RESEARCH CENTRE

Bordeaux - Sud-Ouest

IN PARTNERSHIP WITH:

CNRS, Institut Polytechnique de Bordeaux, Université de Bordeaux

2020

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

Contents

Project-Team MNEMOSYNE

Creation of the Team: 2012 February 01, updated into Project-Team: 2014 July 01

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

1 Team members, visitors, external collaborators

Research Scientists

- Frédéric Alexandre [Team leader, Inria, Senior Researcher, HDR]
- Thalita Firmo Drumond [Univ de Bordeaux, Researcher, until Jun 2020, ATER]
- Xavier Hinaut [Inria, Researcher]
- Nicolas Rougier [Inria, Researcher, HDR]
- Thierry Viéville [Inria, Senior Researcher, HDR]

Faculty Member

- André Garenne [Univ de Bordeaux, Associate Professor, Until Sep 2020]

Post-Doctoral Fellows

- Luca Pedrelli [Inria, until Aug 2020]
- Jianyong Xue [Inria, from Dec 2020]

PhD Students

- Hugo Chateau-Laurent [Inria, from Nov 2020]
- Snigdha Dagar [Inria]
- Fjola Hyseni [Univ de Bordeaux, from Oct 2020]
- Pramod Kaushik [Inria, until Oct 2020]
- Chloe Mercier [Inria, from Oct 2020]
- Subba Reddy Oota [Inria, from Nov 2020]
- Guillaume Padiolleau [CEA]
- Silvia Pagliarini [Inria]
- Remya Sankar [Inria]
- Anthony Strock [Univ de Bordeaux, until Oct 2020]
- Nikolaos Vardalakis [Univ de Bordeaux, from Oct 2020]

Technical Staff

- Nathan Trouvain [Inria, Engineer, from Oct 2020]

Interns and Apprentices

- Clemence Chauvet [Inria, Nov 2020]
- Lola Denet [Inria, from Jun 2020 until Aug 2020]
- Thanh Trung Dinh [Inria, from Feb 2020 until Aug 2020]
- Romain Ferrand [Inria, from Feb 2020 until Jul 2020]
- Amelie Gruel [Univ de Bordeaux, from Mar 2020 until Aug 2020]
- Ali Issaoui [Inria, from Nov 2020]
- Kepa Labescau [Univ de Bordeaux, from May 2020 until Jul 2020]
- Dimitri Lereverend [École normale supérieure de Rennes, from May 2020 until Jul 2020]
- Nicolas Thou [Inria, from Jun 2020 until Sep 2020]
- Nathan Trouvain [Inria, from Feb 2020 until Jul 2020]
- Alexandre Variengien [École Normale Supérieure de Lyon, from Jun 2020 until Jul 2020]
- Charles Verstraete [Inria, from Apr 2020 until May 2020]

Administrative Assistant

- Chrystel Plumejeau [Inria, part time in the team]

External Collaborator

- Arthur Leblois [CNRS, HDR]

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 [73, 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 [72, 67, 74]. 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 [75] 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 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.

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. In 2020, this collided with the sanitary crisis that de facto reduced our travel capacity. But beyond the crisis, we aim at enforcing this policy.

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. This is especially important in order to convince people to change their daily habits and consider alternative when they move from point A to point B.

6 Highlights of the year

- Contributions of the team to the IEEE ICDL 2020 conference `https://cdstc.gitlab.io/icdl-2020/`, important in our domain, with F. Alexandre, Bridge Chair in the organizing committee, X. Hinaut, Associate Editor in the program committee and S. Pagliarini and X. Hinaut, organizers of the SMILES workshop of the conference with more than 100 (virtual) participants: `https://sites.google.com/view/smiles-workshop/`

- Nicolas Rougier organized in June 2020 the "Ten Years Reproducibility Challenge," with Konrad Hinsen (CNRS). The goal of the Ten Years Reproducibility Challenge was to check if researchers would be able to run their own code that has been published at least ten years ago (i.e. before 2010). Results were published in Nature (see `https://www.nature.com/articles/d41586-020-02462-7`).

7 New software and platforms

7.1 New software

7.1.1 ReservoirPy

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

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 advance 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). 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.

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

Authors: Xavier Hinaut, Nathan Trouvain, Nathan Trouvain, Alexis Juven, Luca Pedrelli, Thanh Trung Dinh, Nicolas Rougier, Alexandre Variengien

Contact: Xavier Hinaut

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

Contacts: Thierry Viéville, Nicolas Rougier, Frédéric Alexandre, Xavier Hinaut

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

Functional Description: This library includes - 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

Contacts: Thierry Viéville, Frédéric Alexandre

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

8 New results

8.1 Overview

This year we have addressed several important questions. We have studied and modeled higher cognitive functions (*cf.* § 8.2) and the brain circuitry that emulate them. We have also studied how they are made possible, by interaction with the environment (*cf.* § 8.3), embodiment in a robotic platform and temporal organization of the behavior. We have also been active in Machine Learning (*cf.* § 8.4), and have studied relations of our work to classical Artificial Intelligence and to the symbolic and numerical aspects of cognition (*cf.* § 8.5), raising the question of using knowledge, ontologies and aspects of logics.

8.2 Modeling higher cognitive functions

This year, we have studied how the contribution of working memory and episodic memory can contribute to going beyond reactive immediate behavior, toward cognitive control. We have also proposed that these processes can play a central role in creativity [14].

As part of the **Philosophical Transactions of the Royal Society B** themed issue on the *Existence and prevalence of economic behaviours among non-human primates*, we published a collaborative work [7] on the evolutionary orign of the prospect theory. In humans, the attitude toward risk is not neutral and is dissimilar between bets involving gains and bets involving losses. The existence and prevalence of these decision features in non-human primates are unclear. In addition, only a few studies have tried to simulate the evolution of agents based on their attitude toward risk. Therefore, we still ignore to what extent Prospect theory's claims are evolutionarily rooted. To shed light on this issue, we collected data from nine macaques that performed bets involving gains or losses. We confirmed that their overall behaviour is coherent with Prospect theory's claims. In parallel, we used a genetic algorithm to simulate the evolution of a population of agents across several generations. We showed that the algorithm selects progressively agents that exhibit risk-seeking, and has an inverted S-shape distorted perception of probability. We compared these two results and found that monkeys' attitude toward risk is only congruent with the simulation when they are facing losses. This result is consistent with the idea that gambling in the loss domain is analogous to deciding in a context of life-threatening challenges where a certain level of risk-seeking behaviour and probability distortion may be adaptive.

