RESEARCH CENTRE

Inria Centre at the University of Bordeaux

IN PARTNERSHIP WITH:

Université de Bordeaux, CNRS, Institut Polytechnique de Bordeaux

2024 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

Inria

Contents

Project-Team MNEMOSYNE

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Keywords

Computer sciences and digital sciences

A1.1.12. – Non-conventional architectures

A1.5. – Complex systems

A3.1.1. – Modeling, representation

A3.1.7. – Open data

A3.2.2. – Knowledge extraction, cleaning

A3.2.5. – Ontologies

A3.3. – Data and knowledge analysis

A3.3.2. – Data mining

A3.4.1. – Supervised learning

A3.4.2. – Unsupervised learning

A3.4.3. – Reinforcement learning

A3.4.4. – Optimization and learning

A3.4.6. – Neural networks

A3.4.8. – Deep learning

A5.1.1. – Engineering of interactive systems

A5.1.2. – Evaluation of interactive systems

A5.2. – Data visualization

A5.3.3. – Pattern recognition

A5.4.1. – Object recognition

A5.4.2. – Activity recognition

A5.7.1. – Sound

A5.7.3. – Speech

A5.7.4. – Analysis

A5.8. – Natural language processing

A5.9.1. – Sampling, acquisition

A5.10.5. – Robot interaction (with the environment, humans, other robots)

A5.10.7. – Learning

A5.10.8. – Cognitive robotics and systems

A5.11.1. – Human activity analysis and recognition

A7.1. – Algorithms

A9.2. – Machine learning

A9.5. – Robotics

Other research topics and application domains

- B1.2. – Neuroscience and cognitive science
- B1.2.1. – Understanding and simulation of the brain and the nervous system
- B1.2.2. – Cognitive science
- B2.2.6. – Neurodegenerative diseases
- B8.5.2. – Crowd sourcing
- B9.1.1. – E-learning, MOOC
- B9.5.1. – Computer science
- B9.6.8. – Linguistics
- B9.7. – Knowledge dissemination
- B9.8. – Reproducibility
- B9.11.1. – Environmental risks

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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 [70]. 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 [65], 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 [72, 63]. 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 [59, 58] and were the basis for several contributions in our group [71, 67, 73]. 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 [64]; the associated formalism [74] 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 [68], that demonstrated a richness of behavior [69] 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 [67, 66] and their use for observing the emergence of typical cortical properties [61]. 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 [62] 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 [60, 56]. 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* [57]). 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, economy, philosophy and ethics.

Futhermore, our implication in science outreach actions, including computer science teaching in secondary and primary school, 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.

6 Highlights of the year

In cooperation with the Hypermondes association, we've edited and released a book ("IA Logs", 250 pages) that gathers novels from 20 researchers in computer science, philosophy, social sciences and law. This book is the output of two workshops that have been organized during 2024, whose goal was to offer alternative views on Artificial Intelligence.

In association with the Region Nouvelle Aquitaine, we organized a one-day exhibition on place Pey-Berland (in front of the town hall) in order to show and explain robotics to the general public. Several robots were displayed and we welcome a lot of people, including many children.

In collaboration with SISTM project-team (Bordeaux Population Health) and ASTRAL project-team we demonstrated that Reservoir Computing (RC) in combination with Genetic Algorithms was able to deal with a high-dimensional setting (409 input features of various kinds). This approach outperformed the use of RC alone and other conventional methods: LSTM, Transformers, Elastic-Net, XGBoost. This collaboration led to a publication in a top machine learning conference (ICML) and in a evolutionary method conference (EA) obtaining the best student paper award.

In collaboration with other Inria members (C. Moulin-Frier & D. Trocellier) we successfully organized two editions of Hack1robo hacakthons in February at Cap Sciences and Le Node (Bordeaux). This demonstrates our ability to sustain such an event, that it is starting to attract attention and gain momentum, as we now plan to organize yearly now .

7 New software, platforms, open data

7.1 New software

7.1.1 ReservoirPy

Name: Reservoir computing with Python

Keywords: Reservoir Computing, Physical Computing

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: ReservoirPy enables the fast and efficient training of artificial recurrent neural networks.

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.

