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Project-Team CORTEX

Neuromimetic Intelligence

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THEME COG

Activity Report

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1. Team

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2. Overall Objectives

2.1. Overall Objectives

The goal of our research is to study the properties and capacities of distributed, numerical and adaptive automated information processing and to show that that kind of processing may allow to build “intelligent” systems, i.e. able to extract knowledge from data and to manipulate that knowledge to solve problems. More precisely, these studies rely on the elaboration and analysis of neuromimetic connectionist models (*cf.* § 3.1), developed along two sources of inspiration, computational neuroscience and machine learning.

Both sources of inspiration are studied together because they are interested in better understanding how such distributed models can learn internal representations, and manipulate knowledge and both propose complementary approaches allowing cross-fertilization. Machine learning proposes connectionist numerical models for information processing in a statistical framework, to extract knowledge from data (*cf.* § 3.2). Computational neuroscience proposes distributed theoretical models and elementary mechanisms that aim at explaining how the human or animal nervous system processes information at various levels, from perception to reasoning (*cf.* § 3.3).

Complementarily to our multidisciplinary domains of inspiration, our research is applied in domains like data and signal interpretation, intelligent sensors, robotics, and computer-aided decision. More generally, our models are dedicated to monitoring complex, multimodal processes, perceiving and acting on their environment (*cf.* § 4.1).

These models are firstly implemented on classical computers, but other architectures are also explored, namely parallel machines, autonomous robots, and more generally specialized circuits for embedded systems, as suggested by our applications (*cf.* § 3.5).

Accordingly, four topics of research are currently carried out. (i) In computational neuroscience, at a behavioral level, we are developing models of cerebral neuronal structures (*cf.* § 6.1), to allow the navigation of autonomous robots. (ii) In computational neuroscience, at the neuronal level, we are modeling spiking neurons (*cf.* § 6.2), seen as dynamic systems with temporal behavior, allowing synchronization within populations of neurons. (iii) From a more statistical point of view, we are studying how classical continuous neuronal models can be adapted to database and signal interpretation, for knowledge extraction (*cf.* § 6.3). (iv) From a more technological point of view, all the above-mentioned models are adapted to allow implementations on dedicated architectures (*cf.* § 6.4).

3. Scientific Foundations

3.1. Connectionism

Keywords: *artificial neural network, connectionism, multi-layer perceptron, perceptron, self-organizing map*.

Connectionism can be defined as the study of graphs of simple interconnected units, performing elementary numerical computations, derived from their input and internal parameters. In particular, neuro-inspired connectionism is interested in artificial neural networks, like perceptrons or self-organizing maps. These models have been thoroughly studied in the domain of machine learning for their properties of learning and approximation and their links with other statistical tools.

Artificial neural networks have been successfully applied to a variety of tasks (pattern matching, prediction, control) in a variety of domains (signal processing, industrial processes, medicine). Beyond computing statistics on databases from such domains, one can also wonder about using such capabilities for more cognitive tasks like interpretation and knowledge extraction, which are not classical properties of artificial neural networks, but are fundamental from an expertise point of view. Current research aims at extending their capabilities to these tasks (*cf.* § 3.2).

Other connectionist approaches aim at going back to the basis of connectionism and look for a tighter inspiration from neuroscience. The inspiration can be local and look for more realistic models of neuronal functioning and particularly of its dynamical aspect (*cf.* § 3.4). It can be global with the goal of implementing tasks related to the modeling of integrated behavior (*cf.* § 3.3). Both biologically inspired approaches are refered to as computational neuroscience. They are multidisciplinary and aim at a better understanding of brain function (biological aspect) and of neuronal computation, seen as a new paradigm of computation (computer science aspect).

Another important issue in connectionism is to take benefit from the parallel distributed nature of its computation and to develop implementations that exploit those characteristics. As such implementations lead to cope with the real nature of neural computation, they may improve the performance of algorithms and be embedded in electronic devices (*cf.* § 3.5).

3.2. Intelligent information processing

Keywords: *data analysis*, *knowledge extraction*, *neuro-symbolic integration*, *pre-processing*, *visualization*.

Artificial neural networks are information processing systems that can be widely applied to data mining. They have a lot of capabilities for analyzing and pre-processing data, as well as visualizing and extracting knowledge. These capabilities can be developed through unsupervised and supervised networks or by their combination in order to obtain data analysis and forecasting models close to the ones performed by statistical methods but with other interesting properties.

To improve the performance of such information processing systems, several approaches can be followed depending of the prior knowledge available. Indeed, depending on additional labels (class or continuous value) which can be used (or avalaible) on none of the patterns, on a subset of the patterns or on all of them, unsupervised, semi-supervised or supervised learnings can be sequentially performed. When there is no prior knowledge on the problem to be solved, knowledge extraction may use an unsupervised neural network as a front-end for forecasting applications or extracting rules. Because of its synthesis capabilities, an unsupervised neural network can be used both for limiting the computation complexity and for extracting the most significant knowledge. Moreover, knowledge extraction is facilitated as soon as multi-viewpoint unsupervised neural network model is used. This kind of methods also allows to use in a second step additional information when it is avalaible for optimizing a forecasting problem. However, for a forecasting problem where all patterns are labelled, classical networks using supervised learning can be successfully improved by finding the minimal architecture using pruning algorithms. The pruning methods consist in removing, during learning, the connections or neurons, or both, that have the least influence on the system's performance. Reducing the complexity of the networks prevents overtraining and allows easier implementation and knowledge extraction (variable selection, rule extraction). Semi-supervised learning mixes the two previous approaches. In this situation, preliminary fixed labels can be associated to the clusters and furthermore to the unlabelled patterns. In any case, combining several models into a committee helps to improve the quality of the knowledge extracted or the forcasting; thus this is also an approach recently developed in the project.

3.3. Computational neuroscience: behavioral approach

Keywords: *behavioral model*, *computational neuroscience*, *cortical column*, *cortical model*, *population of neurons*.

In the behavioral approach of computational neuroscience, inspiration from neuroscience corresponds to defining and modeling the main information flows in the brain, together with the functional role of the main neuronal structures and their relation to some cognitive tasks.