Gated working memory is defined as the capacity of holding arbitrary information at any time in order to be used at a later time. Based on electrophysiological recordings, several computational models have tackled the problem using dedicated and explicit mechanisms. We have proposed instead to consider an implicit mechanism based on a random recurrent neural network [71]. We have previously introduced a robust yet simple reservoir model of gated working memory with instantaneous updates. The model is able to store an arbitrary real value at random time over an extended period of time. We rencently introduced a method based on conceptors [12] that allows us to manipulate information stored in the dynamics (latent space) of this previously developped gated working memory model. The memorized information results in complex dynamics inside the reservoir that can be faithfully captured by a conceptor. Such conceptors allow us to explicitly manipulate this information in order to perform various, but not arbitrary, operations. In this work [29], we show how working memory can be stabilized or discretized using such conceptors, how such conceptors can be linearly combined to form new memories, and how these conceptors can be extended to a functional role. These preliminary results suggest that conceptors can be used to manipulate the latent space of the working memory even though several results we introduce are not as intuitive as one would expect.

8.3 Interactions with the environment

Understanding the mechanisms enabling children to learn rapidly word-to-meaning mapping through cross-situational learning in uncertain conditions is still a matter of debate. In particular, many models simply look at the word level, and not at the full sentence comprehension level. We present a model of language acquisition, applying cross-situational learning on Recurrent Neural Networks with the Reservoir Computing paradigm [16]. Using the co-occurrences between words and visual perceptions, the model learns to ground a complex sentence, describing a scene involving different objects, into a perceptual representation space. The model processes sentences describing scenes it perceives simultaneously via a simulated vision module: sentences are inputs and simulated vision are target outputs of the RNN. Evaluations of the model show its capacity to extract the semantics of virtually hundred of thousands possible combinations of sentences (based on a context-free grammar); remarkably the model generalises only after a few hundred of partially described scenes via cross-situational learning. Furthermore, it handles polysemous and synonymous words, and deals with complex sentences where word order is crucial for understanding. Finally, further improvements of the model are discussed in order to reach proper reinforced and self-supervised learning schemes, with the goal to enable robots to acquire and ground language by themselves (with no oracle supervision). We futher investigated the developmental plausibility of such model in [15]: (i) if it can learn to generalize from single-object sentence to double-object sentence; (ii) if it can use more plausible representations: (ii.a) inputs as sequence of phonemes (instead of words) and (ii.b) outputs fully independent from sentence structure (in order to enable purely unsupervised cross-situational learning). Interestingly, tasks (i) and (ii.a) are solved in a straightforward fashion, whereas task (ii.b) suggests that learning with tensor representations is a more difficult task.

More studies on the modelling of language acquisition and language processing are described in section 8.4 "Machine Learning" because of their potential impact in this field. S. Oota started his PhD in November 2020 in the team: he will continue these studies on language.

More generally, sensorimotor learning (e.g. language learning) represents a challenging problem for artificial and natural systems. Several computational models try to explain the neural mechanisms at play in the brain to implement such learning. These models have several common components: a motor control model, a sensory system and a learning architecture. In order to make complete sensorimotor models, we also investigate at "simpler" learning problems such as song developmental learning by birds. In S. Pagliarini's PhD, our challenge is to build a biologically plausible model for song learning in birds including neuro-anatomical and developmental constraints. We made a major comparative review of existing vocal sensorimotor models in order to give an overall view useful to this multidisciplinary community [8]. We grouped the methodologies in order to clearly identify the learning algorithms and representations used for the sensory, perceptual and motor spaces. We expect this review to be beneficial to the community by facilitating the comparison of newly proposed models with already existing ones.

This year, a particular fruitful collaboration between S. Pagliarini and N. Trouvain (M2 intern during the first half of 2020) was made. Indeed, N. Trouvain developped a "canary decoder" which makes the transcription of canary songs based on the sounds recordings from Orsay (see below). S. Pagliarini has trained a low-dimensional Generative Adversarial Network (GAN) with canary sounds: this GAN is able to reproduce faithfully canary syllables, which are most of the time indistinguishable from real canary sounds. The derived version of N. Trouvain's decoder enables to make advanced quantitative and qualitative analyses of sounds generated by the GAN, which would have been more limited otherwise.

On this songbird topic, X. Hinaut is also collaborating with Catherine del Negro's team (CNRS, NeuroPSI, Orsay) on the representation of syntax in songbird brains. In particular, the project aims at (1) linking the neural activity of a sensorimotor area (HVC) to syntax elements in the songs of domestic canaries ; (2) analysing the audio files and transcripts of canary songs in order to find syntax cues and higher order representations (graph properties of songs, evaluate Markovian forward and backward transition probabilities of various orders). The newly developped canary decoder by N. Trouvain will enable to transcribe more raw data of canary songs already available (indeed this process was time consuming previously because manually made). Additionally, N. Trouvain developped a graphical user interface in order to simplify the cleaning and class merging operations on manually transcribed data. Indeed, prior human classification is still needed to create the dictionary of syllables which is specific to each canary. This new tool will speed-up our collaborative studies with Orsay on syntax analysis while improving the quality and statistical significance of the results.

8.4 Machine learning

The basic problem in Parkinson's disease is loss of dopamine-producing nerve cells in a region of the brain called the substantia nigra pars compacta. Everybody has a gradual loss of these dopamine-producing nerve cells as they age, but patients with Parkinson's disease have lost more of them than other people. Why these cells die in Parkinson's disease is unclear, and the focus of much research. To answer this question, research requires the use of a variety of animal models to study different aspects of the disease. With colleagues, we published an article in Science Advances [5] showing that dopaminergic neurodegeneration can be induced in non-human primates by both, small and large aggregates of alpha-synuclein. In contrast, experiments in rodents, used in 85% of studies, show that small alpha-synuclein aggregates do not induce neurodegeneration.

