RESEARCH CENTRE

Inria Center at the University of Bordeaux

IN PARTNERSHIP WITH:

Université de Bordeaux, CNRS, Institut Polytechnique de Bordeaux

2022

ACTIVITY REPORT

Project-Team

MNEMOSYNE

Mnemonic Synergy

IN COLLABORATION WITH: Laboratoire Bordelais de Recherche en Informatique (LaBRI)

DOMAIN

Digital Health, Biology and Earth

THEME

Computational Neuroscience and Medicine

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Project-Team MNEMOSYNE

Creation of the Project-Team: 2014 July 01

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1 Team members, visitors, external collaborators

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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

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 [60]. 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 [55], 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 [62, 53]. 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 [49, 48] and were the basis for several contributions in our group [61, 57, 63]. 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 [54]; the associated formalism [64] 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 [58], that demonstrated a richness of behavior [59] 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 [57, 56] and their use for observing the emergence of typical cortical properties [51]. 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.

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.

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 [52] 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 [50, 46]. 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* [47]). 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

Modeling the brain to emulate cognitive functions offers direct and indirect application domains. Our models are designed to be confronted to the reality of life sciences and to make predictions in neuroscience and in the medical domain. Our models also have an impact in digital sciences; their performances can be questioned in informatics, their algorithms can be compared with models in machine learning and artificial intelligence, their behavior can be analysed in human-robot interaction. But since what they produce is related to human thinking and behavior, applications will be also possible in various domains of social sciences and humanities.

4.2 Applications in life sciences

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. 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 and related domains like for example educational science.

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.

4.3 Application in digital sciences

Of course, digital 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 undoubtly 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.

4.4 Applications in human sciences

Because we model specific aspects of cognition such as learning, language and decision, our models could be directly analysed from the perspective of educational sciences, linguistics and economy. Because we manipulate such concepts as embodiment of cognition, theory of mind and emotions, we could also participate in debates in philosophy and ethics, as for instance in [26]

Futhermore, our implication in science outreach actions, including computer science teaching in secondary and primary school (e.g., [38]), with the will to analyse and evaluate the outcomes of these actions, is at the origin of building a link between our research in computational learning and human learning, providing not only tools but also new modeling paradigms.

5 Social and environmental responsibility

5.1 Footprint of research activities

As part of the Institute of Neurodegenerative Diseases that developed a strong commitment to the environment, we take our share in the reduction of our carbon footprint by deciding to reduce our commuting footprint and the number of yearly travels to conference.

5.2 Impact of research results

We're engaged in the EcoMob regional project in collaboration with the University of Bordeaux and the University of La Rochelle to study and model the behavior of individuals during their daily trips to and from work places. In this context and based on our previous work on decision making, our team is interested in elucidating how habits are formed and more importantly, how can they be changed.

6 Highlights of the year

6.1 Awards

Best paper award for the paper [19] at International Conference on Developmental Learning (ICDL 2022, London, UK).

7 New software and platforms

7.1 New software

7.1.1 ReservoirPy

Name: Reservoir computing with Python

Keywords: Recurrent network, Artificial intelligence, Reservoir Computing, Multi-label classification, Timeseries Prediction, Time Series, Machine learning, Classification, Offline Learning, Online Learning, Nonlinear system

Scientific Description: Reservoirs Computing is based on random Recurrent Neural Networks (RNNs). ESNs are a particular kind of networks with or without leaking neurons. The computing principle can be seen as a temporal SVM (Support Vector Machine): random projections are used to make dimensionality expansion of the inputs. The input stream is projected to a random recurrent layer and a linear output layer (called "read-out") is modified by learning. This training is often done offline, but can also be done in an online fashion.

Compared to other RNNs, the input layer and the recurrent layer (called "reservoir") do not need to be trained. For other RNNs, the structure of the recurrent layer evolves in most cases by gradient descent algorithms like Backpropagation-Through-Time, which is not biologically plausible and is adapted iteratively to be able to hold a representaion of the input sequence. In contrast, the random weights of the ESN's reservoir are not trained, but are often adapted to possess the "Echo State Property" (ESP) or at least suitable dynamics to generalize. The reservoir activities include non-linear transformations of the inputs that are then exploited by a linear layer. The states of the reservoir can be mapped to the output layer by a computationally cheap linear regression. The weights of the input and recurrent layer can be scaled depending on the task at hand: these are considered as hyperparameters (i.e. parameters which are not learned) along with the leaking rate (or time constant) of neurons and the random matrix densities.

Functional Description: This library provides implementations and tools for the Reservoir Computing paradigm: a way of training Recurrent Neural Networks without training all the weights, by using random projections. ReservoirPy provides an implementation only relying on general scientific librairies like Numpy and Scipy, in order to be more versatile than specific frameworks (e.g. TensorFlow, PyTorch) and provide more flexibilty to build custom architectures. It includes useful and advanced features to train reservoirs. ReservoirPy especially focuses on the Echo State Networks flavour, based on average firing rate neurons with tanh (hyperbolic tangent) activation function.