The main cognitive tasks we are interested in are related to the autonomous navigation of a robot in an unknown environment (perception, sensorimotor coordination, planning). The corresponding neuronal structures we are modeling are part of the cortex (perceptive, associative, frontal maps) and the limbic system (hippocampus, amygdala, basal ganglia).

Corresponding models of these neuronal structures are defined at the level of the population of neurons and functioning and learning rules are built from neuroscience data to emulate the corresponding information processing (filtering in perceptive maps, multimodal association in associative maps, temporal organization of behavior in frontal maps, episodic memory in hippocampus, emotional conditioning in amygdala, selection of action in basal ganglia).

Our goal is to iteratively refine these models, implement them on autonomous robots and make them cooperate and exchange information, toward a completely adaptive, integrated and autonomous behavior.

3.4. Computational neuroscience: spiking neurons

Keywords: *computational neuroscience*, *neural code*, *olfaction*, *spiking neurons*, *synchronization of activity*.

Computational neuroscience is also interested in having more precise and realistic models of the neuron and especially of its dynamics. Compartmental models describe the neuron through various compartments (axon, synapse, cellular body) and coupled differential equations. Such models describe the activity of real neurons to a high degree of accuracy. However, because of their complexity, these models are difficult to understand and to analyze. For this reason our work focuses on the use of simplified models, i.e. simple phenomenological models of spiking neurons, that try to capture the dynamic behavior of the neuron in leaky integrators that explain how spikes can be emitted through time from input integration.

These models are interesting for several reasons. From a neuroscience point of view, they allow a better understanding of neuronal functioning. Indeed, although it is well known that real neurons communicate with spikes, i.e. a short electrical pulse called action potential, the precise nature of the neural code is a topic of intense debate. The firing-rate coding hypothesis stating that the firing frequency of a neuron estimated by temporal averaging encodes information is now challenged by a number of recent studies showing that precise spike timing is a significant element in neural encoding. In particular, stimulus-induced synchronization and oscillatory patterning of spike trains have been experimentally observed in perceptive systems like in vision or olfaction. Moreover, synchronization of neural activities seems to play a role in olfactory perception; for example, when the synchronization is pharmacologically abolished, honeybees do not discriminate anymore between similar odors.

From a computer science point of view, we investigate the spatio-temporal dynamics of simplified models of spiking networks using both mathematical analysis and numerical simulations. Therefore, we have to define (i) a tractable mathematical analysis with methods coming from the theory of nonlinear dynamical systems and (ii) an efficient computing scheme with either event-driven or time-driven simulation engines. These models can also be applied to difficult coding tasks for machine perception like vision and olfaction, and can help to understand how sensory information is encoded and processed by biological neural networks.

3.5. Connectionist parallelism

Keywords: *FPGA*, *connectionism*, *digital circuits*, *parallelism*.

Connectionist models, such as neural networks, are the first models of parallel computing. Artificial neural networks now stand as a possible alternative with respect to the standard computing model of current computers. The computing power of these connectionist models is based on their distributed properties: a very fine-grain massive parallelism with densely interconnected computation units.

The connectionist paradigm is the foundation of the robust, adaptive, embeddable and autonomous processings that we develop in our team. Therefore their specific massive parallelism has to be fully exploited. Furthermore, we use this intrinsic parallelism as a guideline to develop new models and algorithms for which parallel implementations are naturally made easier.

Our approach claims that the parallelism of connectionist models makes them able to deal with strong implementation and application constraints. This claim is based on both theoretical and practical properties of neural networks. It is related to a very fine parallelism grain that fits parallel hardware devices, as well as to the emergence of very large reconfigurable systems that become able to handle both adaptability and massive parallelism of neural networks. More particularly, digital reconfigurable circuits (e.g. FPGA, Field Programmable Gate Arrays) stand as the most suitable and flexible device for fully parallel implementations of neural models, according to numerous recent studies in the connectionist community. We carry out various arithmetical and topological studies that are required by the implementation of several neural models onto FPGAs, as well as the definition of hardware-targetted neural models of parallel computation.

4. Application Domains

4.1. Overview

Keywords: *database interpretation, multidisciplinary applications, perception/action interaction, robotics, signal interpretation.*

Our connectionist models are applied to two kinds of tasks. From a machine learning point of view, the idea is to combine the statistical exploration of databases with knowledge extraction from these databases. From a computational neuroscience point of view, we are interested in modeling various aspects of intelligent behavior. Domains of application are thus very wide since they include domains where databases have to be structured and interpreted and domains where perception-action loops have to be elaborated from the exploration of an unknown world.

Beyond the good performances of the neuronal paradigm on these tasks, these applications are also interesting for several reasons. From an expertise point of view, they allow to extract knowledge from databases including geographical and geological data (*cf.* § 7.2), industrial data (*cf.* § 7.3), bibliographical data (*cf.* § 7.3) or EEG signals (*cf.* § 7.3).

From a technological point of view, they allow to define a methodology for using artificial neural networks (*cf.* § 5.) and they can lead to hardware implementation (*cf.* § 5.5). From a multidisciplinary point of view, they lead to projects (*cf.* § 7.2 and § 7.3) including partners from different domains and working together for a better understanding of the brain (neuroscientists, ethologists, physicians).

5. Software

5.1. Spiking neural networks simulation

Keywords: *event-driven simulator, spiking neurons.*

Participant: Dominique Martinez.

A spiking neuron is usually modeled as a differential equation describing the evolution over time of its membrane potential. Each time the voltage reaches a given threshold, a spike is sent to other neurons depending on the connectivity. A spiking neural network is then described as a system of coupled differential equations. For the simulation of such a network we have written two simulation engines using either (i) an event-driven approach or (ii) a time-driven approach. They are respectively more dedicated to the simulation of integrate-and-fire neurons or Hodgkin-Huxley neurons.

- The event-driven simulation engine was developed in C++ by O. Rochel during his PhD thesis. It allows to achieve good performance in the simulation phase while maintaining a high level of flexibility and programmability in the modeling phase. A large class of spiking neurons can be used ranging from standard leaky integrate-and-fire neurons to more abstract neurons, e.g. defined as complex finite state machines.
- The time-driven simulator engine called SIRENE was written in C and developed for the simulation of a model of the antennal lobe, the first structure of the insect olfactory system. This simulator engine can simulate any type of spiking neural network and is indeed more dedicated to the simulation of biologically detailed models of neurons —such as conductance-based neurons— and synapses. Its high flexibility allows the user to implement easily any type of neuronal or synaptic model and use the appropriate numerical integration routine (e.g. Runge-Kutta at given order). In the context of an application to large networks (*cf.* § 7.2), we developed this year a graphical interface to visualize the spikes and the evolution of our networks.