In [6], we provide theoretical conditions guaranteeing that a self-organizing map efficiently develops representations of the input space. The study relies on a neural field model of spatiotemporal activity in area 3b of the primary somatosensory cortex. We rely on Lyapunov's theory for neural fields to derive theoretical conditions for stability. We verify the theoretical conditions by numerical experiments. The analysis highlights the key role played by the balance between excitation and inhibition of lateral synaptic coupling and the strength of synaptic gains in the formation and maintenance of self-organizing maps.

We extended this work in [11] where we propose a variation of the self organizing map algorithm by considering the random placement of neurons on a two-dimensional manifold, following a blue noise distribution from which various topologies can be derived. These topologies possess random (but controlable) discontinuities that allow for a more flexible self-organization, especially with high-dimensional data. The proposed algorithm has been tested on one-, two- and three-dimensions tasks as well as on the MNIST handwritten digits dataset and validated using spectral analysis and topological data analysis tools. We also demonstrate the ability of the randomized self-organizing map to gracefully reorganize itself in case of neural lesion and/or neurogenesis

We propose a novel architecture [18, 36] called Hierarchical-Task Reservoir (HTR) suitable for real-time applications for which different levels of abstraction are available. We apply it to semantic role labelling based on continuous speech recognition. Taking inspiration from the brain, that demonstrates hierarchies of representations from perceptive to integrative areas, we consider a hierarchy of four sub-tasks with increasing levels of abstraction (phoneme, word, part-of-speech and semantic role tags). These tasks are progressively learned by the layers of the HTR architecture. Interestingly, quantitative and qualitative results show that the hierarchical-task approach provides an advantage to improve the prediction. In particular, the qualitative results show that a shallow or a hierarchical reservoir considered as baselines do not produce a quality of estimation as the HTR model. Moreover, we show that it is possible to further improve the accuracy of the model by designing skip connections and by considering word embedding in the internal representations. Overall, the HTR outperformed the other state-of-the-art reservoir-based approaches. The HTR architecture is proposed as a step toward the modeling of online and hierarchical processes at work in the brain during language comprehension. It is also developed for real-time and efficient Human-Robot Interaction (HRI) for which the availability of different levels of abstraction would provide more robustness.

Echo States Networks (ESN) and Long-Short Term Memory networks (LSTM) are two popular architectures of Recurrent Neural Networks (RNN) to solve machine learning task involving sequential data. However, little has been done to compare their performances and their internal mechanisms on a common task. We trained ESNs and LSTMs on a Cross-Situationnal Learning (CSL) task [39]. This task aims at modelling how infants learn language: they create associations between words and visual stimuli in order to extract meaning from words and sentences. The results are of three kinds: performance comparison, internal dynamics analyses and visualization of latent space. (1) We found that both models were able to successfully learn the task: the LSTM reached the lowest error for the basic corpus, but the ESN was quicker to train. Furthermore, the ESN was able to outperform LSTMs on datasets more challenging without any further tuning needed. (2) We also conducted an analysis of the internal units activations of LSTMs and ESNs. Despite the deep differences between both models (trained or fixed internal weights), we were able to uncover similar inner mechanisms: both put emphasis on the units encoding aspects of the sentence structure. (3) Moreover, we present Recurrent States Space Visualisations (RSSviz), a method to visualize the structure of latent state space of RNNs, based on dimension reduction (using UMAP). This technique enables us to observe a fractal embedding of sequences in the LSTM. RSSviz is also useful for the analysis of ESNs (i) to spot difficult examples and (ii) to generate animated plots showing the evolution of activations across learning stages. Finally, we explore qualitatively how the RSSviz could provide an intuitive visualisation to understand the influence of hyperparameters on the reservoir dynamics prior to ESN training.

In [19] we present a simple user-friendly library called ReservoirPy based on Python scientific modules. It provides a flexible interface to implement efficient Reservoir Computing (RC) architectures with a particular focus on Echo State Networks (ESN). Advanced features of ReservoirPy allow to improve up to 87.9 percent of computation time efficiency on a simple laptop compared to basic Python implementation. Overall, we provide tutorials for hyperparameters tuning, offline and online training, fast spectral initialization, parallel and sparse matrix computation on various tasks (MackeyGlass and audio recognition tasks). In particular, we provide graphical tools to easily explore hyperparameters using random search with the help of the hyperopt library.

Several people participated in the development of the ReservoirPy library, among which N. Trouvain during his internship. An Inria ADT grant ("Aide au Dévelopment Technologique") was obtained to recruit an engineer for 20 months to pursue the development of ReservoirPy. Thanks to this grant, N. Trouvain is continuing this development in the team.

8.5 Symbolic and numerical cognition

This year, we have contributed several book chapters [25, 23, 24], dealing about interactions between neuroscience and artificial intelligence. In order to explore new ways of building direct and inverse models of sensorimotor transition functions, we have studied, in our collaboration with CEA (*cf.* § 9.1.1), an original way to learn both at the same time [17].

The on-going work on an original prototype based approach of deep-learning considering standard learning and meta-learning paradigms, on not so big data sets, including a fine study on metaparameter adjustment in this context, has been finalized [28], offering an important and deeply analyzed bibliography on recurrent deep learning networks and not so big data set management. The capability to easily explain the "how it works" mechanism to non specialist of the field is an important outcome of this work.