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News of the Year: The last release of ReservoirPy is version 0.3.5 (one year ago was lauchned the 0.3.0 version). New development of methods including "Intrinsic Plasticity" (see Schrauwen et al. in

2008 and Triesch in 2005), "NVAR" method (Gauthier et al. 2021) and bug fixes. Documentation was improved. We also added new tutorials and examples (e.g. Japanese vowels classification). We also replicated papers with codes like Asabuki et al. 2018 and Gauthier et al. 2021 papers. We also include various datasets in the library: new chaotic attractors (Rössler, Lorenz96, Kuramoto-Sivashinsky) and japanese vowels.

We presented ReservoirPy features at different conferences (SAB 2022, EuroScipy 2022, Dataquitaine 2022). We also published a preprint comparing it to various similar libraries.

We were invited to talk about ReservoirPy at different events: SCAI Dev (Paris Sorbonne University), AI4industry workshop (Bordeaux), ETIS lab (Cergy), PHDS Impulsion project kick-off (Bordeaux), ML-MTP online seminar of Machine Learning in Montpelier. We were also invited to presented it at the LyRE research lab (Bordeaux) of SUEZ company. We also did a half-day tutorial for students and researchers of the PHDS network (May 2022).

Due to a strong interest from colleagues to try this new library with their data, an interface to another language was developped. We helped SISTEM Inria team to develop an interface in R language to ReservoirR: https://github.com/reservoirpy/reservoirR It is currently used by a PhD student of their team.

URL: `https://github.com/reservoirpy/reservoirpy`

Publications: hal-03699931, hal-02595026, hal-03533731, hal-03203318, hal-03482372, hal-03203374, hal-03761440, tel-03946773, hal-03628290, hal-03780006, hal-03945994

Contact: Xavier Hinaut

Participants: Xavier Hinaut, Nathan Trouvain, Nicolas Rougier

7.1.2 Neurosmart

Name: Neurosmart

Keywords: Science outreach, Web Application, JavaScript, JSon, Cognitive sciences, Neurosciences

Functional Description: The software consists of a web interface allowing to run the scenario of a presentation of cognitive functions while visualizing the brain areas involved. It's made of : - a 3D brain model - an interactive visualization module of this brain model with low computation consumption - a command language in JSON syntax to drive the display of the model and interactive multi-media content, which can be extended - an "indulgent" JSON syntax analyzer, i.e., allowing to build the data structure with a minimum of control characters, all is programmed in Javascript to run in any browser.

Release Contributions: Initial version

URL: `https://gitlab.inria.fr/mnemosyne/neurosmart`

Contact: Thierry Viéville

Partners: Fondation Blaise Pascal, EchoScience

7.1.3 AIDElibs

Name: Artificial Intelligence Devoted to Education

Keywords: Cognitive sciences, Neurosciences, Educational Science, C++, JavaScript, Python, Connected object, Automatic Learning, Learning

Scientific Description: We want to explore to what extent approaches or techniques from cognitive neuroscience related to machine learning and symbolic tools to represent knowledge, could help to better formalize human learning as studied in education sciences. . To this end, we are developing a research code for measuring learning analytics during activities with tangible objects and middleware between the major tools and algorithms used in this exploratory action of research.

Functional Description: This library includes

- the preliminary implementation of metrizable symbolic data structure allowing performing symbolic derivations using numerical embedding, in an explicitly (thus easily explainable) way, targeting reinforcement symbolic learning or open-ended creative complex problem-solving.
- a set of C/C++ routines for basic calculations, with the portions of code executed on connected objects which allow measurement of learning traces, and the control of experiments,
- C/C ++ or Javascript tools to interface the different software modules used, and a Python wrapper to develop above these functionalities.

Release Contributions: Initial version

News of the Year: - Finalization of descriptive ontologies of a human learning task and deployment of associated software tools

- Started the implementation of symbolic structure manipulation mechanisms in a metric space.

URL: `https://gitlab.inria.fr/line/aide-group/aide`

Contact: Thierry Viéville

Participants: Chloe Mercier, Axel Palaude, Lola Denet, Éric Pascual

Partners: Laboratoire LINE, Université Côte d'Azur, PoBot

8 New results

8.1 Overview

This year we have addressed several important questions related to our scientific positioning. Central to this positioning, we have studied and modeled bio-inspired learning mechanisms and collaborative mnesic functions (*cf.* § 8.2). We have also studied higher cognitive functions, related to cognitive control (*cf.* § 8.3) and have also considered how important characteristics can be associated to this framework, like symbolic abstract knowledge (*cf.* § 8.4), and oscillations (*cf.* § 8.5). Endly, we have also pursued our work on language processing in birds and robots (*cf.* § 8.6).

8.2 Learning mechanisms and collaborative mnesic functions

This year, we have been working on several bio-plausible learning mechanisms like hebbian learning, contrastive divergent learning (CDL) and reinforcement learning and their combination in different frameworks. This is the case for the development of original versions of Restricted Boltzmann Machines in robotic applications (*cf.* § 9.1.1) and for the development of Reservoir Computing.