5.2. Implementation of computational neuroscience mechanisms

Keywords: *computational neuroscience*.

Participants: Nicolas Rougier, Julien Vitay, Jérémy Fix, Zhor Ramdane-Cherif.

Most of our models are based on the Continuum Neural Field Theory (CNFT) which requires heavy processing power and memory since most interesting properties emerge from the interaction of many processing units. To cope with this problem we had to design efficient management of both CPU and memory together with an ease of use when designing simulations. The resulting software is core/plugin architecture where the core has been designed in C++ and the plugins in python which offers a very flexible way of manipulating models via scripts. For example , a user can view or modify any variables or objects using either a console or a graphical interface. Furthermore, a graphical display of the network has been designed using OpenGL that allows an easy debugging using visual 3D manipulations of the network. Finally, resulting models are running in real-time and can be used on the PeopleBot Robot to perform tasks such as target tracking or attention shifting among moving targets.

5.3. Decision-making platform

Keywords: *decision-making*.

Participants: Laurent Bougrain, Nizar Kerkeni, Marie Tonnelier.

GINNet (Graphical Interface for Neural Networks) is a decision-aid platform written in Java, intended to make neural network teaching, use and evaluation easier, by offering various parametrizations and several data pre-treatments. GINNet is based upon a local library for dynamic neural network developments called DynNet. DynNet (Dynamic Networks) is an object-oriented library, written in Java and containing base elements to build neural networks with dynamic architecture such as Optimal Cell Damage and Growing Neural Gas. Classical models are also already available (multi-layer Perceptron, Kohonen self-organizing maps, ...). Variable selection methods and aggregation methods (bagging, boosting, arcing) are implemented too.

The characteristics of GINNet are the following: Portable (100% Java), accessible (model creation in few clicks), complete platform (data importation and pre-treatments, parametrization of every models, result and performance visualization). The characteristics of DynNet are the following: Portable (100% Java), extensible (generic), independent from GINNet, persistent (results are saved in HML), rich (several models are already implemented), documented.

This platform is composed of several parts:

1. Data manipulation: Selection (variables, patterns), descriptive analysis (stat., PCA..), detection of missing, redundant data.
2. Corpus manipulation: Variable recoding, permutation, splitting (learning, validation, test sets)
3. Supervised networks: Simple and multi-layer perceptron.
4. Competitive networks: Kohonen maps, Neural Gas, Growing Neural Gas.
5. Metalearning: Arcing, bagging, boosting.
6. Results: Error curves, confusion matrix, confidence interval.

DynNet and GINNet are free softwares distributed under CeCILL license, Java 1.4 compatible (http://ginnet.gforge.inria.fr). GINNet is available as an applet. For further information, see http://gforge.inria.fr/projects/ginnet (news, documentations, forums, bug tracking, feature requests, new releases...)

5.4. MicroNOMAD-MultiSOM

Keywords: *documentary database, knowledge discovery*.

Participants: Shadi Al Shehabi, Jean-Charles Lamirel.

The MicroNOMAD-MultiSOM software mainly focuses on the automatic extraction and organization of knowledge that is embedded in documentary databases. The basic principle of this software is to provide users with interactive and interconnected cartographies of knowledge materializing several different syntheses of the content of a given documentary database. The underlying model of the MicroNOMAD-MultiSOM software represents an extension of Kohonen's SOM model to a multi-maps (i.e. multi-viewpoints) context. Due to the flexibility of this extension, the resulting maps can both play the role of elaborated browsing tools, data mining tools, as well as tools for assisting users in querying the documentary database. The model allows users to exploit dynamic exchange between the multiple viewpoints for highlighting correlations between the different views on the same data. It also permits the use of partial or incomplete descriptions of the data and accepts simultaneous representations of the same data with regard to different media.

The MicroNOMAD-MultiSOM software has been used on different operational applications of data mining (*cf.* § 7.3 and § 7.4). The versions 1 and 2 of this software have been patented by INRIA. The MicroNOMAD-MultiSOM software has been chosen as one of the two softwares of reference for analyzing Web data in the framework of the European EICSTES project (*cf.* § 7.3). The version 3 of this software that offers numerous extensions for analyzing non structured data as well as numerous functions for the automation of analysis has been finalized in the project. Many different analyses have been conducted with the MicroNOMAD-MultiSOM software in the framework of this project. Comparison of the results with the ones that have been obtained with the other software selected in the project have also been performed. A new extension of the MicroNOMAD-MultiSOM is currently under construction. It consists in adding an automatic rule extraction module.

5.5. Neural network synthesis on FPGA

Keywords: *FPGA, digital circuits, parallelism*.

Participants: Bernard Girau, Cesar Torres-Huitzil.

To date the majority of neural network implementations have been in software. Despite their generally recognised performances, the high cost of developing ASICs (Application Specific Integrated Circuits) has meant that only a small number of hardware neural-computing devices has gone beyond the research-prototype stage in the past. With the appearance of large, dense, highly parallel FPGA circuits, it has now become possible to realize large-scale neural networks in hardware, with the flexibility and low cost of software implementations.

Though easier than ASIC development, implementations on FPGAs still require a significant amount of work, especially for connectionists who are not very familiar with such tools as the VHDL language, synthesis tools, etc. Therefore, we have started a software project that aims at developing a generic methodology to fully automatically specify, parametrize and implement neural networks according to various application and technological constraints (e.g. area of targeted FPGAs, required precision, etc).

This project implies that we handle very different aspects: numerous different technological choices to fit the implementation constraints, genericity and modularity of solutions, precise analysis of the relations between application data, device specifications, and performances, for each valid technological solution.

