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Activity Report 2014

Project-Team MNEMOSYNE

Mnemonic Synergy

RESEARCH CENTER
Bordeaux - Sud-Ouest

THEME
Computational Neuroscience and Medecine

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Project-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 mnesic 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 protocoles.

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 controling 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 [42]. 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 [38], 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 undoubtly 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 [44], [32]. 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 mimick 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 homonculus or any central clock. Numerical schemes developed for distributed dynamical systems and algorithms elaborated for distributed computations are of central interest here [29], [37] and were the basis for several contributions in our group [43], [40], [45]. 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 [30]; the associated formalism [35] 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 [27], that demonstrated a richness of behavior

[31] 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 [40], [41] and their use for observing the emergence of typical cortical properties [34]. 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 [36] 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 [33], [26]. 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 episods and supervising the training of a procedural memory in the cortex.

At the behavioral level, as mentionned 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 continous re-arrangement is supposed to involve several kinds of learning, at different time scales (from msec to years in humans) and to interfer 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 protocoles 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 [28], 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 mimick 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 mnesic 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 undoublty 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. New Software and Platforms

5.1. Positioning

Our previous works in the domain of well-defined distributed asynchronous adaptive computations [43], [40], [45] have already made us define a library (DANA [39]), 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://gforge.inria.fr/projects/enas) our numerical and theoretical developments, allowing to simulate and analyze so called "event neural assemblies".

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 [30], 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 [39] 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. 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 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 consists of a platform associated to a scenario that is the closest possible to a survival situation (foraging, predator-prey relationship, partner approach to reproduction) and in which it is 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 can be slowed down enough to be able to run non trivial brainy-bot implementations. This platform [13] 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. 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

Pavlovian conditioning is an outstanding example of a systemic process involving several cerebral structures and several modes of learning. This year, we have made more precise our model of amygdala [7], with a special emphasis on the variety of its inputs, including by neuromodulation [12]. We have also specifically discussed and contrasted the role of cerebral structures involved in this learning, from the point of view of information processing [11]. In addition to the amygdala, the structures of interest are the hippocampus and the posterior and prefrontal cortex and begin to be investigated in ongoing studies.

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. Our modeling and bibliographic studies were carried out in the Keops project (*cf.* § 7.2) with our chilean neuroscientist colleagues studying non standard ganglion cells in the retina. Particularly, the PhD work by Carlos Carvajal [1] led us to propose a biologically-founded algorithm for the interplay between the modulatory and driving connections between the thalamus and the cortex, with the strong constraint of proposing a system working on a real visual flow.

6.4. 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 [24]. For this reason, we have conducted a systematic study of several basal ganglia computational models to check of their scalability in terms of ation representational space [25]. Unfortunately, we found most of them to not be scalable and some of them to not be reproducible at all.

Another way to explore the computational efficiency of neuronal models is to implement them at lower levels of description. This is currently being done with one model developed in our lab at a level corresponding to a neuronal assembly with a mean activity expressed using a single variable. This mesoscopic approach has been refined to a microscopic scale description level, i.e taking into account individual neurons and synapses. Besides the confirmation of many of the results of initial model with a more detailed formalism, this new model has allowed us to highlight the facilitating role of inhibitory interneurons in the decision-making and action selection processes.

6.5. Distributed Self-Organization

The formation of the sensory homunculus in the primary sensory cortex (SI) is believed to be the result of a dynamic neural self-organization process that starts before birth and lasts for several years, allowing the brain to cope with sensory or brain lesions. The exact neural mechanisms driving this self-organization are not yet known and the role of the somatosensory attention remains unclear in this picture. We thus investigated the influence of somatosensory attention onto the two-dimensional structure of area 3b neuronal receptive fields (RFs) using a computational model [2] based on the dynamic neural field theory. This computational model of SI (area 3b) is able to explain experimental data in the monkey and hypothesizes role for the somatosensory attention in the shaping of SI receptive fields.

7. Partnerships and Cooperations

7.1. Regional Initiatives

As our team just settled in Bordeaux, it was an important priority for our early years of activity to initiate local collaborations, at the regional level.

