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Activity Report 2015

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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Other Research Topics and Application Domains:

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9.6. - Reproducibility

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 these 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.* § 6.1). 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 at various levels of description. From a mesoscopic 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 macroscopic 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.

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 [61]. 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 [57], 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 [63], [50]. 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 [47], [56] and were the basis for several contributions in our group [62], [59], [64]. 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 [48]; the associated formalism [53] 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 [45], that demonstrated a richness of behavior

[49] 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 [59], [60] and their use for observing the emergence of typical cortical properties [52]. 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.* § 6.1). 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 § 6.1).

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 [55] 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 [51], [44]. 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 (*embodiment of cognition* [46]). In addition to real robotic platforms, software implementations of autonomous robotic systems including components dedicated to their body and their environment will be also possibly exploited, considering that they are also a tool for studying conditions for a real autonomous learning.

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 extracortical 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. Highlights of the Year

5.1. Highlights of the Year

5.1.1. ReScience journal

Nicolas Rougier has co-founded the ReScience journal (http://rescience.github.io/) with Konrad Hinsen and is one the Editor-in-chief. ReScience is a peer-reviewed journal that target computational research and encourage the explicit replication of already published research promoting new and open-source implementations in order to ensure the original research is replicable.

5.1.2. Most viewed and downloaded article

Our paper [4] is in the spotlight of the Frontiers blog (cf. http://blog.frontiersin.org/2015/12/22/spotlight100/): among the 100 articles the most viewed and downloaded among over 12,500 articles published by Frontiers in 2015.

5.1.3. Awards

Our paper was given the Best Paper Award at the 2015 International Conference on Neural Computation Theory and Applications, cf. http://www.ncta.ijcci.org/PreviousAwards.aspx

BEST PAPER AWARD:

[11]
R. KASSAB, F. ALEXANDRE. *A Heteroassociative Learning Model Robust to Interference*, in "International Joint Conference on Computational Intelligence", Lisboa, Portugal, Proceedings International Conference on Neural Computation Theory and Applications, November 2015, Best Paper Award, https://hal.inria.fr/hal-01232017

6. New Software and Platforms

6.1. Positioning

Our previous works in the domain of well-defined distributed asynchronous adaptive computations [62], [59], [64] have already made us define a library (DANA [58]), 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 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 [48], 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).

6.2. DANA

Distributed Asynchronous Numerical & Adaptive computing framework
FUNCTIONAL DESCRIPTION

DANA is a python framework 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.).

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- URL: http://dana.loria.fr/

6.3. Virtual Enaction

KEYWORDS: Neurosciences - Simulation - Health
FUNCTIONAL DESCRIPTION

VirtualEnaction: A Platform for Systemic Neuroscience Simulation. 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 has already being used by two students of the team and is now a new deliverable of the KEOpS project.

- Participants: André Garenne, Frédéric Alexandre, Nicolas Rougier and Thierry Viéville
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- URL: http://virtualenaction.gforge.inria.fr/

7. New Results

7.1. Overview

Though our view is systemic, our daily research activities are also 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 integrate these elements in a systemic view, i.e. to put a specific emphasis on the way each neuronal structure communicates with the rest of the system and to highlight how its learning paradigms interact 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 aspects of 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 aspects of loops”, the goal of which is to rely on this sensory and emotional information to decide, plan and trigger actions for the benefit of the body.

This year, our team was engaged on the following topics: Concerning perception aspects of loops, we published original models of the amygdala and of the hippocampus and considered their role in pavlovian conditioning and their evaluation as classical models in machine learning. Concerning action aspects of loops, in addition to a critical analysis of the current views of the interactions between the prefrontal cortex and the basal ganglia [15], we have proposed an original model for the formation of habits and have also studied related theoretical problems in machine learning, for data representation. Finally, we also report here more methodological achievements, corresponding to the design of algorithmic ersatz of cerebral subsystems.

