image des Maths", January 2014, <http://hal.inria.fr/hal-00926349>
- [23] A. ALVAREZ, T. VIÉVILLE. *Dis papa (ou maman), comment arrivent les bugs dans le monde numérique ?*, in "Image des Maths", January 2014, <http://hal.inria.fr/hal-00926346>
- [24] N. ROUGIER. *Outils et bibliothèques de visualisation*, in "High Performance Computing Magazine France", November 2013, vol. 1, n^o 8, pp. 64-65, <http://hal.inria.fr/hal-00907289>
- [25] E. TEFTEF, T. VIÉVILLE. *La grenouille gobe t'elle aussi les cailloux ? Une introduction aux neurosciences computationnelles*, in "EpiNet", February 2013, vol. 152, <http://hal.inria.fr/hal-00789149>

Other Publications

- [26] C. CARVAJAL, T. VIÉVILLE, F. ALEXANDRE. , *A modeling study of the dynamic interplay between pathways in the thalamocortical visual system: The Magno and Koniocellular streams case*, October 2013, Poster, <http://hal.inria.fr/hal-00874115>
- [27] C. CARVAJAL, T. VIÉVILLE, F. ALEXANDRE. *Impact of the Konio pathway in the thalamocortical visual system: a modeling study*, in "Twenty Second Annual Computational Neuroscience Meeting : CNS 2013", Paris, France, July 2013, P6 p. , <http://hal.inria.fr/hal-00842314>
- [28] G. DETORAKIS, N. ROUGIER. *A computational view of area 3b of primary somatosensory cortex*, in "Twenty Second Annual Computational Neuroscience Meeting : CNS 2013", Paris, France, July 2013, P333 p. , <http://hal.inria.fr/hal-00842311>
- [29] T. VIÉVILLE. , *Comment le travail scientifique interagit avec la société : vraies et fausses bonnes idées*, April 2013, Blog sur science et citoyenneté, articles validés par leur comité de lecture, <http://hal.inria.fr/hal-00809857>

References in notes

- [30] F. ALEXANDRE. *Biological Inspiration for Multiple Memories Implementation and Cooperation*, in "International Conference on Computational Intelligence", V. KVASNICKA, P. SINCAK, J. VASCAK, R. MESIAR (editors), 2000
- [31] S. AMARI. *Dynamic of pattern formation in lateral-inhibition type neural fields*, in "Biological Cybernetics", 1977, vol. 27, pp. 77–88
- [32] D. H. BALLARD, M. M. HAYHOE, P. K. POOK, R. P. N. RAO. *Deictic codes for the embodiment of cognition*, in "Behavioral and Brain Sciences", 1997, vol. 20, n^o 04, pp. 723–742, <http://dx.doi.org/10.1017/S0140525X97001611>
- [33] D. BERTSEKAS, J. TSITSIKLIS. , *Parallel and Distributed Computation: Numerical Methods*, Athena Scientific, 1997
- [34] R. BRETTE, M. RUDOLPH, T. CARNEVALE, M. HINES, D. BEEMAN, J. BOWER, M. DIESMANN, A. MORRISON, P. H. GOODMAN, F. C. JR. HARRIS, M. ZIRPE, T. NATSCHLÄGER, D. PECEVSKI, B. ERMENTROUT, M. DJURFELDT, A. LANSNER, O. ROCHEL, T. VIÉVILLE, E. MULLER, A. DAVISON, S. E. BOUSTANI, A. DESTEXHE. *Simulation of networks of spiking neurons: a review of tools and strategies*, in "Journal of Computational Neuroscience", 2007, vol. 23, n^o 3, pp. 349–398
- [35] S. COOMBES. *Waves, bumps and patterns in neural field theories*, in "Biol. Cybern.", 2005, vol. 93, pp. 91-108
- [36] P. DAYAN, L. ABBOTT. , *Theoretical Neuroscience : Computational and Mathematical Modeling of Neural Systems*, MIT Press, 2001
- [37] K. DOYA. *What are the computations of the cerebellum, the basal ganglia and the cerebral cortex?*, in "Neural Networks", 1999, vol. 12, pp. 961–974

- [38] J. FIX, N. P. ROUGIER, F. ALEXANDRE. *A dynamic neural field approach to the covert and overt deployment of spatial attention*, in "Cognitive Computation", 2011, vol. 3, n^o 1, pp. 279-293 [DOI : 10.1007/s12559-010-9083-Y], <http://hal.inria.fr/inria-00536374/en>
- [39] W. GERSTNER, W. KISTLER. , *Spiking Neuron Models: Single Neurons, Populations, Plasticity*, Cambridge University PressCambridge University Press, 2002
- [40] T. GOLLISCH, M. MEISTER. *Eye Smarter than Scientists Believed: Neural Computations in Circuits of the Retina*, in "Neuron", January 2010, vol. 65, n^o 2, pp. 150–164, [http://www.cell.com/neuron/abstract/S0896-6273\(09\)00999-4](http://www.cell.com/neuron/abstract/S0896-6273(09)00999-4)
- [41] T. MITCHELL. , *Machine Learning*, Mac Graw-Hill Press, 1997
- [42] D. MITRA. *Asynchronous relaxations for the numerical solution of differential equations by parallel processors*, in "SIAM J. Sci. Stat. Comput.", 1987, vol. 8, n^o 1, pp. 43–58
- [43] R. O'REILLY, Y. MUNAKATA. , *Computational Explorations in Cognitive Neuroscience: Understanding the Mind by Simulating the Brain*, MIT PressCambridge, MA, USA, 2000
- [44] N. P. ROUGIER, J. FIX. *DANA: Distributed (asynchronous) Numerical and Adaptive modelling framework*, in "Network: Computation in Neural Systems", December 2012, vol. 23, n^o 4, pp. 237-253 [DOI : 10.3109/0954898X.2012.721573], <http://hal.inria.fr/hal-00718780>
- [45] N. ROUGIER, A. HUTT. *Synchronous and Asynchronous Evaluation of Dynamic Neural Fields*, in "J. Diff. Eq. Appl.", 2009
- [46] N. ROUGIER. *Dynamic Neural Field with Local Inhibition*, in "Biological Cybernetics", 2006, vol. 94, n^o 3, pp. 169-179
- [47] L. SQUIRE. *Memory systems of the brain: a brief history and current perspective*, in "Neurobiol. Learn. Mem.", 2004, vol. 82, pp. 171-177
- [48] W. TAOUALI, T. VIÉVILLE, N. ROUGIER, F. ALEXANDRE. *No clock to rule them all*, in "Journal of Physiology", 2011, vol. 105, n^o 1-3, pp. 83-90
- [49] T. TRAPPENBERG. , *Fundamentals of Computational Neuroscience*, Oxford University Press, 2002
- [50] T. VIÉVILLE. *An unbiased implementation of regularization mechanisms*, in "Image and Vision Computing", 2005, vol. 23, n^o 11, pp. 981–998, <http://authors.elsevier.com/sd/article/S0262885605000909>