This work has led to a first software platform that handles both FPGA boards and neural implementations. Multilayer neural networks and graphically designed networks of neurons are automatically "compiled" onto FPGA by this tool. Communications between the FPGA, the host and the memory slots are also taken into account. This software is already functional. Nevertheless, numerous technological solutions still have to be included, as well as advanced neural mapping methods. Simultaneously, a compatible software is being designed to automatically generate FPNA architectures (*cf.* § 6.4) from large neural networks that cannot be directly mapped onto FPGAs. This part of the project aims at providing advanced tools such as hardware-targetted neural models for users who are not familiar with the specific field of neural network implementations.

6. New Results

6.1. Behavioral computational neuroscience

Participants: Frédéric Alexandre, Yann Boniface, Claudio Castellanos Sanchez, Hervé Frezza-Buet, Olivier Ménard, Nicolas Rougier, Julien Vitay, Thomas Voegtlin.

The works reported this year are all concerned with modeling several parts of the visual path in the cortex, from the most elementary to the most integrated (motion detection, attention and active vision, visiomotor coordination, visual recognition by components). We have also begun to explore ways to reconciliate such models, using the frequency rate code at the level of the population of neurons, with our spiking models as reported in the next section.

6.1.1. Motion detection

Visual perception of motion is a major challenge in machine perception research, since it constitutes an important parameter in a wide variety of tasks such as path-finding, estimation of time to collision, perception of gestures, movement control, etc.

We have developed a bio-inspired neural architecture to detect, extract and segment the direction and speed components of the optical flow within sequences of images. The structure of this model derives directly from the course of the optical flow in the human brain. It begins in the retina and receives various treatments at every stage of its magnocellular pathway through the thalamus and the cortex.

We have mainly focused on two fundamental problems in the treatment of a sequence of images. Firstly, the computation of their optical flow (a three-stage process: pre-processing based on filters, extraction of elementary characteristics and integration into a 2D optical flow), and secondly, the extraction of several moving objects in a scene with some possible egomotion. This work faces many concrete difficulties, such as specular effects, shadowing, texturing, occlusion and aperture problems. Moreover, the complexity of this task must be dealt with within the implementation constraint of real-time processing.

Our model mostly handles the properties of three cortical areas called V1, MT (middle temporal), and MST (middle superior temporal): the MT area detects patterns of movement, while spatio-temporal integration is made at the local level by V1 and at the global level by both MT and MST, so that a multi-level detection and integration may discriminate egomotion from movements of objects in a scene and from the scene itself.

This model currently consists of three layers. The first one extracts spatio-temporal estimations of local movements. The second one performs a bio-inspired inhibitory/excitatory mechanism where strong local inhibitions exist between neurons that represent antagonistic movements and makes coherent moving areas appear. The third layer is based on CNFT principles (*cf.* § 5.2). Using different data such as motion intensities in the second layer, this third layer is able to identify one or several moving objects [28].

Future works will introduce strong feedback interactions between the different layers of this architecture, as they exist between the different involved cortical areas. Such interactions may improve the coherence of the local motions that interact in the second layer, and they may lead to the detection of specific motions.

6.1.2. Attention and active vision

In the domain of robotic, modeling perceptive and executive attention is quite a critical feature given the limited computational power available on such mobile devices. More specifically, it allows to recruit the vast majority of available resources for processing of a given location of the considered space (either perceptive or executive) in order to process it finely while rest of resources are allocated for a broader processing of the remaining space. In the framework of the Europen MirroBot project (*cf.* § 7.3) and the CPER (*cf.* § 7.1), we have been exploring the perceptive attentional paradigm in for the visual space.

Based on the Continuum Neural Field Theory (CNFT), we have first designed a simple model in order to study properties of that theory (*cf.* § 5.2). We were able to show that such a simple model implement a very rudimentary form of attention that is an emergent property of the model. More specifically, we numerically demonstrated that such a model is very resistant to both noise and distractors and is able to bypass the saliency hierarchy by attending any stimulus of the visual scene, independently of its intrinsic saliency. We then further refined this model to be able to switch "at will" using a more complex and biologically inspired architecture that allows to memorize visited stimulus. Visited stimuli are moving within the visual field and the model have to keep track of them. This has been done using a dynamic working memory based on a reverbatory loop. Finally, the model has been implemented on a real robot (PeopleBot) to track three identical targets. The challenge was to be able to look at them successively without looking twice at the same target. From experiments we conducted, the model is very reliable and also very resistant to both noise and distractors.

This model [17] has been developed as a first step toward active vision where saccadic eye movements are considered to be a part of the recognition process. We further developed these ideas and design a model able to build a motor representation of its environment by actively memorizing what saccades would be necessary to reach any object that have been focused in the past. This allows for example to efficiently scan a given scene in order to find a given object. This has been implemented both as a simulation and on the real robot.

6.1.3. Visiomotor coordination

In the domain of robotic, modeling the visiomotor axis is an important issue that we explore for various aims described in the European MirrorBot project (*cf.* § 7.3) and the CPER (*cf.* § 7.1).

Visiomotor transformations are among the basic elements of the cognitive and motor behaviour of a robot. This step was studied extensively and permitted the use of redundant and distributed representations (such as our models of visual perception) which can be reused by other modules. They were applied to our Peoplebot robot which is now able to perform gaze centering and grasping tasks in a reactive way with a satisfying precision, and they were also applied to a robotic arm performing pointing tasks. These transformations are furthermore reversible, which means they can be used to predict the sensorial consequences of an action, either executed or imagined. This is capital for cognitive tasks requiring evaluation of an eventual reward depending on the action.

The underlying associative models have been developed to highlight several aspects like the design of an original and cheap connectivity between the visual and motor information and the unsupervised self-organized learning of these two representations together with the associative visiomotor distributed representation. Using a simple reward signal, given only at the motor level, was possible because of the joint multimodal learning. This prevents us from using an inverse model. This model [7] was also successfully used to learn a motor-dependent phonetic representation in an application including language instructions for a moving robot.

6.1.4. Visual recognition by components

Recently, it has been proposed that the primate visual system uses canonical representations in order to recognize objects invariant to the location of the stimuli on the retina. In this hypothesis, canonical representations result from foveated stimuli, and stimuli presented in the periphery are associated to canonical representations through learning. It has been proposed that a motor signal (eye movements) is used to reinforce those associations.