Reservoirs Computing is based on random Recurrent Neural Networks (RNNs). The computing principle can be seen as a temporal SVM (Support Vector Machine): random projections are used to make dimensionality expansion of the inputs towards a non-linear high-dimensional space. The input stream is projected to a random recurrent layer and a (often) 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 are often modified by gradient descent algorithms like Backpropagation-Through-Time (BPTT). This more classical kind of learning is not biologically plausible and often needs to see the training data several time (i.e. for several epochs), whereas with Reservoir Computing training data are used once usually. 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. In addition, sparse matrices are often used for these random matrices. Overall, this greatly speeds up the learning process and enables online learning, which is an advantage in many applications.

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.

News of the Year: Within the development of the ReservoirPy library, we have released various versions from 0.3.10 to 0.3.12. A notable novelty: we started a collaboration with Nicolas Dubreuil at Institut d'Optique (Bordeaux) on optical reservoirs. We created a version of physical optical reservoir simulator inside reservoirpy in order to compare with experiments performed on physical reservoirs. We created a lecture of 16h for students of Institut d'Optique (Jan/Feb2025) to make them discover the general Reservoir Computing framework, ReservoirPy and the new simulated optical reservoir in the library. We published a work on bio-inspired arm prosthesis control with reservoir computing at ICANN conference (Sept 2024) in collaboration with INCIA (Neurocampus, Bordeaux). In another collaboration with SISTEM and Bordeaux CHU, on the prediction of COVID hospitalization at 14 days combining reservoirs with genetic algorithms, we presented and published our results at three venues: Dataquitaine (March24, Bordeaux), EA-Artificial Evolution with a conference paper (Oct24, Bordeaux) and at ICML with a conference paper (Juil24, Vienna, Austria). The first author student of EA conference won the best paper award. Notably, in the ICML paper we showed that our approach was best among several other state-of-the-art methods. We presented Reservoir Computing principles and the ReservoirPy library at AI4industry 2024 workshop (Jan24, Bordeaux), at ECML-PKDD "Tutorial on Sustainable Deep Learning for Time-series" tutorial (Sept24, Vilnius (online), Latvia), at our own PFIA Tutorial (Juil 2024, La Rochelle, FR). We were also invited to give particular presentations on similar topics at CATIE (Oct24, Bordeaux), at SCRIME, LaBRI (combined with a presentation of "ReMi" hackathon spin-off project, Fev24, Bordeaux), to CONCACE Inria team with their Airbus collaborators (Feb24, Bordeaux), and at SONY CSL lab (Nov24, Paris, FR). We also pitched ReservoirPy at "HackAfond" meeting day between investors and researchers (Dec24, Bordeaux).

Below is a summary of main changes during 2024. All releases details are available on GitHub. - ReservoirPy v0.3.12 1. New LIF spiking reservoir (experimental) paves the way for Liquid State Machines, plus ring/line/orthogonal topologies. 2. Datasets include Multiple Superimposed Oscillator, Santa-Fe laser, classification from timeseriesclassification.com, and a one-hot encoder. 3. Observables gain memory capacity, dimensionwise scores, and effective spectral radius (Jaeger, 2007). 4. Parameter handling is more consistent, allowing direct ‘node.param = ...‘ updates. 5. Ensures NumPy v2.0 compatibility, fixes ESN feedback, and pretty-prints hyperparameter JSON files. - ReservoirPy v0.3.11 1. Fixes concurrent ‘numpy.memmap‘ issues for parallelization by using unique memmap names. 2. Introduces a Delay node (shift inputs in time) and allows sparse matrix initialization by degree. 3. Reimplements ScikitLearnNode for consistency (breaking changes from v0.3.10). 4. Improves ‘dataset.narma‘ with a ‘u‘ parameter and ensures consistent ESN results across backends. 5. Drops Python 3.6 support and adds minor documentation fixes and error-handling improvements.

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

Publications: hal-04401731, hal-04354303, hal-04404054, hal-03699931, hal-04905975, hal-04700006, hal-04693930, 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, Paul Bernard

7.1.2 AIDElibs

Name: Artificial Intelligence Devoted to Education

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

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

Contact: Thierry Viéville

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

7.2 Open data

N.Rougier has been nominated as the representant for Open Science for the Inria Bordeaux Center and is part of the Software College of the "Comité pour la Science Ouverte".