Within the development of the ReservoirPy library, we have released the version 0.3.5. We presented the library at various events (DatAquitaine, EuroScipy, ...), including at the Suez Bordeaux area research lab. Side repository emerged on the ReservoirPy organisation on github: especially an interface to the library in R language was jointly developed with the SISTM team and called reservoirR

We've also investigated the development of automatized skills, such as song production in the songbird that is driven by the basal ganglia through dopamine-modulated reinforcement learning in order to guide learning in a parallel "cortical" pathway, which eventually governs the production of the skill [6]. From a theoretical perspective, this can be considered as a dual learning system, one being reactive and dependent on instantaneous reward (reinforcement learning) while the other being much slower and independent of reward but being able to strongly bias the output. These results [19] were awarded the best paper award for the paper at the International Conference on Developmental Learning (ICDL 2022, London, UK). This hypothesis is has been tested in the newt where the absence of a proper cortex should prevent such dual learning but unfortunately, experiments were not conclusive.

Concerning more microscopic mechanisms of learning rules, we have also presented new hypotheses about the computation of reward prediction errors in reinforcement learning, in cooperation with neuroscientific colleagues [9].

8.3 Cognitive control

In cognitive control, the working memory in the prefrontal cortex and the episodic memory in the hippocampus play a major role in the definition of flexible contextual rules that can replace the dominant behavior. This year, to elaborate more on the biological bases of this cognitive function, we have pursued our work on the definition of a flexible switching between rules, thus stressing the difference between simple and abstract rules [14], and we have studied the relations between the prefrontal cortex and the hippocampus [13]. We have also considered implications of this work in Machine Learning by proposing a model of modular reinforcement learning, seen as the combination of contextual rules [21, 22].

8.4 Integrating abstract symbolic knowledge

Within the AIDE AEx (*cf.* § 10.3.4), we carried on introducing the idea of a symbolic description of a complex human learning task, in order to contribute to better understanding how we learn [10], in the very precise framework of a task, named #CreaCube, related to initiation to computational thinking presented as an open-ended problem, which involves solving a problem and appealing to creativity [40, 37], and also to participate in the experimental design and analysis [32, 33]. We also proposed to map an ontology onto a SPA-based architecture with a preliminary partial implementation into spiking neural networks [24] in order to provide an effective link between symbolic presentation of information and biologically plausible numerical implementation, including regarding representation of belief, revisiting the possibility theory [36]. We also still work on making explicit how a reinforcement learning paradigm can be applied to a symbolic representation of a concrete problem-solving task, modeled here by an ontology, for instance with applications to robotics [27]. This work is embedded in a strong collaboration with education science collaborators [34] working on computational thinking initiation and computer science tools in education with a multi-disciplinary vision of cognitive function modeling [30].

8.5 Integrating oscillations

Theta-nested gamma oscillations have been reported in many areas of the brain and are believed to constitute a fundamental mechanism to transfer information across spatial and temporal scales. Such transfer is known to occur between hippocampus and prefrontal cortex and this is the reason that leads us to first investigate oscillations inside a detailed model of the hippocampus based on the model by our new colleague A. Aussel. We introduced in this model a set of Kuramoto oscillators in order to model the oscillatory properties of the medial septum. These oscillators are able to induce a theta reset in the presence of a strong sensory input as it has been observed in rodents.This work has been presented at the FENS and ENCODS conferences in July 2022.

In a different direction, the detailed hippocampus model from the team was also expanded by adding several pathological (epileptic) mechanisms so as to study the transition from physiological to pathological oscillations. This model predicts that epileptic seizures are mostly the consequence of network anomalies while interictal rhythms (associated with memory deficits) are also dependant on dynamical changes at the single-cell level ([7]).

8.6 Language processing

We pursue our research on the understanding of how children acquire language through noisy supervision and model how their brain could process language with the little information available. We take the perspective of a learning agent by focusing on robotic corpora, in order to integrate the "Grounding Problem" (a question also important for other topics of the team 8.4). We build on previous cross-situational learning experiments towards robot language grounding, and made an extensive comparison on different datasets related to robot instructions, various word embedding representations, and comparing various architectures (Reservoir Computing, LSTMs, ...) [31].

This year we started to investigate a new subfield in computational language studies: using language machine learning models to "encode" brain dynamics. This means that we try to predict fMRI (functional Magnetic Resonance Imaging) activity of human subjects from computational language models. We investigated computational models processing the same sentences in written or spoken form. Our first results concern the investigation of how long-term (memory) information is a good predictor of fMRI activity of subjects [18][42].

A long term project on language processing and production with reservoir computing was proposed in the Habilitation thesis of X. Hinaut [28].

9 Bilateral contracts and grants with industry

9.1 Bilateral contracts with industry

9.1.1 Contract with CEA Cesta

Participants: Frédéric Alexandre, Guillaume Padiolleau.

In the context of the PhD of Guillaume Padiolleau, we are working with the CEA on possible interactions between model-based and model-free approaches of reinforcement learning, based on cognitive consideration. Particularly, to decrease the complexity of exploration of a large data space in model-free approaches, we aim at considering introducing a priori knowledge coming from a model and we also propose to consider motivation as another way to orient the search in the learning space. This is applied in the robotic domain to manipulations by a robotic arm.