Co-leaded by Margarida Romero scientific director of the LINE laboratory of the UCA and researchers of our team, an Inria AEx action has been launched, regarding artificial intelligence devoted to education (AIDE) (*cf.* § 10.3.4). We want to explore to what extent approaches or methods from cognitive neuroscience, linked to machine learning and knowledge representation, could help to better formalize human learning as studied in educational sciences. In other words: we are taking advantage of our better understanding of how our brains work to help us better understand how our children learn. The focus here is on learning computational thinking, i.e., what to share in terms of the skills needed to master the digital world, not just consume or endure it, considering specific learning tasks modeling. Preliminary results include positioning papers [13] and multi-disciplinary scientific preliminary outcomes [14], continuing contribution to educational science in order to raise our level of competence in this companion field [26], [22]. We also have started experimental setup realization [33], [32] and started the main work on modeling the brain of the learner and the context of the learning activity [38], [44], including large audience publication [54, 55, 50].

While language and birdsongs both involve symbols and sub-symbolic representations, related studies of the team are reported in section 8.3 "Interaction with the environment" because of their links with sensorimotor learning during the processing and production of symbols.

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.

9.1.2 Contract with Ubisoft

Participants Frédéric Alexandre, Pramod Kaushik.

Together with the Inria Project-team Flowers, we are working with the video game editor Ubisoft to define original bio-inspired learning methods. We are more specifically interested in methods to improve representation sizes and learning times, which are generally prohibitive with classical architectures in Reinforcement Learning.

10 Partnerships and cooperations

10.1 International initiatives

10.1.1 Inria associate team not involved in an IIL

MENG PO

Title: Memory ENGineering for Problem sOlving

Duration: 2020 - 2023

Coordinator: Frédéric Alexandre

Partner: Brainnetome Center and National Laboratory of Pattern Recognition, Institute of Automation, Chinese Academy of Sciences (China)

Inria contact: Frédéric 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.

SARASWATI

Title: Saraswati

Duration: 2020 - 2023

Coordinator: Nicolas Rougier

Partners: Cognitive Science Lab, IITH (India)

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 Collaborations in European programs, except FP7 and H2020

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 [35] [41], including large audience dissemination [52].

10.3 National initiatives

10.3.1 FUI Sumatra

Participants Frédéric Alexandre, Thalita Firmo Drumond, Xavier Hinaut, Nicolas Rougier, Thierry Viéville.

This FUI project, supported by the Aerospace Valley Innovation Pole, gathers two industrial groups (Safran Helicopter and SPIE), three research labs and four SME. Its goal is to provide contextualized information to maintenance operators by the online analysis of the operating scene. We are concerned in this project with the analysis of visual scenes, in industrial contexts, and the extraction of visual primitives, categories and pertinent features, best decribing the scenes, with biologically inspired neuronal models.

Firstly, this is an opportunity for us to revisit the principles of deep network architectures by adapting principles that we will elaborate from the context of the hierarchical architecture of the temporal visual cortex. Secondly, we intend to exploit and adapt our model of hippocampus to extract more heterogenous features. This project is an excellent opportunity to associate and combine our models and also to evaluate the robustness of our models in real-world applications.

10.3.2 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.

10.3.3 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.

10.3.4 Exploratory action AIDE

Participants Frédéric Alexandre, Hugo Chateau-Laurent, 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 at `https://team.inria.fr/mnemosyne/en/aide/` and 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

Participant Nicolas Rougier.

Project gathering researchers from: MSH Lorraine (USR3261), InterPsy (EA 4432), APEMAC, EPSaM (EA4360), Archives Henri-Poincaré (UMR7117), Loria (UMR7503) & 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 a motorized lamp that can or cannot interact with them while they're doing a specific task. We've organized our third national conference in Nancy gathering speakers from philosophy, robotics, art and psychology and closed a three years cycle. The group now aims at publishing a book gathering text from all the invited speakers.

11 Dissemination

11.1 Promoting scientific activities

11.1.1 Scientific events: organisation

General chair, scientific chair Frederic Alexandre was in charge of the scientific organization of the one-week workshop AI for Industry https://www.ai4industry.fr/quest-ce-que-cest/ including 250 attendees, with teaching in the morning and hands-on experiments on industrial applications in the afternoon.

Nicolas Rougier organized and chaired the Ten Years Reproducibility challenge whose goal is to invite researchers to try to run the code they've created for a scientific publication that was published more than ten years ago. This code can be anything (statistical analysis, numerical simulation, data processing, etc.), can be written in any language and can address any scientific domain. The only mandatory condition to enter the challenge is to have published a scientific article before 2010, in a journal or a conference with proceedings, which contains results produced by code, irrespectively of whether this code was published in some form at the time or not. Results of the challenge were published in Nature.

Xavier Hinaut organized the "Sensorimotor Interaction, Language and Embodiment of Symbols" (SMILES) at the ICDL2020 conference jointly with S. Pagliarini and C. Moulin-Frier (Flowers team). The SMILES workshop aims to bridge the gap from low-level sensorimotor interaction to high-level compositional symbolic communication. Through an interdisciplinary approach it involves researchers from (but not limited to): Sensori-motor learning, Emergent communications, Chunking of perceptuo-motor gestures, Symbol grounding and symbol emergence, Compositional and hierarchical representations, Language processing and acquisition in brains and machines, Enaction, active perception, perception-action loop, ... Workshop website: https://sites.google.com/view/smiles-workshop/

Member of the organizing committees F. Alexandre, Bridge Chair in the organizing committee of the IEEE ICDL 2020 conference, X. Hinaut, Associate Editor in the program committee.

11.1.2 Scientific events: selection

Member of the conference program committees F. Alexandre: TAIMA20 and others postponed due to the pandemics. X. Hinaut was Associate Editor in the Program Committee and Session Chair of the IEEE ICDL 2020 conference.

Reviewer X. Hinaut was reviewer of these conferences: CogSci'20, Drôles d'Objets'20 (postponned to '21), ICANN'20 (postponned to '21 but proceedings were published), ICDL'20 (also meta-reviewer), IROS'20, IEEE RA-L and ICRA'20.

11.1.3 Journal

Member of the editorial boards Nicolas 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.