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, also called Metacognition (*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

In collaboration with SISTM and the ASTRAL teams, we developed innovative methods combining Reservoir Computing (RC) and Genetic Algorithms (GA) for high-dimensional time series forecasting. This approach aimed to predict SARS-CoV-2 hospitalizations at 14 days using 409 predictors derived from public data and electronic health records. Our two studies introduce feature selection via GA to optimize RC hyperparameters, achieving superior performance compared to conventional methods such as LSTM and XGBoost [17]. Key findings highlighted the impact of GA hyperparameters on RC's behavior and the importance of mutation rates in balancing feature selection and regularization [16].

In a collaboration with C. Moulin-Frier et al. (Inria-Flowers team) we explored a new way to combine Reservoir Computing with Reinforcement Learning (RL) to model animals' adaptive abilities. Using meta-reinforcement learning, we evolved reservoirs by optimizing hyperparameters and integrated them into RL to learn behavioral policies [21].

In collaboration with the INCIA team (Neurocampus), we investigated the use of recurrent neural networks to reconstruct the dynamics of distal joints for controlling prosthetic upper limbs. Comparing Echo State Networks (ESN) and LSTMs, we found that ESNs perform better for single-subject tasks, while LSTMs excel in multi-subject contexts [13].

In the framework of the BrainGPT AEx project, we explored the potential of Large Language Models (LLMs) in synergy with the biologically inspired Reservoir Computing framework to achieve scalable, energy-efficient mechanisms. The first study evaluates the performance of LLMs (e.g., Mistral, LLaMa) across various GPU setups using the vLLM library, offering practical insights into deploying LLMs efficiently [45]. The second study addresses the computational inefficiency and biological implausibility of Transformers' quadratic scaling by combining their attention mechanisms with Reservoir Computing. It proposes a novel architecture, where attention blocks are incorporated into reservoirs, with a variation that decomposes the attention block into QKV and memory-based units, modeling brain structures like the cortex and hippocampus [12].

8.3 Metacognition

In cognitive control, a major mechanism of metacognition, 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, Hugo Chateau-Laurent has defended his thesis, considering the role of the hippocampus in episodic memory and in cognitive control [39] and we have also published important results [14] about the contextual control of associative memory implemented by modern Hopfield networks, within a hippocampus-inspired autoencoder, and we have also proposed more theoretical results relating this approach to the framework of Neural Episodic Control [15].

This year we have also developed original works about the use of Predictive Coding in the learning and use of bio-inspired generative models, at the interface between the prefrontal cortex and the hippocampus. As another major function of metacognition, we have also begun to explore how confidence might be modeled and the way this could influence contextually adapted decision making, as we have continued to study, in association to the modeling of the encoding of values in the orbitofrontal cortex [54].

8.4 Integrating abstract symbolic knowledge

Finalizing the AIDE AEx exploratory action, we have finalized ongoing work regarding the idea of a symbolic description of a complex human learning task, in order to contribute to better understanding how we learn [40], related to initiation to computational thinking presented as an open-ended problem, which involves solving a problem and appealing to creativity. Creativity has also be a subject of modeling research [44, 49] with applications in education [52] and in art [53]. The main iusse is thus to model problem-soving, and related strategies, as discussed and studied this year [42].

We also are finalizing more formal work on manipulating symbolic knowledge equipped with a metric [48] and studying at the computational level how such mechanisms can be implemented in an effective biologically plausible framework [47].

At the experimental level, we have been involved in a collaboration in learning with immersive technology [20], in order to enhance the capability to collect pertinent observables in learning experiments.

This work has been embedded in a strong collaboration with education science collaborators, especially regading artificial intelligence and educational issues, this at a very applicative level, such has how it impacts the daily lives of educational school actors [26, 27, 29, 30, 31], including with a computational thinking perspective [22, 34], considering learning pratices [33, 35, 36, 28] and ethical issues [32], this within the scope of the GTnum ScolIA in which three members of the team have participated.

8.5 Integrating oscillations

This year, we carried on studying the neural oscillations involved in cognition, and how these can be influenced by neuromodulation techniques.

Nikolaos Vardalakis successfully defended his PhD [43]. His computational work on the modeling of hippocampal theta-nested gamma oscillations and their restoration with electrical stimulation [11] was complemented with experimental contributions to surgery techniques so as to improve the precision of the implantation of deep brain stimulation electrodes. An internship student was later recruited so as to try to build a mean-field approximation of Vardalakis' computational model. Preliminary results indicate that some aspects of the original model dynamics (in particular higher frequency oscillations) cannot be reproduced accurately with such approximation, which argues towards the usage of conductance-based models.