10 Partnerships and cooperations

10.1 International initiatives

10.1.1 Associate Teams in the framework of an Inria International Lab or in the framework of an Inria International Program

MENG PO

Title: Memory ENGineering for Problem sOlving

Duration: 2020 ->

Coordinator: Shan Yu (shan.yu@nlpr.ia.ac.cn)

Partners:

- Brainnetome Center and National Laboratory of Pattern Recognition (Chine)

Inria contact: Frederic Alexandre

Summary: Artificial Intelligence (AI) has been built on the opposition between symbolic problem solving that should be addressed by explicit models of planning, and numerical learning that should be obtained by neural networks. But it is clear that in ecological conditions, our cognition has to mix both capabilities and this is nicely carried out by our brains. Our behavior is sometimes described as a simple dichotomy between Goal-Directed (explicit deliberation and knowledge manipulation for planning) and habitual (automatic Stimulus-Response association) approaches. Recent results rather report more general strategies, including the hybrid combinations of both. Importantly, they highlight key mechanisms, corresponding to detect explicitly contexts in which the strategy should be modified and to adapt simple Stimulus-Response associations to these contexts. We propose here to associate our experiences to develop a more general framework for adapting neural networks to problem solving, thus augmenting their usability in AI and the understanding of brain reasoning mechanisms. On the Chinese side, connectionist models like deep neural networks are adapted to avoid so-called catastrophic forgetting and to facilitate context-based information processing. On the French side, models in computational neuroscience explore the capacity of neuronal structures like the hippocampus to categorize contexts and investigate the role of the prefrontal cortex, known to modulate behavioral activity depending on the context. The main impact of this associate team is in the better understanding of brain circuits and their relation to higher cognitive functions associated to problem solving. This might also have an impact in the medical domain, through the possibility of studying lesioned systems and their relations to dysfunctions of the brain. In addition, the new algorithms and network architecture for deep learning generated in this project promise a wide range of applications in complex and dynamic environments.

10.1.2 Inria associate team not involved in an IIL or an international program

SARASWATI

Title: Sequential motor skills: a dual system view

Duration: 2020 ->

Coordinator: Raju Surampudi BAPI (srinivasa.chakravarthy@gmail.com)

Partners:

- Indian Institute of Technology Hyderabad Hyderabad (Inde)

Inria contact: Nicolas Rougier

Summary: Action-outcome (A-O) and stimulus-response (S-R) processes, two forms of instrumental conditioning, are important components of behavior. The former evaluates the benefit of an action in order to choose the best one among those available (action selection), while the latter is responsible for automatic behavior (routines), eliciting a response as soon as a known stimulus is presented , independently of the hedonic value of the stimulus. Action selection can be easily characterized by using a simple operant conditioning setup, such as a two-armed bandit task, where an animal must choose between two options of different value, the value being probability, magnitude or quality of reward. After some trial and error, a wide variety of vertebrates are able to select the best option . After intensive training, which depends on the species and the task and whether the same values are used throughout the series of the experiments, the animal will tend to become insensitive to change and persist in selecting the formerly best option . Most of the studies on action selection and habits/routines agree on a slow and incremental transfer from the action-outcome to the stimulus-response system such that after extensive training, the S-R system takes control of behavior and the animal becomes insensitive to reward devaluation. Oddly enough, very little is known on the exact mechanism underlying such transfer and there exists many different hypothesis. One difficult question that immediately arises is when and how the brain switches from a flexible action selection system to a more static one. Therefore, this collaborative project aims at answering this question on both the theoretical and experimental side.

10.2 European initiatives

10.2.1 Other european programs/initiatives

We are member of the "Communauté d'Apprentissage de l'Informatique" CAI Erasmus+ project which aims to bring teachers into a community to facilitate the discovery of computers and the tools necessary for their learning for students aged 10 to 18. A platform and digital tools will allow mutual assistance between teachers through discussions and sharing of experiences and educational resources, this part of the project being leaded by our team working in cooperation with the LINE laboratory, including large audience dissemination.

10.3 National initiatives

10.3.1 ANR SOMA (PRCI)

Participants: Nicolas Rougier, Remya Sankar.

This project is a convergence point between past research approaches toward new computational paradigms (adaptive reconfigurable architecture, cellular computing, computational neuroscience, and neuromorphic hardware):

1. SOMA is an adaptive reconfigurable architecture to the extent that it will dynamically re-organize both its computation and its communication by adapting itself to the data to process.
2. SOMA is based on cellular computing since it targets a massively parallel, distributed and decentralized neuromorphic architecture.
3. SOMA is based on computational neuroscience since its self-organization capabilities are inspired from neural mechanisms.
4. SOMA is a neuromorphic hardware system since its organization emerges from the interactions between neural maps transposed into hardware from brain observation.

This project represents a significant step toward the definition of a true fine-grained distributed, adaptive and decentralized neural computation framework. Using self-organized neural populations onto a cellular machine where local routing resources are not separated from computational resources, it will ensure natural scalability and adaptability as well as a better performance/power consumption tradeoff compared to other conventional embedded solutions.