Frédéric Alexandre is Academic Editor for PLOS ONE; Review Editor for Frontiers in Neurorobotics;

X. Hinaut is member of the Editorial Board of Frontiers in Neurorobotics as Review Editor.

Reviewer - reviewing activities F. Alexandre: Reviewer for Biological Cybernetics, Cognitive Neurodynamics;

X. Hinaut: Reviewer for MDPI Brain Sciences, Cognitive Computation, Frontiers in Neurorobotics, IEEE Transactions in Cognitive Developmental Systems (TCDS), Kunstliche Intelligenz, Neural Networks.

11.1.4 Invited talks

Nicolas Rougier has been invited to ENCODS, Glascow, UK, 2020 (post-poned to 2021), NeuroDoWo, Cologne, Germany, 2020 (post-poned to 2020) , Royal Statistical Society, London, UK, 2020 (canceled), Société Informatique de France, Paris, 2020 (canceled).

Frédéric Alexandre gave an invited talk to the seminar of the Line Laboratory in educational science of Univ. of Nice on march 3rd.

Xavier Hinaut gave invited talks to: AI4Industry workshop, Bordeaux (FR); COML and ENS Dupoux's lab, Paris (FR); LACORO'20 summer school (Chile),

11.1.5 Leadership within the scientific community

X. Hinaut is Co-Head of the "Apprentissage et neurosciences pour la robotique" CNRS Working Group (GT8) which organises several workshops through-out the year https://www.gdr-robotique.org/groupes_de_travail/?id=8. 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".

11.1.6 Scientific expertise

Nicolas Rougier has been expert for Comité pour la Science Ouverte (CNSO, 2020) – National Natural Science Foundation of China (Chine, 2020) – Israel Science Foundation (Israel, 2020) – Alfred P. Sloan Foundation (USA, 2020).

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.

X. Hinaut has been an expert for the ANR generic call 2020 for grant projects. He was part of the evaluation comittee of internships of the Neuroscience Master 2 of the University of Bordeaux.

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.

X. Hinaut is member of the "Committee for Technological Development" (CDT) and the "Committee for Research Jobs" (CER) of Inria Bordeaux Sud-Ouest.

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.

Thierry Viéville is teaching computational thinking in the Msc #CreaSmartEdtech ("Digital Expertise", "Educational Informatics" including Artificial Intelligence and Ontologies, "Digital Interdisciplinary Project ") and is co-organizing this Master of Science [13].

Frédéric Alexandre and Thierry Viéville have been involved in the production of the "Intelligence Artificielle Intelligente" citizen formation https://classcode.fr/iai, via the creation of a MOOC, with more than 20,000 participants after six months, allowing everyone to master these disruptive technologies by better understanding ground notions [20], [30].

11.2.2 Juries

F. Alexandre: 3 PhD review teams; member of a selection committee for a professor at Univ. Cergy.

11.3 Popularization

F. Alexandre gave a conference for TeDx Bordeaux about decision making https://www.tedxbordeaux.com/edition-2019/tedxbordeauxsalon-3-je-decide-donc-je-suis/ and gave a conference about AI to the high school of management of Bordeaux, ISG. Other large live conferences were canceled. Two articles by F. Alexandre in the blog Binaire of the French newspaper Le Monde: https://www.lemonde.fr/blog/binaire/2020/01/16/de-quelles-facons-lintelligence-artificielle-se-sert-elle-des-neurosciences/ and https://www.lemonde.fr/blog/binaire/2020/04/26/les-modeles-mathematiques-miracle-ou-supercherie/, the latter one being about the covid pandemics [45]. One article in Interstices https://interstices.info/les-relations-difficiles-entre-lintelligence-artificielle-et-lesneurosciences/ about AI and neuroscience [46];

Thierry Viéville gave several large audience online conferences about Artificial Intelligence popularization, within the scope of https://classcode.fr/iai, and participated in formation sessions regarding computer science teaching and continue contributing to computer science teaching in secondary school https://hal.inria.fr/hal-02445562.

The team has been involved and has succeeded in producing the https://neurosmart.inria.fr science outreach resource allowing everyone to better understand the functional aspects of the brain processing [31], with a good dissemination, e.g. http://www.scilogs.fr/intelligence-mecanique/neurosmart-une-histoire-de-cerveau-et-de-passionnes/, https://www.lemonde.fr/blog/binaire/2020/11/27/neurosmart-une-histoire-de-cerveau-et-de-passionnes/ and https://www.fondation-blaise-pascal.org/neurosmart-le-logiciel-pour-comprendre-le-cerveau/.

Thierry Viéville and other colleagues have published several large audience papers regarding our own research [54, 55, 50], which is very important due top the societal impact of our work, and also beyond [51, 49].

Nicolas Rougier co-created the Hypermondes association whose goal is to support a yearly festival around science and fiction open to the general public. The annual budget of the festival is around 75,000 euros. First edition will be held in September 2021 (initially date was June 2020).

11.3.1 Education

Thierry Viéville is the one co-author, while Frédéric Alexandre is also a contributor, of the Inria "white book" https://medsci-sites.inria.fr/education-et-numerique on research in digital sciences and technologies regarding digital education issues, questionning: What priority challenges to take up? What are the challenges linked to the coupling between digital and education ? What EdTechs research topics and solutions are to be considered ? This triple analysis made possible to propose seven recommendations according to three themes: (i) research actions, (ii) digital training, (iii) public action [21].

12 Scientific production

12.1 Major publications

[1] 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.

[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] S. Pagliarini, A. Leblois and X. Hinaut. 'Vocal Imitation in Sensorimotor Learning Models: a Comparative Review'. In: *IEEE Transactions on Cognitive and Developmental Systems* (Nov. 2020). DOI: 10.1109/TCDS.2020.3041179. URL: https://hal.inria.fr/hal-02317144.

12.2 Publications of the year

International journals

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

[5] 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 (13th May 2020), eaaz9165. DOI: 10.1126/sciadv.aaz9165. URL: https://hal.inria.fr/hal-02611441.

[6] G. I. Detorakis, A. Chaillet and N. P. Rougier. 'Stability analysis of a neural field self-organizing map'. In: *Journal of Mathematical Neuroscience* (1st Dec. 2020). DOI: 10.1186/s13408-020-00097-6. URL: https://hal.inria.fr/hal-03005121.