At the microscopic scale, as part of the PhD project of Maeva Andriantsoamberomanga, we are currently investigating the effects of extracellular electrical stimulation on hippocampal networks with multiple cell types, and in particular we are studying the influence of electrode placement on the recruitment of action potentials and theta-nested gamma oscillations using very detailed multicompartmental neuron models capturing the geometry of hippocampal neurons.

A new PhD student is now co-supervised by A.Aussel, Mathilde Reynes, who obtained funding from the Fondation pour la Recherche Médicale (FRM). With her, as part of the new Vascular Brain Health Institute (VBHI), we will be studying the effect of transcranial alternating current stimulation (tACS) on EEG and cognitive performance in patients suffering from small vessels disease. So far, we have been working on tools to optimize electrode placements and compute electric fields through finite element models.

8.6 Language processing

Subba Reddy Oota defended his PhD [41] and made a consequent review accepted in the TMLR journal [10]. This comprehensive survey explores the intersection of artificial intelligence (AI) and neuroscience, addressing key questions about the parallels between deep learning mechanisms and neural circuits, and how brain recordings can enhance AI. The review focuses on encoding models (predicting brain activity from sensory inputs) and decoding models (reconstructing perceptions from neural signals), highlighting their potential in diagnoses and brain-computer interfaces. It presents an overview of cognitive neuroscience datasets, advances in deep learning architectures, and their application across modalities like language, vision and speech.

We also presented ongoing work with Subba Reddy Oota on language acquisition modeling in three forums: an invited talk (X. Hinaut) at ICDL (Austin, Texas, USA) and two abstracts at CogSci (Rotterdam, NL) [19] and the VIHAR workshop (Interspeech, Kos, Greece, online) [18]. This research investigates how children bootstrap language under noisy supervision, focusing on sentence-level cross-situational learning (CSL) with minimal training examples. Comparing Reservoir Computing (RC) and LSTMs, RC demonstrated robust generalization with increasing vocabulary sizes, unlike LSTMs, which require significant scaling in hidden units. These findings suggest that random projections in RC facilitate quick generalization, opening new questions about biologically plausible mechanisms for learning.

9 Partnerships and cooperations

9.1 International initiatives

9.1.1 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 -> 2024

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.

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

SARASWATI

Title: Sequential motor skills: a dual system view

Duration: 2020 - 2024

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.

9.2 International research visitors

9.2.1 Visits of international scientists

Other international visits to the team

Anne Collins

Status Professor

Institution of origin: University of California, Berkeley

Country: USA

Dates: Jan-June 2024

Context of the visit: common work

Mobility program/type of mobility: visiting scholars programme of the university of Bordeaux

Guangfu Hao

Status PhD

Institution of origin: CASIA

Country: China

Dates: Mar-April 2024

Context of the visit: Meng Po Associate team

Mobility program/type of mobility: research stay

9.3 National initiatives

9.3.1 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 will last four years (2022-2025). We regularly discuss with our colleague from the University of Bordeaux (Gaël Jobard).

9.3.2 Exploratory action BrainGPT

Participants: Xavier Hinaut, Yannis Bendi-Ouis.

In the wake of the emergence of large-scale language models such as ChatGPT, the BrainGPT project is at the forefront of research in Artificial Intelligence and Computational Neuroscience. While these models are remarkably efficient, they do not reflect how our brain processes and learns language. BrainGPT takes up the challenge by focusing on the development of models more faithful to human cognitive functioning, inspired by data from brain activity during listening or reading. The ambition is to create more efficient models, less reliant on intensive computations and massive volumes of data. BrainGPT will open new perspectives on our understanding of language and cognition.

The project will last four years (2023-2027).

9.4 Regional initiatives

9.4.1 Observatory of surveillance in democracy

Participants: Frédéric Alexandre, Nicolas Rougier.

The University of Bordeaux has labeled one of our activities as an interdisciplinary and exploratory research project. In collaboration with university partners in the field of law, the aim of this project is to understand the changes in society imposed by the development of digital surveillance technologies in a democratic context and to organize seminars and general public conferences to disseminate this information.