7.1.1. Project of the Aquitaine Regional Council: Decision making, from motor primitives to action

The aim of this project (partly funding the PhD of Meropi Topalidou) is to investigate decision making at intermediate level in order to establish the link between motor primitives and higher level actions. The question is to understand how continuous complex motor sequences can be dynamically represented as actions such that they can be manipulated to resolve conflict when several actions are possible. This PhD work will require an extensive review of the literature and more specifically literature that promote a global view on decision making. The DANA modeling framework will be used for the design of distributed, numerical and adaptive models using rate based neuron models. The model will ideally be embodied into a simulator or a robotic platform in order to solve a simple taks such as for example, foraging or grasping, with a continuous component at the motor level.

7.1.2. Project of the Department Sciences and Technologies of the University of Bordeaux: Pinokio

In collaboration with school of engineers ENSEIRB and the support of the Department Sciences and Technologies of the University of Bordeaux, we've built a prototype of a motorized lamp equipped with a camera and leds. It can move autonomously and track faces with dedicated algorithms. The goal of this project is to have a dedicated robotic platform to study motor interaction and to investigate decision making in order to establish the link between motor primitives and higher level actions.

7.1.3. Project PEPS of the Idex: Dopamine control of a novel basal ganglia cell-type

The neurotransmitter dopamine (DA) plays a key role in basal ganglia (BG) circuits. However, despite the fundamental importance of DA in those circuits, the electrophysiological effects of dopamine on target neurons are largely unknown. Furthermore, contrary to classical models that only view the globus pallidus (GP) as a relay station of the indirect pathway, our neuroscientist colleagues at IMN have discovered a novel GP cell-type called the Arkypallidal (Arky-GP) neurons that only project to striatum in a very dense way. Arky-GP cells represent a novel BG pathway that might contribute massively to the GABAergic inhibition in striatum. In this project, we would like to explore for the first time whether DA has a direct action on Arky-GP neurons through D2 DA receptors. To do so, this project is based on multidisciplinary approaches that bring together 3 teams of IMN with different but complementary expertise (anatomical, in vivo electrophysiology, optogenetic manipulation, and computational modeling).

7.1.4. Collaboration with the Neurocentre Magendie on parameter optimization: Neurobees

The development of computational models of neurons and networks typically involves tuning of the numerical parameters to fit experimental results. This fitting is necessary to obtain consistent neural activity and therefore consistent action potential genesis and timing which play a key role in neural information encoding. However his task requires the exploration of multidimensional parameter spaces which are rarely accessible to analytical approaches. Moreover, if the parameter tuning can sometimes be manually completed it is more convenient to use automated optimization algorithms at least for two reasons: (i) to apply an homogeneous processing to all the calculation and parameter space exploration which alleviates operator influence and (ii) to avoid a tedious and uncertain result from human operators when the dimensionality increases. In computational neuroscience, the optimization algorithms are often applied to cell scale models to mimic the electrical activity of their biological counterpart. Most of the time, it is necessary for the neuroscientist to quantify biophysical parameters such as dynamic conductances, ionic concentrations or even neuronal structure to understand the neuron dynamic properties. In this field, there is an important need for innovative optimization tools. We have recently developed with neuroscientists of the Bordeaux Magendie Neurocentre, a new multi-agent algorithm in line with ABC (Artificial Bee Colony) paradigm. This algorithm whose principle is based on honeybees food foraging has been successfully applied to several neural modeling optimization problems. We have applied it to several benchmarks and it has shown significantly higher performances in computing optimal parameter values in comparison with the previous optimization tools. A method paper summarizing all these results will be submitted at the begining of 2015.

7.1.5. Collaboration with IMS on GSM signal effects: JNNS (Julia Neural networks Simulator)

In collaboration with IMS (Laboratory of Material and System Integration, in Bordeaux) we have developed a electrophysiological setup aiming at the investigation of the effects of GSM (Global System for Mobile communications) signal on neural living tissue [15]. Our biological model consists in a cortical cell culture growing on a multi-electrode array. A first series of observations have been published showing a significant effect of these wavelengths on primary neural cell cultures spontaneous electrical activity. We are now looking for the action mechanism and site which could explain the observed effects. Along with these experimental investigations, modeling studies are considered. A spiking neuron network model is developed, taking into account biological features of the cell culture and exhibiting similar excitatory/inhibitory connectivity ratios as well as spontaneous bursting activity and a model of the recording setup (extracellular electrodes). To optimize the model development and notably the simulation speed, we have implemented the model using the Julia language. This tool is also be developed following the NeuroML initiative standards.

7.2. National Initiatives

7.2.1. ANR

7.2.1.1. ANR project KEOPS

Participants: Frédéric Alexandre, Thierry Viéville.