[7] 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* (21st Jan. 2021). DOI: 10.1098/rstb.2019.0668. URL: https://hal.inria.fr/hal-03005035.

[8] S. Pagliarini, A. Leblois and X. Hinaut. 'Vocal Imitation in Sensorimotor Learning Models: a Comparative Review'. In: *IEEE Transactions on Cognitive and Developmental Systems* (30th Nov. 2020). DOI: 10.1109/TCDS.2020.3041179. URL: https://hal.inria.fr/hal-02317144.

[9] E. Roesch and N. P. Rougier. 'New journal for reproduction and replication results'. In: *Nature* 581.7806 (May 2020). DOI: 10.1038/d41586-020-01328-2. URL: https://hal.inria.fr/hal-02564844.

[10] M. Romero, S.-C. Lefèvre and T. Viéville. 'When a Master of Sciences on EdTech becomes an International Community'. In: *ERCIM News* (30th Jan. 2020). URL: https://hal.inria.fr/hal-02418510.

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

[12] A. Strock, N. P. Rougier and X. Hinaut. 'Latent space exploration and functionalization of a gated working memory model using conceptors'. In: *Cognitive Computation* (2020). URL: https://hal.inria.fr/hal-02494493.

National journals

[13] M. Romero, F. Alexandre, T. Viéville and G. Giraudon. 'LINE - Mnémosyne : Des neurosciences computationnelles aux sciences de l'éducation computationnelles pour la modélisation du cerveau de l'apprenant et du contexte de l'activité d'apprentissage'. In: *Bulletin de l'Association Française pour l'Intelligence Artificielle* 108 (Apr. 2020). URL: https://hal.inria.fr/hal-02541099.

International peer-reviewed conferences

[14] F. Alexandre. 'Creativity explained by Computational Cognitive Neuroscience'. In: ICCC'20 - International Conference on Computational Creativity. Coimbra, Portugal, 7th Sept. 2020. URL: https://hal.inria.fr/hal-02891491.

[15] T. T. Dinh and X. Hinaut. 'Language Acquisition with Echo State Networks: Towards Unsupervised Learning'. In: ICDL 2020 - IEEE International Conference on Development and Learning. Valparaiso / Virtual, Chile, 26th Oct. 2020. URL: https://hal.inria.fr/hal-02926613.

[16] A. Juven and X. Hinaut. 'Cross-Situational Learning with Reservoir Computing for Language Acquisition Modelling'. In: 2020 International Joint Conference on Neural Networks (IJCNN 2020). Glasgow, Scotland, United Kingdom: https://wcci2020.org/, 19th July 2020. URL: https://hal.inria.fr/hal-02594725.

[17] G. Padiolleau, O. Bach, A. Hugget, D. Penninckx and F. Alexandre. 'A Structure of Restricted Boltzmann Machine for Modeling System Dynamics'. In: IJCNN 2020 - International Joint Conference on Neural Networks. Glasgow, United Kingdom, 21st July 2020, p. 8. URL: https://hal.inria.fr/hal-02925519.

[18] L. Pedrelli and X. Hinaut. 'Hierarchical-Task Reservoir for Anytime POS Tagging from Continuous Speech'. In: 2020 International Joint Conference on Neural Networks (IJCNN 2020). Glasgow, Scotland, United Kingdom: https://wcci2020.org/, 19th July 2020. URL: https://hal.inria.fr/hal-02594495.

[19] N. Trouvain, L. Pedrelli, T. T. Dinh and X. Hinaut. 'ReservoirPy: an Efficient and User-Friendly Library to Design Echo State Networks'. In: ICANN 2020 - 29th International Conference on Artificial Neural Networks. Bratislava, Slovakia: https://e-nns.org/icann2020/, 15th Sept. 2020. URL: https://hal.inria.fr/hal-02595026.

Conferences without proceedings

[20] F. Alexandre, R. De Barretin, J. Becker, M.-H. Comte, M. Courbin-Coulaud, S. Cruchon, A. Lagarrigue, B. Masse, S. De Quatrebarbes, J. Stein, C. Terosier and T. Viéville. 'Understanding Intelligently Artificial Intelligence : a citizens' open formation'. In: International Workshop on Education in Artificial Intelligence K-12 (EduAI). Ifrane, Morocco, 10th July 2020. URL: https://hal.inria.fr/hal-02889682.

Scientific books

[21] G. Giraudon, P. Guitton, M. Romero, D. Roy and T. Viéville. *Éducation et numérique, Défis et enjeux*. Livre Blanc Inria. https://medsci-sites.inria.fr/education-et-numerique, 10th Dec. 2020, p. 137. URL: https://hal.inria.fr/hal-03051329.

[22] E. Sanchez, M. Romero and T. Viéville. *Apprendre en jouant*. 8th Oct. 2020. URL: https://hal.inria.fr/hal-02946280.

Scientific book chapters

[23] F. Alexandre. 'IA et neurosciences'. In: *L'intelligence artificielle: De quoi s'agit-il vraiment ?* Vol. 117. https://www.cepadues.com/livres/l-intelligence-artificielle-quoi-agit-vraiment-9782364938502.html, 1st July 2020, pp. 15–43. URL: https://hal.inria.fr/hal-02891480.

[24] F. Alexandre. 'Plusieurs sortes d'IA ?' In: *L'intelligence artificielle: De quoi s'agit-il vraiment ?* https://www.cepadues.com/livres/l-intelligence-artificielle-quoi-agit-vraiment-9782364938502.html, 1st July 2020. URL: https://hal.inria.fr/hal-02891487.

[25] F. Alexandre, P. F. Dominey, P. Gaussier, B. Girard, M. Khamassi and N. P. Rougier. 'When Artificial Intelligence and Computational Neuroscience meet'. In: *A guided tour of artificial intelligence research, Interfaces and applications of artificial intelligence*. Vol. 3. Interfaces and Applications of Artificial Intelligence. 8th May 2020. URL: https://hal.archives-ouvertes.fr/hal-01735123.