10.3.2 ANR DeepPool (JCJC)

Participants: Xavier Hinaut, Nathan Trouvain, Subba Oota.

Language involves several abstraction levels of hierarchy. Most models focus on a particular level of abstraction making them unable to model bottom-up and top-down processes. Moreover, we do not know how the brain grounds symbols to perceptions and how these symbols emerge throughout development. Experimental evidence suggests that perception and action shape one-another (e.g. motor areas activated during speech perception) but the precise mechanisms involved in this action-perception shaping at various levels of abstraction are still largely unknown. The PI proposes to create a new generation of neural-based computational models of language processing and production: i.e. to (1) use biologically plausible learning mechanisms; (2) create novel sensorimotor mechanisms to account for action-perception shaping; (3) build hierarchical models from sensorimotor to sentence level; (4) embody such models in robots in order to ground semantics.

The project started this year and will last four years (2022-2025). We regularly discuss with our colleague from the University of Bordeaux (Gaël Jobard).

10.3.3 GTnum Scolia

Participants: Frédéric Alexandre, Chloé Mercier, Thierry Viéville.

Our team is part of an international consortium selected by the French ministry of education, to investigate AI for new modes of interaction, new modes of assessment and hybridization of learning environments. Our team is more specifically in charge of the part dedicated to modeling the learner and to evaluation.

The project ended this year with a collective book accepted for publication.

10.3.4 Exploratory action AIDE

Participants: Frédéric Alexandre, Axel Palaude, Chloé Mercier, Thierry Viéville.

The modelling and assessment of computational thinking (CT) skills is a challenge that has a major impact on how learning activities are integrated into the curricula of OECD countries, particularly in terms of equal opportunities. The Artificial Intelligence Devoted to Education (AIDE) Inria exploratory action (AEx)aims to help address this challenge in an innovative way by modelling computational thinking through a neuro-inspired cognitive model, allowing analysis of the learner engaged in learning activities.

It's an exploratory subject. We are taking the scientific risk of looking at things differently. For example, instead of using the so-called artificial intelligence mechanisms to try to make "assistants", i.e., algorithms to better learn, we start focusing on how formalisms from the field of "artificial intelligence" (numerical and symbolic) contribute to better understand how we learn. But it is also a research with applications. Our hope is to contribute to the reduction of educational inequalities and improve school perseverance, focusing on transversal competencies, also called 21st century competencies which include computer thinking. More details on our activities here and a public presentation here.

10.4 Regional initiatives

10.4.1 Ecomob

Participants: Frédéric Alexandre, Snigdha Dagar, Nicolas Rougier.

Project gathering researchers from: University of La Rochelle (Cerege lab in social sciences and L3I lab in computer science); University of Bordeaux (IRGO lab in organisation management); Town and suburbs of La Rochelle.

The goal of this project is to study and model user urban mobility behaviours in an eco-responsibility context. Interactive mobile applications are used to measure the effective evolution of behaviour. Our team is in charge of studying models of decision in such complex contexts, in interaction with teams in social sciences aiming at influencing user behaviours.

10.4.2 PsyPhINe

Participants: Nicolas Rougier.

Project gathering researchers from: MSH Lorraine (USR3261), InterPsy (EA 4432), APEMAC, EPSaM (EA4360), Archives Henri-Poincaré (UMR7117), Loria (UMR7503) and Mnemosyne.

PsyPhiNe is a pluridisciplinary and exploratory project between philosophers, psychologists, neuroscientists and computer scientists. The goal of the project is to explore cognition and behavior from different perspectives. The project aims at exploring 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, we ran a series of experiments with human subject confronted to amotorized lamp that can or cannot interact with them while they're doing a specific task.

10.4.3 Regional and local Research Networks

We are members of three Regional Research networks, devoted to Artificial Intelligence, Robotics and Computational Education.

We are members of two Networks of Research of the University of Bordeaux: PHDS (Public Health Data Science) and RobSys (Robustness of Autonomous Systems).

11 Dissemination

11.1 Promoting scientific activities

11.1.1 Scientific events: organisation

General chair, scientific chair:

- F. Alexandre was in charge of the scientific organization of the one-week workshop AI for Industry AI4I'22 including 350 attendees on january 17-21, with teaching in the morning and hands-on experiments on industrial applications in the afternoon.
- The team has also organized on May 12th, a scientific meeting with the INSPE of Bordeaux (component of the University of Bordeaux for the training of primary school teachers) for the mutual presentation of our activities, related to the domain of education science (*cf.* § 8.4).
- X. Hinaut was the main co-organizer of the SMILES (Sensorimotor Interaction, Language and Embodiment of Symbols) workshop at the ICDL 2022 conference (London, UK), and the "Bilingual Sentence Processing: when Models Meet Experiments" symposium at CogSci22 conference (Toronto, CA). He was also the local organizer, together with Frederic Alexandre, of the 2022 Inria-DFKI workshop, Bordeaux, FR.

Member of the organizing committees

- F. Alexandre: member of the organizing committee of the Dataquitaine regional conference of AI and Data Science and of the International Workshop AMINA.
- N.Rougier co-organized the 14th ASPP summer school (Bilbao).