A major challenge to this approach is that associations between peripheral and canonical representations are difficult to learn. For complex objects, made of several constituents, the number of possible combinations explodes, and learning models are quickly overwhelmed. In order to solve this, we implemented a divide-and-conquer approach, where objects are decomposed into (i) a list of simple elementary features, and (ii) a description of their overall shape, which does not depend on local features. This decomposition makes the problem of learning invariances much easier, because features at the corresponding levels of descriptions have less complexity.

In this approach, object recognition involves a pre-attentive step, where salient points of the object are detected. Local features are then extracted at those points, and combined into a synthetic representation of the object. In this representation, information about the structure of the object is represented explicitly. Our model has been tested on complex stimuli made of several elementary features. Robustness to noise, as well as to geometrical deformations (stretching) of the objects has been shown to some extent.

6.1.5. *From spikes to frequency*

Works reported in the section above are concerned with functional modeling of neuronal structures at the level of population of neurons, typically using mean frequency models like the CNFT. On the other hand, the next section will present works using a finer grain, at the level of the spike. We have began works this year to reconciliate these levels, towards the understanding of modeled phenomena at both levels of description.

We have developed a spiking model of visual attention. Similarly to the one presented above, this model is based on the Continuum Neural Field Theory (CNFT).

This work made us approach and sometimes deepen different problems:

- A 'fine grain' validation, closer to our biological inspiration, from numerical models, with spiking communication between neurons.
- A study of the dynamic and properties of the CNFT at continuous time.
- The implementation of functional models using networks of spiking neurons.
- The study and the design of the emergence of functional properties from populations of networks of spiking neurons.
- The study, definition and representation of the concept of a network activity within a population of spiking neurons, the representation of an activity bubble.

These studies enabled us to obtain a model reproducing the functional properties and the dynamics of the numerical and 'discrete time' implementation of the Continuum Neural Field Theory.

6.2. Spiking neurons

Participants: Frédéric Alexandre, Yann Boniface, Bernard Girau, Dominique Martinez, Arnaud Tonnelier.

Our research in fine grain computational neuroscience (*cf.* § 3.4) is performed at different structural scales: the cellular, the circuit and the systems levels. We investigate how information is processed at these different levels and we aim at elucidating the link from cellular functions to cognitive functions. The new results obtained at these three different scales are developed in three parts (1) neural excitability (2) propagation in neural networks and (3) neural synchronization and network oscillations.

Modeling is based on mathematical tools: we used the nonlinear dynamical systems theory and the associated limit cycles. Since they largely appear in physical and biological systems, limit cycles have attracted a wide attention. Limit cycles model self sustained oscillations that are involved in numerous applications and observed in several experiments. The existence of a periodic regime for a system is related to the existence of a limit cycle for the associated dynamical system. The question of the number and the position of limit cycles for a dynamical system is a difficult question that is related to the unsolved Hilbert's 16th problem. Given the difficulty of the general problem, we restrict our attention to the so-called Liénard system

$$\begin{aligned} \dot{x} &= p(x) - y, \\ \dot{y} &= x, \end{aligned} \tag{1}$$

where $(x, y) \in \mathbb{R}^2$ and $p(x)$ is a piecewise linear function. One expects that results from piecewise linear systems can lead to insights into the general problem. The phase plane of (1) is divided into zones so that the restriction of the system into each zone is a linear system. We have conjectured: "The piecewise linear Liénard system (1) with $n + 1$ zones has up to $2n$ limit cycles". In [14], we give a general class of Liénard systems satisfying the conjecture. Moreover, we give a simple recursive algorithm to generate this class of functions.

6.2.1. Neural Excitability

Action potential or spike is the elementary unit of signal processing and signal transmission in biological neural networks. Despite the large number of ionic mechanisms underlying the initiation of action potentials, a broad class of neurons presents two types of excitability. The properties of membrane excitability are determined according to the emerging frequency of repetitive firing. The frequency response of a single cell is crucial since it models the input-output relation, i.e. the gain function, commonly used in firing rate description of neural networks. The caracterization of the frequency curve as a function of the intrinsic properties of the neuron provides a link between the *spike code* paradigm and the *rate code* paradigm. Previous studies for classifying excitability used the bifurcation resulting in transition from quiescent to an oscillatory state. However, this classification is not perfect and suffers from a lack of quantitative predictions. In [13], we present an easy and intuitive way to charactetize the neural excitability of spiking neurons: the existence of a delayed afterdepolarization monitors the type of excitability. Our criterion suggests that the excitability of a neuron is mainly determined by the voltage-dependent potassium currents. Our analysis used the analytical framework of the spike-response-model that allows us to derive the value of the emerging frequency. We check the validity of our classification on more complex models.

6.2.2. Propagation in neural networks

Homogeneous networks of neurons can be in a state of synchronous or asynchronous activity. In spatially structured networks additional states are possible that are characterized by the propagation of wave-like activity patterns. Recently, a number of experiments have indicated the existence of propagating activity waves in neuronal tissue, notably the cortex, thalamus and hippocampus. The mechanisms underlying the wave propagation is believed to be synaptic in origin and has recently been the subject of several theoretical studies. There are basically two complementary frameworks where the propagation has been investigated: models of spiking neurons and firing rate models. We have investigated the propagation of an excitatory activity in both networks:

- We have studied the propagation of solitary waves in a discrete one-dimensional excitatory network of integrate-and-fire neurons. We have shown the existence and the stability of a fast wave and a family of slow waves. Stable slow waves have not been previously reported in purely excitatory networks. The number of these waves is parametrized by the number of presynaptic neurons and their existence depends crucially on the form of the EPSP (excitatory post-synaptic potential). The presence of weak noise does not alter our results but we have shown that a moderate amount of noise can induce both propagation failure or switching between different stable propagating modes.
- Neural tissues are commonly seen as neural fields which form and propagate patterns of excitation. We have considered a firing rate model of a neural network consisting of an excitatory and inhibitory layer with an excitatory feedforward connectivity. We have demonstrated the role of inhibition in stable pulse propagation. In a purely excitatory network, pulse waves are unstable because of the existence of stable front wave and back wave with different velocities leading to an enlarging pulse. When excitation is balanced appropriately by inhibition the growing pulse observed in the excitatory network is suppressed and an initial perturbation converges towards the traveling pulse solution. The regime where a traveling pulse propagates depends strongly on the kinetic of the inhibitory population [15].