7.2. Pavlovian conditioning

Within perception aspects of loops, pavlovian conditioning is a very interesting learning paradigm to study in a systemic view because it is tightly related to other learning paradigms like episodic and semantic memory. This year, we have published papers presenting the biological basis of models of two fundamental structures in pavlovian conditioning, the amygdala [1] and the hippocampus [2]. We have also evaluated their most critical features, when considered as models of machine learning, namely their architecture and implementations at both rate and spiking levels [10] and their robustness to interference [11].

7.3. The formation of habits

Concerning action aspects of loops, we made important extensions to a model of basal ganglia that we developed recently [54] in interaction with another team in our neuroscience lab. In addition to extending the bio-plausibility of this model with an implementation at the spiking level, we have also developed this year a new theoretical framework that provides a novel explanation for the formation and the expression of habits in the cortex of primates by considering the basal ganglia as an implicit supervisor. This has been achieved with a model of basal ganglia running both at the rate and spiking levels. This framework predicts that Hebbian learning and reinforcement learning can be explicitly dissociated by inactivating the output of the basal ganglia during learning and later tested in normal conditions. Experimental results in the monkey confirmed this prediction and explain how a behavioral decision results from both the cooperation (acquisition) and competition (expression) of two distinct but entangled memory systems.

7.4. Beyond symbolic models

Using a biologically plausible model, we have been investigating some external and internal factors related to the stimulus representation that might affect the decision making and action selection [41]. We used a computational model of the cerebral structure Basal Ganglia, inspired and replicated from a model designed in previous studies [54]. One of the questions we attempt to address is to what extent the physical properties of the stimulus affect the decision to overcome the impact of reward associated to the stimuli.

7.5. Algorithmic ersatz of cerebral subsystems

As far as the systemic modeling and simulation of high-level brain functions are concerned (e.g., sensory-motor behavior, action selection and planning, perceptual categorization), we need to confront biologically plausible models at different scales of description with functional models that are not constrained by biological facts but still reproduce the expected functional response. This is mandatory to benchmark bio-physical models with respect to their equivalent in classical machine learning, in order to evaluate the degree of naiveness of their performances and also to build feasible simulation in which detailed biological models can interact with less plausible modules in order to be evaluated in realistic numerical situations.

This year, a set of formalism such as the Friston free-energy minimization general principle, deep-learning and related architectures, and more specific formalisms such as harmonic control or adaptive-subspace self-organizing maps have been studied and reviewed. The next step is to write a review, with the challenge of proposing an unifying view of those, and at a more concrete level, to propose the integration of a relevant subset of the related algorithms as a easily usable toolbox. This can be particularly useful to design global models of cognitive functions, even if biologically-inspired models are not yet available for all their components.

Preliminary key points regarding numerical experimentations have been published in this methodological paper [16].

8. Bilateral Contracts and Grants with Industry

8.1. Bilateral Contracts with Industry

8.1.1. Contract with Algotech

Participants: Frédéric Alexandre, Ikram Chraibi Kaadoud, Nicolas Rougier, Thierry Viéville.

Algotech is a SME working in the domain of CADD software edition for electrical circuit diagram interpretation and design. Its activity is interesting for our team because they are also interested in the design, by learning, of perception (for diagram identification) and action aspects of loops (for diagram genesis) with the specificity of working at a small scale, considering the variety of items to be manipulated. This is consequently a very interesting benchmark for transfering our bio-inspired models to the domain of classical machine learning, as we have begun this year.

9. Partnerships and Cooperations

9.1. Regional Initiatives

9.1.1. PsyPhINe: Cogito Ergo Es

Participant: Nicolas Rougier.

PEPS site Mirabelle (CNRS & University of Lorraine) gathering researchers from the following institutes: MSH Lorraine (USR3261), InterPsy (EA 4432), APEMAC, EPSaM (EA4360), Archives Henri-Poincaré (UMR7117), Loria (UMR7503).