Student Volunteer

- S. R. Oota: SNL-2022; NAACL-2022; Cogsci-2022; ACL-2022 (All In Person).

11.1.2 Scientific events: selection

Member of the conference program committees:

- F. Alexandre: ICANN22; SAB22; ACAIN22;
- S. R. Oota: CoDS COMDA-2022; ICDCIT-2022;
- N.Rougier: SAB22, Bench22, CogSci22, WSOM22;
- T. Viéville : AIED22; ICANN22.

Reviewer:

- F. Alexandre: reviewer for ICDL22; ICANN22;
- S.R. Oota: Cogsci-2022; IJCNN-2022; ACL ARR-2022; ICML-2022; NeurIPS-2022; ICLR-2022; WACV-2022; ECML PKDD-2022; CHIL-2022;
- T. Viéville: reviewer for ICDL22; AIED22; ICANN22;
- C. Mercier: reviewer for ICDL22;
- X. Hinaut: reviewer for ACL ARR OpenReview, CogSci22, IJCNN22, ICDL22 (reviewer and meta-reviewer).

11.1.3 Journal

Member of the editorial boards:

- N. Rougier is redactor in chief for ReScience C and ReScience X, academic editor for PeerJ Computer Science and review editor for Frontiers in Neurobotics, Frontiers in Psychology and Frontier in Neuroscience.
- F. Alexandre is Academic Editor for PLOS ONE; Review Editor for Frontiers in Neurorobotics; member of the editorial board of Cognitive Neurodynamics.
- X. Hinaut is member of the Editorial Board of Frontiers in Neurorobotics as Review Editor.
- T. Viéville is member of the Editorial Board of Frontiers in Neurorobotics as Review Editor.

Reviewer - reviewing activities:

- F. Alexandre: reviewer for Cognitive Computation;
- N. Rougier: reviewer for PLOS Computational Biology, Journal of Computer Graphics and Technology, Text & Talk, Cognitive System Research, Scientific Data (Nature), Artificial Intelligence Review;
- T. Viéville: Frontiers in Neurobotics;
- A. Aussel : PNAS;
- C. Mercier: Computers & Education
- X. Hinaut: Philosophical Transactions of the Royal Society B, PLoS Computational Biology, IEEE Transaction on Cognitive and Developmental Systems.

11.1.4 Invited talks:

- F. Alexandre: talk given to the event Data & AI organized by the company La Poste on November 22.
- N. Rougier: invited talk given at the Open Planetary Lunch (Online), INSEP (online), Hacking Cognition Summer school (online), GT8 Summer school (Moliets et Maa), Comité des projets (Inria Rennes), Ecole Centrale (Lille).
- X. Hinaut: invited talks at Department of Cybernetics, Czech Technical University (Prague), Dec 2022; the "International Workshop on Reservoir Computing and Neural Networks" (IIT Madras, India - by visio), Nov 2022; "Computational and mathematical approaches for neuroscience workshop" (Paris Brain Institute, Paris, FR), June 2022. He also presented the ReservoirPy library with N. Trouvain: Le Lyre lab Suez, SCAI Dev (Paris Sorbonne University), AI4industry workshop (Bordeaux), ETIS lab (Cergy), PHDS Impulsion project kick-off (Bordeaux), ML-MTP online seminar of Machine Learning in Montpelier.

11.1.5 Leadership within the scientific community:

- F. Alexandre was among the three french scientists invited by the Embassy of France in the United States to give a presentation and participate to round tables during the NeuroAI event held in Seattle, USA, on September 27-30.

11.1.6 Scientific expertise

- F. Alexandre is the french expert for Mathematics and Computer Science of the PHC (Hubert Curien Program) Utique for scientific cooperation between France and Tunisia. This year, he also made expertises for the Natural Sciences and Engineering Research Council of Canada (NSERC) and for the ANID (Agencia Nacional de Investigacion y Desarrollo) in Chile.
- N. Rougier has been nominated permanent expert for the French Open Science initiative. This year, he served as an international expert for SwissUniversities (Open Science call).

11.1.7 Research administration

- F. Alexandre is member of the steering committee of Inria Bordeaux Sud-Ouest Project Committee; member of the Inria International Chairs committee; corresponding member for Inria Bordeaux Sud- Ouest of the Inria Operational Committee for the assesment of Legal and Ethical risks;
- N. Rougier is the local correspondent for the IES committee, co-creator/organizer for Causer'IES & Coffee meetings, member of the open software collegium of COSO (co-heading the international working group), member of the ReiSO (Réseau d'experts internationaux de la Science ouverte) and member of the Vispy governing board with voting rights.
- X.Hinaut is member of the "Committee for Technological Development" (CDT), the "Committee for Research Jobs" (CER) of Inria Bordeaux Sud-Ouest, and addressee of the PlaFRIM high-performance computing cluster. He is also member of IEEE Task Forces (TF) about: "Reservoir Computing", "Cognitive and Developmental Systems Technical Committee": "Language and Cognition" and "Action and Perception". He is co-Head of the "Apprentissage et Neurosciences pour la Robotique" (GT8) CNRS Robotics Working Group. He manages a WP in the PHDS Impulsion Bordeaux network.