9.4.2 Hyperhum@in

Participants: Nicolas Rougier.

The Hyperhum@in research program brings together a core group of researchers in HSS and life sciences committed to questioning exploratory engineering projects “at the frontiers of the human”. The second part, entitled “brain-machine: analogy, model, identity”, proposes to take a combined look at Artificial Intelligence and cognitive neuroscience which have today become inseparable in their mutual quest for intelligibility of the functioning of the human brain.

9.4.3 RT-HippoNeuroStim

Participant: Amélie Aussel.

The University of Bordeaux has labeled this project as an interdisciplinary and exploratory research project.

The RT-HippoNeuroStim project aims at translating the hippocampal model previously developed by A. Aussel, together with Fabien Wagner (IMN), onto the new neuromorphic computing architecture developed by the team of Timothée Levi at the IMS. This architecture is based on Field Programmable Gate Arrays (FPGA) and is much more efficient than current simulation software. We will leverage this platform to simulate the activity of the hippocampus in real time, which will greatly accelerate research on hippocampal neurostimulation.

9.4.4 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.

9.4.5 Regional and local Research Networks

We are members of two Regional Research networks, devoted to Robotics and Computational Education and of two Networks of Research of the University of Bordeaux: PHDS (Public Health Data Science) and RobSys (Robustness of Autonomous Systems).

10 Dissemination

10.1 Promoting scientific activities

10.1.1 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'24 including 400 attendees on january 22-26, with teaching in the morning and hands-on experiments on industrial applications in the afternoon. He co-organized CogGames2024 on November 18-19, a national event of prospective in cognitive science. He co-organized a working day "Society and AI" on July 1-2 [37], within the major French event in AI, PFIA. He also co-organized a scientific day about "Neuroscience and AI" on April 9, in the framework of PDIA events (Perspectives and Challenges in AI) of the AFIA, the french association on AI.

N.Rougier has been in charge of the scientific organization of the Neuroscience and Artificial Intelligence conference for the French Society of Neuroscience, the ROBNA conference on Robotics and Ethic, a public round table on Robotics and Agroecology, a public demonstration of research in robotics that took place in Bordeaux.

X. Hinaut with colleagues from Inria organised the second and third editions of Hack1robo hackathon (in February and November). This hackathon focuses on areas such as AI, robotics, cognitive sciences and arts. Held at the Cap Sciences FabLab (2nd ed.) and Le Node (3rd ed.), the events aimed to mediate and disseminate research knowledge, making technology accessible. He also co-organised several workshops and tutorials on Reservoir Computing and ReservoirPy: ECML-PKDD "Tutorial on Sustainable Deep Learning for Time-series" tutorial (Sept24, Vilnius (online), Latvia), at our own PFIA Tutorial (Juil 2024, La Rochelle, FR).

Member of the organizing committees F. Alexandre organized a session "Learning AI and with AI" in the International Forum of Digital Sciences for Education InFine, in Poitiers on october 11; cf a summary of this meeting in this video.

10.1.2 Scientific events: selection

In the framework of our research project "Observatory of the surveillance in democracy" (*cf.* § 9.3), F. Alexandre and N. Rougier have co-organized in 2024 two conferences open to the general public in Bordeaux.

Member of the conference program committees F. Alexandre was Program Committee member for the 38th AAAI Conference on Artificial Intelligence (AAAI-24), of ECAI-2024, the 27th European Conference on Artificial Intelligence, of the french conference Dataquitaine. A. Aussel was a Program Committee member for the 33rd Annual Computational Neuroscience Meeting (CNS 2024). X. Hinaut was Associate Editor for CogSci 2024 and ICDL 2024.

Reviewer F. Alexandre is a reviewer for ICDL 2024 (the IEEE International Conference on Development and Learning) and ICANN 2024.

T. Viéville is a reviewer for ICANN 2024.

X. Hinaut is a reviewer for ICANN 2024.

10.1.3 Journal

Member of the editorial boards F. Alexandre is Academic Editor for PLOS ONE; Review Editor for Frontiers in Neurorobotics; member of the editorial board of Cognitive Neurodynamics.

N.Rougier is the co-founder and co-editor in chief for ReScience C and ReScience X, Associated editor for PeerJ Computer Science, review editor for Frontiers in Neurobotics, Frontiers in Psychology and Frontier in Neuroscience.