PsyPhiNe is an interdisciplinary and exploratory project between philosophers, psychologists and computer scientists. The goal of the project is related to cognition and behavior. Cognition is a set of processes that are difficult to unite in a general definition. The project aims to explore the idea of assignments of intelligence or intentionality, assuming that our intersubjectivity and our natural tendency to anthropomorphize play a central role: we project onto others parts of our own cognition. To test these hypotheses, our aim is to design a "non-verbal" Turing Test, which satisfies the definitions of our various fields (psychology, philosophy, neuroscience and computer science), using a robotic prototype. Some of the questions that we aim to answer are: is it possible to give the illusion of cognition and of intelligence through such a technical device? How elaborate must be the control algorithms or ”behaviors” of such a device to fool test subjects? How many degrees of freedom must it have?

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

Participants: André Garenne, Nicolas Rougier.

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. We thus have been modeling the structure of the striatum ($\approx$ 3 millions neurons) and the globus pallidus ($\approx$ 50,000 neurons) in the mouse using down-scaled models. Two models have been made, the first one utilized the neural field theory while the other one utilized integrate-and-fire neurons. The goal was to study the activity around the electrode contact point in order to give account on recorded activity in vivo. Unfortunately, electrophysiological recording were not precise enough to conclude on these models.

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

Participants: Nicolas Rougier, Meropi Topalidou.

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. In tight collaboration with Thomas Boraud from the Institute of Neurodegenerative Diseases, we have been modeling the basal ganglia such as to explain the formation of habits in the monkey. This fruitful collaboration lead to the joint publication of several articles [4], [43], [42], [5] and the model enabled us to make very precise prediction on the behavior of the monkeys (dissociation of goal-directed and habitual behavior). Early experiments on two female macaques tend to confirm the prediction.

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

Participant: André Garenne.

The development of computational models of neurons and networks typically involves tuning the numerical parameters to fit experimental results. 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. A multi-agent algorithm in line with ABC (Artificial Bee Colony) paradigm has been applied to new benchmark tests in order to ensure its robustness and better performances, especially when compared to evolutionary and swarm algorithms and this has recently been confirmed, thanks to the local Plafrim computation facilities. A draft paper is then currently modified before submission to take into account these last results.

9.1.5. Thematic Transverse Action of the University of Bordeaux: Project MISTERE

Participant: André Garenne.

The MISTERE (Etude du Mécanisme d'Interaction des Signaux de Téléphonie mobile sur des Réseaux de neurones in vitro) project has been recently accepted and we have obtained financial support and 1 year of post-doctoral contract by the Science and Technology department of the University of Bordeaux. The main topic of this project lies in the elucidation of the cellular mechanisms of the effects of the GSM radio frequencies (GSM-RF) on the neuronal activity. The approach will consist both in computational modeling studies and in pharmacological tests of neuronal cultures activity when submitted to GSM-RF.

9.2. National Initiatives

9.2.1. GDR3672 - BioComp - Material Implementation of natural computation

Participant: Nicolas Rougier [member of the steering commitee].

The GDR BIOCOMP has been officially created on January 2015 and gathers the INP, INSIS, INS2I, INSB, INC institutes of the CNRS. The goal of this GDR is to facilitate interdisciplinary exchanges in France around a common goal: the realization of bio-inspired hardware systems. More precisely, this GDR seeks to understand the mechanisms at work in biological systems to create chips based on natural computation, but also vice versa, building hardware architectures as test systems to better understand biology. In France there is a wealth of expertise in all disciplines concerned with hardware implementations of natural computation: biology, computational neuroscience, mathematics, computer architecture and computer systems, microelectronics, nanotechnology and physics. Making bio-inspired chips is extremely complex and requires advanced skills in all these disciplines. By organizing interdisciplinary meetings and conferences, the goal is hence to bring together different communities so that they can understand each other and work together.

9.2.2. Project Motus of the ANSES

Participant: André Garenne.

The MOTUS project (MOdulaTion dU Signal RF et effets sur le cerveau : approche in vivo et in vitro) has been recently accepted and will be financed by the ANSES (the french national agency for health security). This 3 years project includes substantial financial support as well as 2 years of post-doctoral contracts with our partner IMS regarding the effects of GSM-RF on living matter and especially neuronal activity and development. It is designed to be synergistic with the MISTERE project previously obtained (cf section 9.1.5). Our main involvement will concern electrophysiological data and spike trains analysis as well as the development of pharmacological protocols to test GSM-RF effects hypotheses.