11.2 Teaching - Supervision - Juries

11.2.1 Teaching

Many courses are given in french 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.

- T. Viéville is teaching computational thinking in the Msc #CreaSmartEdtech "Digital Expertise" and is co-organizing this Master of Science, animating both online and blended sessions.
- C. Mercier teached the Education Computing, including Artificial Intelligence and Ontologies initiation, in the Msc #CreaSmartEdtech as an online interactive course, including student follow-up, 6 hours.
- S. R. Oota teached at the Cogsci-2022 Full-day Tutorial: Deep Learning for Brain Encoding and Decoding
- F. Alexandre and T. Viéville have been involved in the animation and online coaching of the "Intelligence Artificielle Intelligente" citizen formation, via the creation of a MOOC, with more than 40,000 participants, allowing everyone to master these disruptive technologies by better understanding ground notions.
- T. Viéville have been involved, as project driver, in the production of the "Numérique et Science Informatique", on-line and interactive teaching platform, with two MOOC and a forum, aiming at offering a French-speaking formation regarding the NSI and SNT teaching, with more than 5000 participants after a few weeks of experimental production. See accompanied community-based self-training of computer science and technology secondary school teachers,
- N. Rougier co-created (with Arthur Leblois and Slim Karkar) the computational neuroscience module for the international master program in neuroscience (University of Bordeaux).
- X. Hinaut is involved in teaching (Machine Learning, Modelling, Neural Networks, Time Series Processing, Reservoir Computing, ...), supervising BSc and MSc interns, and supervising student projects in Bordeaux area: student project at workshop "AI 4 Industry", MSc Eng. Bordeaux INP engineering schools, MSc Cognitive Science, University of Bordeaux, FR. He was also invited to give a guest lecture on Reservoir Computing to MSc Intelligent Adaptive Systems at University of Hamburg, DE. He is also in the monitoring comittee of several PhD students: G. Hamon (Inria), Manel Rakez (Inserm), Tristan Karch (Inria).

11.2.2 Supervision

- T. Viéville supervised 3 students for their Learning Science Master Internship and 1 student in Neuroscience Internship applied to Learning Science
- C. Mercier and A. Palaude supervised four groups of students at ENSCP and ENSEIRB for their PFE/PFA (main project of the program).

11.2.3 Juries

- F. Alexandre: 2 habilitation HDR review teams (one abroad).
- N. Rougier: 1 PhD defense (reviewer)

11.3 Popularization

11.3.1 Internal or external Inria responsibilities

T. Viéville is co-editor of the computer science outreach blog binaire of LeMonde.fr in link with the French Computer Science Society.

11.3.2 Articles and contents

- F. Alexandre: an article about Memory in the journal Science & Vie
- A. Aussel: a video-clip about her research activities for the local television TV7;
- T. Viéville is co-author and co-editor of several large audience articles hal-03845008, hal-03844358, hal-03557770v2, ···

11.3.3 Education

F. Alexandre: interactions with a regional operator in science outreach Lacq Odyssee to help a junior high school prepare and design a strip cartoon about Artificial Intelligence (January); talk given at the regional Maison de la Science to introduce Artificial Intelligence to 25 high-school teachers (April, 12).

11.3.4 Interventions

- F. Alexandre: Cine-debate: discussion about a brain related movie with the public in a cinema (April, 26);
- H. Chateau-Laurent: presentation to the regional Forum on Cognitive Science (March 12);
- T. Viéville: conferences in High-School regarding "Sciences du Numérique" (computer science and related applied mathematics) including artificial intelligence: 4 conferences this year
- T. Viéville: regular participation in Computational Thinking initiation activities (e.g., unplugged activities) targeting underprivileged children and focusing on gender equality, in link with the LINE learning science lab for pedagogical evaluation of the interventions: 12 sessions this year.
- N.Rougier organized a general public event "Mais pourquoi l'IA est-elle aussi méchante (dans les films, livres et jeux) ?" in cooperation with Inria and Hypermondes association.
- N.Rougier co-organized the Hypermondes festival (Mérignac) gathering more than 5,000 people, 80 authors and 25 scientists.
- A. Aussel, H. Chateau-Laurent, C. Mercier and A. Palaude participated at the Inria Fête de la Science event

- A. Aussel participated in the supervision of the club CGénial of the Lycée André Theuriet in Civray, who was awarded at the national "CGénial" contest and presented their project at the EUCYS contest in Leiden, Netherlands.
- A. Aussel presented her research to children at the Montessori International Bordeaux school, to high-schoolers at the lycée Odilon Redon (as part of the "Chiche" program), and young adults at the Bordeaux Geek Festival (as part of an initiative from "Cap Sciences").
- T. Viéville participated in several events during the Fête de la Science week (activity, conference, ...).

12 Scientific production

12.1 Major publications

[1] F. Alexandre. 'A global framework for a systemic view of brain modeling'. In: *Brain Informatics* 8.1 (16th Feb. 2021), p. 22. DOI: 10.1186/s40708-021-00126-4. URL: https://hal.inria.fr/hal-03143843.