T. Viéville is an Associate Editor of Frontiers in Neurorobotics.

Reviewer - reviewing activities T. Viéville is a reviewer for Fontiers in Neurorobotics and Canadian Journal of Learning and Technology.

X. Hinaut is a reviewer for Plos Computational Biology, Neural Networks.

10.1.4 Invited talks

F. Alexandre made an invited talk titled "Metacognition Unveiled: Insights from AI and Cognitive Neuroscience" in the workshop of the university Cote d'Azur "Creativity and artificial intelligence in education" on July 12.

N.Rougier has been invited to 2e Journée d'étude de l'atelier de la donnée ARDoISE (December 2024, Rennes), Hacking Cognition workshop (June 2024, Paris), Observatoire Midi-Pyrénèes (July 2024, Toulouse), Rhodia Laboratoire du Futur, (July 2024, Bordeaux), DKM days (February 2024, Rennes).

X. Hinaut has been invited to talk at AI4indsutry workshop (Jan24, Bordeaux), COSYNE 2024 Workshop on "Reinforcement learning for temporally continuous movement sequences" (Mar24, Cascais, Portugal), ICDL 2024 conference (May24, Austin, Texas), to European Birdsong Symposium (Jun24, Bordeaux), to IDESSAI summer school (Sept24, Saarbrucken, Germany), and to SONY Computer Science Laboratory (Paris).

10.1.5 Scientific expertise

F. Alexandre, scientific expert for the FRQNT (Fonds de recherche du Québec – Nature et technologies); for the institute Carnot Cognition;

N.Rougier has been nominated as expert for the OFIS advisory board. He's also a recurrent Open Science expert for swiss universities.

T. Viéville has been invited in the AI Literacy Framework Expert Group, partnership project between the European Commission, the OECD and TeachAI, with Code.org.

X. Hinaut has been scientific expert for ANR.

10.1.6 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.P. Rougier is the corresponding member for Inria Bordeaux Sud-Ouest on scientific edition, head of the Computational Neuroscience team at Institute of Neurodegenerative Diseases.

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 chair of IEEE Task Forces (TF) about: "Reservoir Computing" (co-chair), "Cognitive and Developmental Systems Technical Committee": "Language and Cognition" (main chair) and is also member of IEEE TF "Action and Perception". He is co-Head of the "Human and Robot" (TS4) CNRS Robotics Working Group. He manages a WP in the PHDS Impulsion Bordeaux network.

A. Aussel is a co-head of the NeuroDTx team at Institute of Neurodegenerative Diseases, and also a member of the Conseil du Département Bordeaux Neurocampus.

10.2 Teaching - Supervision - Juries

10.2.1 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", 12 hours.
- C. Mercier, as an ATER, had a full-time teaching in computer science at the university of Bordeaux. On november 4th, she could also participate to the training of high-school teachers, by giving a talk on Artficial Intelligence.

- 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 60,000 participants, allowing everyone to master these disruptive technologies by better understanding ground notions.
- T. Viéville has co-animated seminars within the scope the AI4T formations (120, 80 and 75 persons).
- T. Viéville has participated in lifelong formations of National Education high-school and post-baccalaureate inspectors (sessions of 80 and more than 100 participants).
- N. Rougier co-created (with Arthur Leblois and Slim Karkar) the computational neuroscience module for the international master program in neuroscience (University of Bordeaux), where A. Aussel also teached.
- N.Rougier helped in the design of the MOOC Intelligence artificielle pour et par les enseignants
- F. Alexandre gave an invited talk about ChatGPT to the Graduate Program Numerics; he is also teaching Machine Learning and Artificial Intelligence to Masters of the University of Bordeaux and to engineering schools of Bordeaux INP.
- A. Aussel is involved in teaching at the ENSEIRB engineering school (Graph Theory) and in the international master program in neuroscience of the University of Bordeaux. She was part of the final internship jury of the M2 Neuroscience at the 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 co-created a new lecture on classical and physical Reservoir Computing with P. Bernard for 16 lectures at Institut d'Optique (Bordeaux).

10.3 Popularization

T. Viéville has co-organized and participated at large scale popularization actions (more than 500 children impacted) targeting underprivileged educational areas, proposing educational robotics activities in application of the previous multidisciplinary collaborations with learning science research.