We were 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, that ended in december 2014. The project was addressing 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. Results concerning the thalamus and the retina evoked in § 6.3 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 (*cf.* the ECOS project in § 7.3).

7.3. International Initiatives

7.3.1. Project BGaL with India

In the 3-years project “Basal Ganglia at Large (BGaL)”, funded by the CNRS and the CEFIPRA, we collaborate with the computer science department of IIIT Hyderabad and the biomedical department of IIT Madras, for the design of models of basal ganglia, of their relation with other brain structures and or their implementation at large scale.

7.3.2. Project ECOS-Sud with Chile

In the 3-years project “A network for computational neuroscience, from vision to robotics”, funded by ECOS-Sud and Conicyt, we collaborate with University Santa Maria and University of Valparaiso in Chile, and also with another Inria EPI, NeuroMathComp. The goal of the project is to rely on our experience of previous collaborations with these teams, to develop original tools and experimental frameworks to open our scientific domains of investigation to new fields of valorization, including medical (neurodegeneration) and technological aspects (robotics).

7.4. International Research Visitors

7.4.1. Internships

P Mehta Hima

Date: June - Dec 2014

Institution: Univ. Hyderabad (India)

7.4.2. Visits to International Teams

M. Topalidou, N. Rougier and F. Alexandre visited IIIT of Hyderabad (India) from 7 to 12 Dec. 2014 (*cf.* the BGaL project in § 7.3).

8. Dissemination

8.1. Promoting Scientific Activities

8.1.1. Collective responsibilities

- F. Alexandre is member of the Inria Evaluation Committee; Vice-head of the Project Committee of Inria Bordeaux Sud-Ouest; Corresponding scientist for Bordeaux Sud-Ouest of the Inria COERLE ethical committee; Member of the local Inria committee for invited professors, for young researchers hiring; Member of the steering committee of the regional Cluster on Information Technology and Health; of the regional Cluster on Robotics; Expert of the ITMO 'Neurosciences, Sciences Cognitive, Neurologie, Psychiatrie'
- N. Rougier is member of the Inria Evaluation Committee; Responsible of the local Inria committee for invited professors
- 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.

8.1.2. Scientific events organisation

8.1.2.1. general chair, scientific chair

Organization of a scientific day common to Inria and the Next Generation Internet Foundation, about bodyware, Bordeaux, May 12 (N. Rougier).

8.1.2.2. member of the organizing committee

F. Alexandre participated to the organization of the workshop Bordeaux Computational Biology and Bioinformatics, Bordeaux, Nov. 25-26 ; of the Braincamp on Innovation and Cognitive Sciences, Paris, March 21.

All the permanent members of the team participated to the organization of LACONEU 2014, the third Summer School in Computational Neuroscience, in Valparaiso, Chile, from 13 to 31 Jan. 2014.

8.1.3. Scientific events selection

8.1.3.1. member of the conference program committee

Member of the program committee of SAB, ICANN (F. Alexandre)

8.1.3.2. reviewer

Reviewing for the Conicyt (Chile), the ANR, the FRM (Foundation for Medical Research), the Hospital of Rennes (F. Alexandre)

8.1.4. Journal

8.1.4.1. reviewer

Reviewer for PlosOne, Frontiers in Neurorobotics, Cognitive Computation, Applied Intelligence (F. Alexandre)

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.

All the permanent members of the team gave lectures at LACONEU 2014, the third Summer School in Computational Neuroscience, in Valparaiso, Chile, from 13 to 31 Jan. 2014.

F. Alexandre gave a tutorial at the summer school on Robotics and Social Interactions (May 19-23), Moliets et Maa (France) and was an invited speaker to the Sino-French International Workshop on Computational Neuroscience in Shanghai (June); to the scientific day Inria/Fing on Bodyware (May 12); to the NeuroSTIC conference (July, 1-2, Cergy).

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 (including on Mnemosyne subjects) and at the methodological level. This explains the amount of references to these external subjects in this document.
- Nicolas Rougier: Invited talk on “The role of the body in human cognition” in the 13th Forum des Sciences Cognitives, Paris, March 2014; Participation to a round-table meeting on the digital society at the Futur en Seine festival; Article in Linux Mag on scientific visualization [21]
- PhD students participated to the regional exhibition Aquitec (C. Héricé and Maxime Carrere) and to “Fête de la Science” C. Héricé).

9. Bibliography

Publications of the year

Doctoral Dissertations and Habilitation Theses

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Invited Conferences

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