9.2.3. Project Mimacore of the CNRS Challenge Imag'In

Participants: Frédéric Alexandre, Nicolas Rougier.

Better understanding the resting states (regional interactions and corresponding functional networks in the brain when the subject is at rest) is of central interest for a systemic approach of brain understanding. As we think that this domain is not mature enough for a direct functional modeling approach, we try to get familiar with it, through this imaging study. In this exploratory study funded by the CNRS, we are associated with three teams in neuroscience developing three imaging techniques (MRS, MRI, Clarity), to explore resting states in rodents and learn more about their genesis.

9.3. International Initiatives

9.3.1. Inria Associate Teams not involved in an Inria International Labs

9.3.1.1. Braincraft

Title: Braincraft

International Partner (Institution - Laboratory - Researcher):

University of Colorado, Boulder (United States) - Computational Cognitive Neuroscience - Randall O'Reilly

Start year: 2015

We develop with this team a computationally-based understanding of the neural circuits involved in decision making, namely basal ganglia and prefrontal cortex. More precisely, we want to understand what are the processes by which animals and humans select their actions based on their motivations and on the consequences of past actions. This is a fundamental question in neurosciences, with implications to ethology, psychology, economics, sociology and computer science. Through a unique combination of expertise in cognitive psychology, neurosciences and computer science, this associate team will foster a collaboration for developing a computationally-based understanding of the neural circuits involved in decision making, namely basal ganglia and prefrontal cortex. One of the key question is to know the overall contribution of these structures and their function in the decision process.

9.3.2. 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 and for their implementation at large scale (*cf.* § 7.4) as well as for their relation with other brain structures (*cf.* § 7.2).

9.3.3. 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).

9.4. International Research Visitors

9.4.1. Visits of International Scientists

9.4.1.1. Internships

Nallapu Bhargav Teja

Date: June 2015 - Dec 2015

Institution: University of Hyderabad (India)

10. Dissemination

10.1. Promoting Scientific Activities

10.1.1. Scientific events organisation

10.1.1.1. General chair, scientific chair

Nicolas Rougier: Program chair for the EuroScipy 2015 conference. Organization of the "Tentatives, Tentations, Intentions" conference (Nancy, December 2015).

10.1.1.2. Member of the organizing committees

Frédéric Alexandre: Member of the organizing committee of the Conference "Cognition and Innovation", Paris, November 5-6th, cf http://fondation-cognition.org/?q=node/259.

10.1.2. Scientific events selection

10.1.2.1. Member of the conference program committees

Frédéric Alexandre: Member of program committee of CAP 2015 (french conference on Machine Learning)

10.1.2.2. Reviewer

- Nicolas Rougier: Reviewer for EuroScipy 2015, Scipy 2015, ICANN 2015.
- Frédéric Alexandre: Reviewer for the International IEEE EMBS Conference on Neural Engineering; for the International Conference on Development and Learning and on Epigenetic Robotics (ICDL-EPIROB 2015);

10.1.3. Journal

10.1.3.1. Member of the editorial boards

- Frédéric Alexandre: Review Editor for Frontiers in Neurorobotics;
- Nicolas Rougier: Editor in chief for ReScience, review editor for Frontiers in Neurorobotics.

10.1.3.2. Reviewer - Reviewing activities

- Nicolas Rougier: Reviewer for PLOS ONE, Frontiers in Neuroscience, IEEE Transactions on Visualization and Computer Graphics, IEEE Transactions on Image Processing, Journal of Computer Graphics Techniques
- Frédéric Alexandre: Reviewer for Cognitive Computation, PlosOne, Applied Intelligence