6.2.3. Neural synchronization and network oscillations in the olfactory system

6.2.3.1. Introduction

We study the role of spike synchronization and field potential oscillations in sensory coding by means of computational modeling. More specifically, during the past few years, our work focused on the olfactory system for the following two reasons:

- Across species, primary olfactory centers show similarities both in their cellular organization and their types of olfactory information coding. The olfactory system is one of the simplest perceptive system and thus one of the best understood.
- Understanding how sensory information is encoded and processed by the olfactory system could be highly beneficial for designing efficient electronic noses for which gas sensors are highly nonselective and respond to a wide variety of odors, as do the broadly tuned olfactory receptors in insects.

In order to understand the mechanisms underlying the odor coding in early olfactory systems and to derive a bio-inspired neural network model that can be applied to the processing of electronic nose data, we have used both mathematical analysis and numerical simulations of models of spiking networks.

6.2.3.2. Numerical simulations

We have considered an excitatory-inhibitory spiking neural network as a model ofearly olfactory systems: antennal lobe (AL) for insects, olfactory bulb (OB) for vertebrates.

In line with experimental results, we have shown that, in our network, odor-like stimuli evoke synchronization of excitatory cells, phase-locked to the oscillations of the local field potential. Each oscillatory cycle is defined by a volley of quasi-synchronized excitatory cell (E-cell) spikes followed, a few milliseconds later, by a similar volley of inhibitory cell (I-cell) activity. Consecutive cycles of activity are separated by periods of silence lasting for about 50 ms and giving rise to 20 Hz LFP oscillations, similar to that of recorded in the locust antennal lobe. Blocking inhibitory synapses in our model disrupted E-cell synchronization and LFP oscillations. This is in agreement with previous experimental and modeling studies which support the functional relevance of fast GABAergic inhibition from I-cells in the synchronization of the E-cells. As shown in our model, the LFP frequency is independent on the odor concentration, on particular input configurations and network connectivities. In contrast, it only depends on the time constant of the inhibitory synapse, which is in agreement with previous studies.

Because the LFP frequency is independent on the applied stimulus (identity and intensity), it defines a 'clock' or a temporal frame of reference for the encoding neurons. If one looks more carefully at particular oscillatory cycles, we see that some E-cells exhibit phase-locked activity while others do not. An E-cell is considered to be phase-locked at a given cycle if it fires within a temporal windows of ε ms around the mean firing time of the E-cell population (typically, ε = 5 ms). The output of an E-cell at each oscillatory cycle is represented as a binary state 1 or 0 depending on whether its firing is phase-locked or not. At each oscillatory cycle, the stimulus is thus characterized by a binary vector lying in a multidimensional space, where each dimension corresponds to the binary state of a given E-cell. We have shown that different simulations of the network for a given stimulus converge to the same representation despite noise and different initial conditions, and that different representations are obtained for different stimuli. A stimulus is thus robustly encoded by the binary code formed by the identity of the phase-locked E-cells, at each oscillatory cycle. Can this binary code be generated by an abstract model using discrete-time dynamics and binary-state neurons? In order to answer this question, we have built an abstract model based on single response probabilities, conditional to field potential oscillations.

6.2.3.3. Mathematical analysis

First, we considered the conditional probability $P(E|k)$ that an E-cell is phase-locked at the current cycle, given it received k inhibitory synaptic events. Using the Chebychev inequality, we derived a lower bound

$$P(E|k) \geq 1 - \frac{1}{\varepsilon^2}\left(\frac{\sigma^2}{k} + \tau^2\left(\ln\frac{k}{<k>}\right)^2\right) \tag{2}$$

where $<k>$ is the mean inhibitory drive, i.e. the mean number of unitary inhibitory post-synaptic currents (IPSCs) received by the E-cells on average at the previous cycle, and σ is the IPSC temporal jitter, i.e. the standard deviation in the occuring times of the inhibitory events.

In the insect AL, we can assume that the inhibitory synaptic events are synchronous (σ small).This is justified both with our simulations, from which we obtained $\sigma \approx 3.5$ ms and with electrophysiological recordings in the locust AL showing a very synchronous I-cell activity ($\sigma \approx 3.8$ ms). Although in the mammal OB, the I-cell activity is less synchronous ($\sigma \approx 22$ ms), the number k of IPSCs received by a particular E-cell at each oscillatory cycle is expected to be large because of the number of I-cells connecting a given E-cell, estimated to be on the order of 10^4. Therefore, both for the AL and the OB, the term σ^2/k is expected to be small and can be neglected in equation (1). Moreover, ε = 5 ms is in the order of the decay time of the inhibitory synapses τ = 6 ms so that the ratio $\tau/\varepsilon \approx 1$. Considering these approximations, the phase-locking probability can be simplified to

$$P(E|k) \approx 1 - \left(\ln \frac{k}{\langle k \rangle}\right)^2 \tag{3}$$

Note that the simplifications made for deriving Eq. (3) necessarily decrease the negative term in Eq. (2). Thus, Eq. (3) is not a lower bound anymore. Eq. (3) is an asymmetric inverted-U function centered on the mean inhibitory drive. We have check numerically that it is a good approximation of the E-cell phase-locking probability. As revealed by a mathematical analysis (not detailed in this report), the firing probability of I-cell is well described by a sigmoid function.

6.2.3.4. Conclusion

The neural response functions derived from the mathematical analysis have been used to reduce the spiking model to a more abstract model with discrete-time dynamics (oscillatory cycles) and binary-state neurons (phase-locked or not). An iterative map, built for explaining the dynamics of the binary model, revealed that it converges to fixed point attractors similar to those obtained with the spiking model. This result is consistent with odor-specific attractors found in recent experimental studies. This work allows us a better understanding of the role of inhibition in shaping oscillatory synchronization in early olfactory systems (AL, OB). For example, we have found that single neuron activity is regulated by the mean activity of the other cells. Such a regulation of the neural response could act as a gain control mechanism. This work also provides insights for designing bio-inspired olfactory associative memories applicable for data analysis in electronic noses. Two lines of research as extension to this work are being pursued. The first one is theoretical; we are investigating how stochastic asynchronous inhibition in the OB can effectively control the spike timing precision of the E-cells and can lead to a temporal evolution in the synchronization pattern. The second one is practical; we are developing an associative olfactory memory built on the ideas derived from our modeling work.