[26] D. Menon and M. Romero. 'Game Mechanics Supporting a Learning and Playful Experience in Educational Escape Games'. In: *Global Perspectives on Gameful and Playful Teaching and Learning*. 1st Dec. 2020, pp. 143–162. DOI: 10.4018/978-1-7998-2015-4.ch007. URL: https://hal.inria.fr/hal-03016797.

[27] M. Romero, T. Viéville and L. Heiser. 'Analyse d'activités d'apprentissage médiatisées en robotique pédagogique'. In: *Traité de méthodologie de la recherche en Sciences de l'Éducation et de la Formation*. 4th Jan. 2021. URL: https://hal.inria.fr/hal-02957270.

Doctoral dissertations and habilitation theses

[28] T. Firmo drumond. 'Interactions between hierarchical learning and visual system modeling : image classification on small datasets.' Université de Bordeaux, 3rd Dec. 2020. URL: https://tel.archives-ouvertes.fr/tel-03129189.

[29] A. Strock. 'Working memory in random recurrent neural networks'. Université de Bordeaux, 19th Nov. 2020. URL: https://tel.archives-ouvertes.fr/tel-03150354.

Reports & preprints

[30] F. Alexandre, J. Becker, M.-H. Comte, A. Lagarrigue, R. Liblau, M. Romero and T. Viéville. *Open Educational Resources and MOOC for Citizen Understanding of Artificial Intelligence*. 24th July 2020. URL: https://hal.inria.fr/hal-03024034.

[31] F. Alexandre, D. Chiron, I. Chraibi-Kaadoud, M. Courbin-Coulaud, S. Dagar, T. Firmo-Drumond, C. Héricé, X. Hinaut, B. T. Nallapu, B. Ninassi, G. Padiolleau, S. Pagliarini, S. De Quatrebarbes, N. P. Rougier, R. Sankar, A. Strock and T. Viéville. *Neurosmart, a story of brains and science enthusiasts*. Inria, 19th Nov. 2020, p. 19. URL: https://hal.inria.fr/hal-03013647.

[32] S. Barnabé, L. Denet, M. Manrique, D. Menon, É. Pascual, M. Romero and T. Viéville. *A low-cost tabletop game to collect learning analytics during computational thinking using unplugged or tangible activities*. Inria, 4th Dec. 2020. URL: https://hal.inria.fr/hal-03040909.

[33] L. Denet. *The AIDE project's Tabletop device: development of itsuser interface*. Inria Bordeaux Sud-Ouest, 10th Sept. 2020, p. 14. URL: https://hal.inria.fr/hal-02935633.

[34] P. Kaushik, J. Naudé, S. B. Raju and F. Alexandre. *A VTA GABAergic computational model of dissociated reward prediction error computation in classical conditioning*. 15th Dec. 2020. DOI: 10.1101/2020.02.06.936997. URL: https://hal.archives-ouvertes.fr/hal-03066295.

[35] B. Ninassi, M. Romero, O. Goletti, S. Barnabé, S. Hoarau, T. Massart, K. Mens, P. Corieri and T. Viéville. *A para-platform to build a community regarding computer science education*. Inria, 9th Nov. 2020, p. 17. URL: https://hal.inria.fr/hal-02994175.

[36] L. Pedrelli and X. Hinaut. *Hierarchical-Task Reservoir for Online Semantic Analysis from Continuous Speech*. 30th Nov. 2020. URL: https://hal.inria.fr/hal-03031413.

[37] N. P. Rougier. *On the design of text editors*. 22nd Nov. 2020. URL: https://hal.inria.fr/hal-03018466.

[38] L. Roux, M. Romero, F. Alexandre, T. Viéville and C. Mercier. *Development of an ontology for the analysis of learner observables in the context of a task with modular robots*. Inria, 19th Nov. 2020, p. 48. URL: https://hal.inria.fr/hal-03013685.

[39] A. Variengien and X. Hinaut. *A Journey in ESN and LSTM Visualisations on a Language Task*. 30th Nov. 2020. URL: https://hal.inria.fr/hal-03030248.

Other scientific publications

[40] Y. Boniface and N. P. Rougier. *Interagir sans interpréter Apport d'une IA pour autonomiser un objet robotique*. Saint Pierre d'Oléron, France, 3rd June 2020. URL: https://hal.inria.fr/hal-02933478.

[41] P. Corieri, M. Romero, T. Massart, O. Goletti, K. Mens, M. Rafalska, T. Viéville, L. Meziane, J. Christophe, S. Hoarau, V. Komis and G. Parriaux. *Enjeux dans la création d'une communauté d'enseignants engagés dans l'apprentissage de l'informatique*. Lille, France, 5th Feb. 2020. URL: https://hal.inria.fr/hal-02426274.

[42] X. Hinaut and A. Variengien. *Recurrent Neural Networks Models for Developmental Language Acquisition: Reservoirs Outperform LSTMs*. Virtual Edition, Canada, 21st Oct. 2020. URL: https://hal.inria.fr/hal-03146558.

[43] A. Langlois and F. Alexandre. *Au plus près du cerveau - Mnemosyne*. 2020. URL: https://hal.inria.fr/hal-03145162.

[44] M. Romero, F. Alexandre, L. Roux, G. Giraudon and T. Viéville. *From computational neuroscience to computational learning science: modeling the brain of the learner and the context of the learning activity*. Sophia-Antipolis / Virtual, France, 20th Nov. 2020. URL: https://hal.inria.fr/hal-03018617.

12.3 Other

Scientific popularization

[45] F. Alexandre. 'Les modèles mathématiques : miracle ou supercherie ?' In: *Binaire* (26th Apr. 2020). URL: https://hal.inria.fr/hal-02925570.

[46] F. Alexandre. 'Les relations difficiles entre l'Intelligence Artificielle et les Neurosciences'. In: *Interstices* (26th Aug. 2020). URL: https://hal.inria.fr/hal-02925517.