10.1.4. Invited talks

- Nicolas Rougier: Invited tutorial ("Neural Fields and cognition") at the 24th Annual Computational Neuroscience Meeting in Prague; Invited talk ("Distributed, Asynchronous, Numerical and Adaptive computing: from neurons to behavior." at the first meeting og the BioComp initiative; Invited tutorial ("matplotlib for beginner") at EuroScipy 2015.
- Frédéric Alexandre: invited talk at the symposium "Modeling the early visual system: From natural vision to numerical applications" of the 12th meeting of the French Neuroscience Society; Invited talk at the special day on modeling irrationality in cognition, organized jointly by the french society of Artificial Intelligence and the french society of Research on Cognition; Invited talk at the scientific council of IMB (institute of mathematics in Bordeaux, june 23rd);

10.1.5. Scientific expertise

Expert for the BBSRC research council (UK) (Nicolas Rougier)

10.1.6. Research administration

- 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 national Inria committee for international chairs; Member of the local Inria committee 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 vice-head of the Mnemosyne team-project; elected member of the Inria Evaluation Committee; Responsible of the local Inria committee for invited professors; Member of the steering committee for the BioComp CNRS consortium; Editor in chief and co-founder of ReScience.

- Thierry Viéville is in charge, at the Inria national level, of the institute science outreach actions and depends on the Direction Générale Déléguée à la Science for this part of his work. He is, for Inria, at the origin of the http://classcode.fr project, and drives it [18], [12].

10.2. Teaching - Supervision - Juries

10.2.1. 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.

Thierry Viéville is since 2009 in charge of formations of high-school teachers in popular computer science.

10.2.2. Juries

We participate to many juries each year.

10.3. Popularization

For a multi-disciplinary team as Mnemosyne, science popularization is not only 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 for 80% of his time involved in popularization actions [35], both at a concrete level (including on Mnemosyne subjects [23]) and at the methodological level [34], [19]. This explains the amount of references to these external subjects in this document.
- Nicolas Rougier: Question/answers about Artificial Intelligence (AI) with the general public (NODE, Bordeaux); popularized article about AI on Interstices; invited talk for the "Pint of Science" festival; interview about AI in the `#Thinovery` magazine; two articles in "The Conversation (FR)" about neurosciences and AI; "Unithé ou Café" at Inria BSO; Blog posts in "Binaires" (36 15 EULA) and "Scilogs" ("L'intelligence artificielle n'aura pas lieu.")
- Frédéric Alexandre: Blog post in Scilogs: "Rien de neuf sous le soleil de l'IA" (www.scilogs.fr/intelligence-mecanique/rien-de-neuf-sous-le-soleil-de-lia/); Conference at the Bordeaux museum of science (Cap Sciences, March 5th) "Modeling the brain to better understand neurodegenerative diseases"; Article in the french scientific magazine Pour la Science: "Where are the real dangers of Artificial Intelligence" (http://www.pourlascience.fr/ewb_pages/a/article-ou-sont-les-vrais-dangers-de-l-apos-intelligence-artificielle-35148.php); Conference at the Multimedia Library of Tulle "Modeling emotions to better understand neurodegenerative diseases" (March 28th); Participation to the french radio broadcast 3D on the national channel France Inter (http://www.franceinter.fr/emission-3d-le-journal-robots-cops, May 31st); Interview in the french scientific magazine Science et Vie Junior ("Must we fear super intelligences", issue of August); Interview in Inriality "Who is afraid about Artificial Intelligence" (http://www.inriality.fr/communication/intelligence-artificielle/qui-peur-de/); Responsible for the Masterclass "Think different" to the Biznext conference (december17th, Bordeaux, cf interview http://objectifaquitaine.latribune.fr/innovation/2015-11-20/les-robots-intelligents-nous-poussent-ils-a-penser-le-monde-autrement.html and announcement on TV http://france3-regions.francetvinfo.fr/aquitaine/emissions/jt-1213-aquitaine);
- PhD students participated to the regional exhibition Aquitec (C. Héricé and Maxime Carrere), to "Fête de la Science" (I. Chraibi Kaadoud and C. Héricé), to "Printemps des filles" (I. Chraibi Kaadoud and C. Héricé) and to the organizing committee of Pint of Science Bordeaux (C. Héricé).

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