[2] A. Nioche, N. P. Rougier, M. Deffains, S. Bourgeois-Gironde, S. Ballesta and T. Boraud. 'The adaptive value of probability distortion and risk-seeking in macaques' decision-making'. In: *Philosophical Transactions of the Royal Society B: Biological Sciences* (Jan. 2021). DOI: 10.1098/rstb.2019.0668. URL: https://hal.inria.fr/hal-03005035.

[3] L. Pedrelli and X. Hinaut. 'Hierarchical-Task Reservoir for Online Semantic Analysis from Continuous Speech'. In: *IEEE Transactions on Neural Networks and Learning Systems* (27th Sept. 2021). DOI: 10.1109/TNNLS.2021.3095140. URL: https://hal.inria.fr/hal-03031413.

[4] N. P. Rougier. *Scientific Visualization: Python + Matplotlib*. 15th Nov. 2021. URL: https://hal.inria.fr/hal-03427242.

[5] N. P. Rougier and G. I. Detorakis. 'Randomized Self Organizing Map'. In: *Neural Computation* (2021). URL: https://hal.inria.fr/hal-03017448.

[6] R. Sankar, N. P. Rougier and A. Leblois. 'Computational benefits of structural plasticity, illustrated in songbirds'. In: *Neuroscience & Biobehavioral Reviews* (2021). URL: https://hal.archives-ouvertes.fr/hal-03416314.

12.2 Publications of the year

International journals

[7] A. Aussel, R. Ranta, O. Aron, S. Colnat-Coulbois, L. Tyvaert, L. Maillard and L. Buhry. 'Cell to network computational model of the epileptic human hippocampus suggests specific roles of network and channel dysfunctions in the ictal and interictal oscillations'. In: *Journal of Computational Neuroscience* 50.4 (Nov. 2022), pp. 519–535. DOI: 10.1007/s10827-022-00829-5. URL: https://hal-cnrs.archives-ouvertes.fr/hal-03721996.

[8] D. Birre, T. Feuillet, R. Lagalis, J. Milian, F. Alexandre, D. Sheeren, R. Serrano-Notivoli, M. Vignal and M. Y. Bader. 'A new method for quantifying treeline-ecotone change based on multiple spatial pattern dimensions'. In: *Landscape Ecology* (6th Jan. 2023), 18p. DOI: 10.1007/s10980-022-01589-4. URL: https://hal.inrae.fr/hal-03942369.

[9] P. Kaushik, J. Naudé, S. B. Raju and F. Alexandre. 'A VTA GABAergic computational model of dissociated reward prediction error computation in classical conditioning'. In: *Neurobiology of Learning and Memory* 193.107653 (2022). DOI: 10.1101/2020.02.06.936997. URL: https://hal.archives-ouvertes.fr/hal-03066295.

[10] C. Mercier. 'An Ontology to Formalize a Creative Problem Solving Activity'. In: *IEEE Transactions on Cognitive and Developmental Systems* (28th Sept. 2022), pp. 1–1. DOI: 10.1109/tcds.2022.3210234. URL: https://hal.inria.fr/hal-03791482.

[11] A. Strock, N. P. Rougier and X. Hinaut. 'Latent space exploration and functionalization of a gated working memory model using conceptors'. In: *Cognitive Computation* (22nd Jan. 2022). DOI: 10.1007/s12559-020-09797-3. URL: https://hal.inria.fr/hal-02494493.

International peer-reviewed conferences

[12] T. Barennes, X. Hinaut and F. Alexandre. 'Contrôle Biomimétique de Prothèse par réseaux de neurones'. In: *Proceedings du workshop AMINA*. Workshop AMINA: Applications Médicales de l'Informatique:Nouvelles Approches. Monastir, Tunisia, 2nd Nov. 2022. URL: https://hal.science/hal-03940097.

[13] H. Chateau-Laurent and F. Alexandre. 'The Opportunistic PFC: Downstream Modulation of a Hippocampus-inspired Network is Optimal for Contextual Memory Recall'. In: *Proceedings of the workshop on Memory in Artificial and Real Intelligence (MemARI)*. 36th Conference on Neural Information Processing System. New Orleans, United States, Dec. 2022. URL: https://hal.science/hal-03885715.

[14] S. Dagar, F. Alexandre and N. P. Rougier. 'From concrete to abstract rules : A computational sketch'. In: BI 22 - The 15th International Conference on Brain Informatics. Padova, Italy, 15th July 2022. URL: https://hal.inria.fr/hal-03695814.

[15] S. R. Oota, J. Arora, V. Agarwal, M. Marreddy, M. Gupta and B. Surampudi. 'Neural Language Taskonomy: Which NLP Tasks are the most Predictive of fMRI Brain Activity?' In: Proceedings of the 2022 Conference of the North American Chapter of the Association for Computational Linguistics: Human Language Technologies. Seattle, United Kingdom: Association for Computational Linguistics, July 2022, pp. 3220–3237. DOI: 10.18653/v1/2022.naacl-main.235. URL: https://hal.science/hal-03946624.

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