6.3. Data exploitation and interpretation

Participants: Frédéric Alexandre, Shadi Al Shehabi, Mohammed Attik, Laurent Bougrain, Randa Kassab, Jean-Charles Lamirel, Georges Schutz.

This research aims at adapting classical models of connectionism (*cf.* § 3.1) to extend their use to data interpretation and knowledge extraction (*cf.* § 3.2). As we exposed, to improve the performance of neural information processing systems, several approaches can be followed depending of the prior knowledge available. They can be gathered into supervised and unsupervised learnings. Another way to improve the performance is to set up collaborative approaches such as neuro-symbolic systems or commitee machines.

6.3.1. Supervised models

6.3.1.1. Optimization

The determination of the optimal architecture of a supervised neural network is an important and a difficult task. The classical neural network topology optimization methods select weight(s) or unit(s) from the architecture in order to give a high performance of a learning algorithm. However, all existing topology optimization methods do not guarantee to obtain the optimal solution. We proposed a hybrid approach which combines variable selection method and classical optimization method in order to improve optimization topology solution. We proposed a new approach to identify the relevant subset of variables which gives a good classification performance in the first step and then to apply a classical topology optimization method to eliminate unnecessary hidden units or weights. A comparison of our approach to classical techniques for architecture optimization is given [25].

6.3.1.2. Novelty detection

Another supervised learning technique than can be suitably applied to data analysis is under development. It concerns a specific novelty detection model based on the Moore-Penrose projectors. This technique is in its preliminary phase. Nevertheless, our first experiment led us to expect promising result both for user's profile modeling and for the analysis of flows of permanently changing information [33], [34]. This technique is currently used in the framework of the European project Sat-at-Once (*cf.* § 7.3). In this project, which is related to information filtering, it is specifically combined with collaborative filtering techniques. We are currently working on the adaptation of our filtering technique to more general filtering tasks, like filtering of data that can be associated with multiple labels. This has led us to change the learning principle of our novelty detection model in order to adapt it to cumulative learning. Our first experimental results have proven the accuracy of this adaptation, as soon as the adapted filtering method outperforms all the reference methods, including SVM methods on the well-known Reuters test collection.

6.3.2. Unsupervised models

6.3.2.1. Optimization

The solution obtained by Self-Organizing Map (SOM) strongly depends on the initial cluster centers. However, all existing SOM initialization methods do not guarantee to obtain a better minimal solution. Generally, we can group these methods in two classes: random initialization and data analysis based initialization classes. We proposed an improvement of linear projection initialization method. This method belongs to the second initialization class. Instead of using regular rectangular grid our method combines a linear projection technique with irregular rectangular grid. By this way the distribution of results produced by the linear projection technique is considered. The experiments confirm that the proposed method gives better solutions compared to its original version [26].

Our former comparison between topographic methods has highlighted the superiority of Neural Gas as compared to other topographic methods, like SOM or Growing Neural Gas, for information analysis. Hence, the Neural Gas method appeared to be the most stable one for information analysis which are conducted on a small number of classes when data are sparse, like documentary ones. Taking these latter results into account the adaptation of the Neural Gas model to a MultiGas model has been in deeply studied this year. It has lead to define a specific Gas generalization model which is based on a triangulation approach. The comparison of the Gas generalization mechanism to our previously proposed SOM generalization mechanism has provided a new proof of the better overall performance of the Neural Gas model as compared to the SOM model. It has also highlighted the lower sensitivity of the Neural Gas model to the presence of outliers in the dataset [21].

6.3.2.2. Knowledge extraction

We are currently working on the extension of the original measures of cluster properties recall and cluster properties precision to more general measures based on cluster properties recall entropy and cluster properties precision entropy. Some preliminary experiments have shown that this new approach can be useful in the domain of unsupervised clustering. Hence, it leads to obtain more accurate results in the task of determining optimal clustering model for a given dataset. Moreover, it can be used for model learning optimization. Last but not least, this new method can be suitably adapted to the task of cluster label analysis as well as to the task of automatic cluster labeling.

The limitations of the numerical classification methods, like MicroNOMAD-MultiSOM, are related to the errors of interpretation that they may generate as soon as they are used without preliminary care by non-specialists for the precise analysis of a given domain. On their own side, symbolic methods when they are used for the same goal present the limitation to deliver results of unmanageable size. After having set up a matching mechanism between Galois lattice and SOM maps and having defined a symbolic evaluation criterion, like cluster properties recall and cluster properties precision, for measuring the quality of numerical classification, we are pursuing our studies about the complementarities that can exist between the two types of methods. This year we have developed a new principle of knowledge extraction that consists in using an unsupervised neural network as a front-end for extracting rules. An unsupervised neural network copes with the problem of rules inflation that is inherent to symbolic methods because of its synthesis capabilities that can be used both for reducing the number of rules and for selecting the most significant ones. Moreover, the rule extraction is facilitated as soon as multi-viewpoint unsupervised neural network model with low topologic constraints and including generalization, like the Multigas model we have already proposed, is used. The experiment we have conduced this year have proven both the soundness and the efficiency of such an approach [20], [37]. In the near future we plan to develop more elaborated algorithms in order to extract complex rules. Moreover, we also plan to develop new methodologies of rule ranking based on specific numerical information, like entropy. Hence, such information can be derived both from the local and from the overall properties of the rule components. It is expected to provide more accurate results than the classical ranking mechanism based on rule support and confidence. We have successfully experimented all the former techniques in the framework of different webometrics and scientometrics experiments [36]. These techniques also permit us to suitably compare the behavior of our model with the one of more classical network analysis model. We are currently investigating this latter point.

We have also pursued of work of extending classical unsupervised methods like Kohonen's map to temporal signal processing and knowledge extraction, particularly in the framework of collaboration with biophysics and medicine for EEG signal interpretation (*cf.* § 7.4).

6.3.2.3. Visualization techniques for data analysis

Our new MultiGas approach also led us to focus on information visualization techniques for representing relationships between classes initially defined in highly multidimensional spaces. Hence, one of our important alleys of research has been an original hyperbolic visualization model based on the definition of hierarchies of Gas clusters. The main advantage of such technique, as compared to classical graph-based techniques or non linear projection techniques is that it suppresses cognitive overload while preserving the most important relationships between the data. Such advantages have been clearly proven through an experiment that has been conduced on data issued from the EISCTES project [36](*cf.* § 7.3).