[47] F. Alexandre, M.-H. Comte, M. Courbin-Coulaud and B. Masse. 'Formation à l'IA -épisode 3 : Class'Code / Inria IAI'. In: *Binaire* (26th Jan. 2021). URL: https://hal.inria.fr/hal-03120951.

[48] M. Coris, N. Vas-Deyres and N. P. Rougier. 'Intelligence artificielle : entre science et fiction'. In: *The Conversation* (20th Nov. 2020). URL: https://hal.inria.fr/hal-03017452.

[49] M.-A. Enard, P. Guitton and T. Viéville. *C'est l'histoire d'un GAN*. 14th Sept. 2020. URL: https://hal.inria.fr/hal-02937739.

[50] M.-A. Enard, P. Guitton and T. Viéville. *Parler de vérité autrement*. 16th Nov. 2020. URL: https://hal.inria.fr/hal-03007070.

[51] M.-A. Enard, P. Guitton and T. Viéville. *Tous au libre !* 25th Dec. 2020. URL: https://hal.inria.fr/hal-03089964.

[52] O. Goletti and T. Viéville. 'Bienvenue dans la communauté d'apprentissage de l'informatique'. In: *Binaire* (22nd Dec. 2020). URL: https://hal.inria.fr/hal-03089967.

[53] P. Guitton and T. Viéville. *Le numérique pour apprendre le numérique ?* 20th Jan. 2020. URL: https://hal.inria.fr/hal-02445562.

[54] L. Roux, M. Romero, F. Alexandre and T. Viéville. 'Les hauts de Otesia'. In: *Binaire* (29th Dec. 2020). URL: https://hal.inria.fr/hal-03089962.

[55] T. Viéville and P. Guitton. *Quels sont les liens entre IA et Éducation ?* 6th Nov. 2020. URL: https://hal.inria.fr/hal-02993232.

12.4 Cited publications

[56] F. Alexandre. 'Biological Inspiration for Multiple Memories Implementation and Cooperation'. In: *International Conference on Computational Intelligence*. Ed. by V. Kvasnicka, P. Sincak, J. Vascak and R. Mesiar. 2000.

[57] D. H. Ballard, M. M. Hayhoe, P. K. Pook and R. P. N. Rao. 'Deictic codes for the embodiment of cognition'. In: *Behavioral and Brain Sciences* 20.04 (1997), pp. 723–742. URL: http://dx.doi.org/10.1017/S0140525X97001611.

[58] D. Mitra. 'Asynchronous relaxations for the numerical solution of differential equations by parallel processors'. In: *SIAM J. Sci. Stat. Comput.* 8.1 (1987), pp. 43–58.

[59] D.P. Bertsekas and J.N. Tsitsiklis. *Parallel and Distributed Computation: Numerical Methods*. Athena Scientific, 1997.

[60] K. Doya. 'What are the computations of the cerebellum, the basal ganglia and the cerebral cortex?' In: *Neural Networks* 12 (1999), pp. 961–974.

[61] J. Fix, N. P. Rougier and F. Alexandre. 'A dynamic neural field approach to the covert and overt deployment of spatial attention'. In: *Cognitive Computation* 3.1 (2011), pp. 279–293. DOI: 10.1007/s12559-010-9083-y. URL: http://hal.inria.fr/inria-00536374/en.

[62] T. Mitchell. *Machine Learning*. Mac Graw-Hill Press, 1997.

[63] P. Dayan and L.F. Abbott. *Theoretical Neuroscience : Computational and Mathematical Modeling of Neural Systems*. MIT Press, 2001.

[64] R. Brette, M. Rudolph, T. Carnevale, M. Hines, D. Beeman, J. Bower, M. Diesmann, A. Morrison, P. H. Goodman, F. Harris, M. Zirpe, T. Natschläger, D. Pecevski, B. Ermentrout, M. Djurfeldt, A. Lansner, O. Rochel, T. Viéville, E. Muller, A.P. Davison, S. E. Boustani and A. Destexhe. 'Simulation of networks of spiking neurons: a review of tools and strategies'. In: *Journal of Computational Neuroscience* 23.3 (2007), pp. 349–398.

[65] R.C. O'Reilly and Y. Munakata. *Computational Explorations in Cognitive Neuroscience: Understanding the Mind by Simulating the Brain*. Cambridge, MA, USA: MIT Press, 2000.

[66] N. P. Rougier. 'Dynamic Neural Field with Local Inhibition'. In: *Biological Cybernetics* 94.3 (2006), pp. 169–179.

[67] N. P. Rougier and A. Hutt. 'Synchronous and Asynchronous Evaluation of Dynamic Neural Fields'. In: *J. Diff. Eq. Appl.* (2009).

[68] S. Amari. 'Dynamic of pattern formation in lateral-inhibition type neural fields'. In: *Biological Cybernetics* 27 (1977), pp. 77–88.

[69] S. Coombes. 'Waves, bumps and patterns in neural field theories'. In: *Biol. Cybern.* 93 (2005), pp. 91–108.

[70] L. Squire. 'Memory systems of the brain: a brief history and current perspective'. In: *Neurobiol. Learn. Mem.* 82 (2004), pp. 171–177.

[71] A. Strock, X. Hinaut and N. P. Rougier. 'A Robust Model of Gated Working Memory'. In: *Neural Computation* 32.1 (Jan. 2020), pp. 153–181. DOI: 10.1162/neco_a_01249. URL: https://doi.org/10.1162/neco_a_01249.

[72] W. Taouali, T. Viéville, N. P. Rougier and F. Alexandre. 'No clock to rule them all'. In: *Journal of Physiology* 105.1-3 (2011), pp. 83–90.

[73] T. Trappenberg. *Fundamentals of Computational Neuroscience*. Oxford University Press, 2002.

[74] T. Viéville. 'An unbiased implementation of regularization mechanisms'. In: *Image and Vision Computing* 23.11 (2005), pp. 981–998. URL: http://authors.elsevier.com/sd/article/S0262885605000909.

[75] W. Gerstner and W.M. Kistler. *Spiking Neuron Models: Single Neurons, Populations, Plasticity*. Cambridge University Press: Cambridge University Press, 2002.