T. Viéville has been invited for high-school interactive and participative conferences to explain artificial intelligence and computational thinking (6 interventions).

A. Aussel has participated in the workshop "Moi Informaticienne Moi Mathématicienne" (MIMM), proposing activities in computer science and mathematics for middle school and high school girls. She has been invited to middle school and high school as part of the "Femmes et Sciences" association as well as the "Un scientifique, une classe : Chiche !" program. She is part of a mentoring program for female PhD students in Bordeaux University organized by "Femmes et Sciences".

C. Mercier and B. Pesquet participated to a Pint of Science event on May 15, where they could present their PhD work.

X. Hinaut organized twice the hackathon Hack1robo in Bordeaux this year, in February at Cap Science and in November at Le Node, gathering 35-40 people each. He participated at a Cap Science event on music discovery on ReMi project (Jun24). He wrote two science fiction short stories for "AI Logs".

10.3.1 Productions (articles, videos, podcasts, serious games, ...)

Based on its great success (over 60,000 participants), the MOOC IAI (Artificial intelligence with Intelligence) has been extended until end of 2025 and a version adapted to smartphones (Electronic Pocket Open Course) has been developed by the Inria learning Lab, with F. Alexandre as a scientific advisor, and launched in december 2024.

F. Alexandre wrote an article about ChatGPT published on The Conversation website (28,000 reads) [55]. He participated to the design of a pedagogical module about AI for the National Council of the

Digital. He also participated to an online article presenting activities of Inria Bordeaux about AI and learning.

N.Rougier edited a book in cooperation with the Hypermondes association ("IA Logs", 250 pages) that gathers novels from 20 researchers in computer science, philosophy, social sciences and law. This book is the output of two workshops that have been organized during 2024, whose goal was to offer alternative views on Artificial Intelligence.

10.3.2 Participation in Live events

F. Alexandre was an invited speaker to a webinar about ethics of AI on June 25, co-organized by two European Digital Innovation Hubs, DIVA and DIHNAMIC. He made a presentation about ChatGPT to two laboratories in physics of the university of Bordeaux in July (LOMA) and september (LP2N).

N.Rougier gave several talks about Artificial Intelligence. Generative AI with DINHAMIC (September 2024, online), AI and law for Conseil National des Barreaux (June 2024, online), AI between science and fiction with Cap Sciences (May 2024, Bordeaux), AI and arts with Ecoles créatives (April 2024, Toulouse), AI and Science Fiction for the Comité de la Légion d'Honneur (March 2024, Bordeaux), AI and arts with ALCA Nouvelle Aquitaine (March 2024, Poitiers).

10.3.3 Others science outreach relevant activities

F. Alexandre: Training of students preparing outreach activities at the frontier between AI and medicine in january and of highschool students developing a project on AI with a performance in a theater in february.

N.Rougier gave several interviews during the year: Usbek & Rica about mind uploading (July 2024), Charlie Hebdo about generative AI (July 2024), the Foresight Institute about AI safety & Neurotechs (September 2024).

11 Scientific production

11.1 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] M. Bourdenx, A. Nioche, S. Dovero, M.-L. Arotcarena, S. M. J. Camus, G. Porras, M.-L. Thiolat, N. P. Rougier, A. Prigent, P. Aubert, S. Bohic, C. Sandt, F. Laferrière, E. Doudnikoff, N. Kruse, B. Mollenhauer, S. Novello, M. Morari, T. Leste-Lasserre, I. Trigo Damas, M. Goillandeau, C. Perier, C. Estrada, N. García Carrillo, A. Recasens, N. N. Vaikath, O. El Agnaf, M. T. Herrero, P. Derkinderen, M. Vila, J. A. Obeso, B. Dehay and E. Bezard. 'Identification of distinct pathological signatures induced by patient-derived α\$-synuclein structures in nonhuman primates'. In: *Science Advances* 6.20 (May 2020), eaaz9165. DOI: 10.1126/sciadv.aaz9165. URL: https://hal.inria.fr/hal-02611441.

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

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

[8] 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.

[9] A. Strock, X. Hinaut and N. P. Rougier. 'A Robust Model of Gated Working Memory'. In: *Neural Computation* (8th Nov. 2019), pp. 1–29. DOI: 10.1162/neco_a_01249. URL: https://hal.science/hal-02371659.

11.2 Publications of the year

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