6.3.3. Neuro-Symbolic systems

We discussed the properties of a neuro-symbolic system named HLS (Hybrid Learning System). HLS System has modules able to carry out a bidirectional transfer of information between a symbolic system and a connexionnist system. Various experiments highlight various strong points of HLS such are: the capacity to integrate theoretical knowledge (rules) and empirical knowledge (examples), the capacity to take initial knowledge (rules) to convert it into a connexionnist network, to use empirical knowledge which by training can refine theoretical knowledge, to acquire new knowledge and to clarify it, and finally, the capacity to improve the performance of a simple symbolic or connexionnist systems alone [27].

We have also proposed this year a new model of information retrieval system which takes into account that knowledge about documents and information need of users are dynamic. Two methods are combined, one qualitative or symbolic and the other quantitative or numeric. In this model, they are introduced to build "long term" knowledge about past queries and concepts in a collection of documents. The "long term" knowledge can guide and assist the user to formulate an initial query and can be exploited in the process of retrieving relevant information. The different kinds of knowledge are organized in different points of view. This may be considered an enrichment of the exploration level which is coherent with the concept of document/query structure. The model has been successfully tested on the Cranfield test-collection [32], [31].

6.3.4. Committee machines

One recent point of interest is the strength of weak learnability. Indeed, artificial neural network methods are not stable in the sense that models built are influenced by small disturbances of the training patterns or the random initialization. Unstable machine learning techniques can be improved combining a set of unstable models built using small disturbances. We developed new techniques of perturbation and combination taking into account the weaknesses and the strengths of classical boosting methods such as bagging, arcing and boosting techniques. More precisely, we studied how these methods deal with unbalanced classes into discrimination problems. Arcing and boosting techniques use an incremental procedure to generate a new expert taking into account the errors of the already defined experts duplicating automatically misclassified patterns. Nevertheless, this exponential replication is too strong and have to be reduced. Thus, we defined a short-term memory to reduce to the responses of the most recent experts the influence of the duplication. We added these method within our decision making application. Now, in the same way that Breiman improved successfully the capabilities of decision trees defining random forests, we wish to introduce a diversity selecting accurately a different subset of variables for each model of the ensemble. To prepare this work, we studied variable selection in a more general way looking at more embedded methods but also wrapper and filter methods.

6.4. Hardware implementations

Participants: Khaled Ben Khalifa, Bernard Girau, Cesar Torres-Huitzil.

Three main axes appear in our study of connectionist parallelism in conjunction with reconfigurable digital hardware: new hardware-adapted frameworks of neural computation, dedicated embeddable implementations, and automatic neural synthesis on FPGAs.

Many neural implementations on FPGAs handle simplified neural computations. Furthermore, many efficient implementation methods (on ASICs, neuro-computers, etc) have to limit themselves to few well-fitted neural architectures. An upstream work is preferable: neural computation paradigms may be defined to counterbalance the main implementation problems, and the use of such paradigms naturally leads to neural models that are more tolerant of hardware constraints. In this domain, our main contribution is the definition and application of the FPNA paradigm (Field Programmable Neural Array): this hardware-adapted framework of neural computation leads to powerful neural architectures that are easy to map onto FPGAs, by means of a simplified topology and an original data exchange scheme. This work is now mature and current studies intend to include it both in embedded low-power implementations (it has been recently applied to our works about embeddable vigilance detection) and in the technological solutions that will be handled by our automatic neural synthesis tool (*cf.* § 5.5).

In the field of dedicated embeddable neural implementations, we use our expertise in both neural networks and FPGAs so as to propose efficient implementations of applied neural networks on FPGAs. We both handle neural models that are still in a research process and neural networks that are applied to concrete problems. Recent works in this axis have mainly focused on the implementation of the first two layers of our bio-inspired model for motion perception [44], [16], [45].

The third axis is the development of a generic synthesis tool to fully automatically specify, parameterize and implement neural networks on FPGAs. This work has been detailed in § 5.5.

7. Other Grants and Activities

7.1. Regional initiatives

7.1.1. Collaboration with INIST

Participants: Randa Kassab, Jean-Charles Lamirel, Shadi Al Shehabi.

The goal of this collaboration is to propose neural models for the creation of easily interpretable representations issued from very big documentary databases. The main characteristic of this problem is that the size of the data description space is important (large set of keywords), but it contains only a small number of representative examples. We firstly work on the detection of the best data projection subspaces and we then pursued the extraction and the representation of concepts that provide a reliable interpretation of the database content.

A significant advancement in this area concerns new adaptation of singular value decomposition techniques for data selection and cleaning. Other neural solutions we are working on are the ones that can be applied for detecting marginal documents or marginal tendencies in a very big documentary database. The approach we have proposed is based on the experimentation of different kinds of neural projectors implementing novelty detection functions. The domain of application of the solutions described above is the analysis of the relations between the different laboratories of the academic domain. Our study combines in a parallel way analysis of the content of the Web pages belonging to the academic institutions and the analysis of the hyperlinks that are embedded in these pages. The multi-viewpoint techniques we deal with not only allow us to highlight correlations between actors and research themes, but also inter-actor correlations and inter-thematic correlations. This year has also been focused on comparison of our technique with concurrent techniques of collaboration network analysis.

7.1.2. *Action Teleoperation and Intelligent Assistants of the CPER*

Participants: Frédéric Alexandre, Hervé Frezza-Buet, Dominique Martinez, Nicolas Rougier, Julien Vitay.

In the framework of the Contrat de Plan État Région, we are contributing to the project Teleoperation and Intelligent Assistants, whose goal is to study systems for the monitoring of industrial processes. More specifically, our role is to develop a biologically inspired connectionist system for visual perception and to integrate it on an autonomous robot.

7.2. National initiatives

7.2.1. *Exploitation of Geographical Information Systems*

Participants: Frédéric Alexandre, Mohammed Attik, Laurent Bougrain.

Our collaboration with the BRGM (the french geological survey) intends to study how neural networks can be used efficiently in a practical problem of mineral exploration, where general domain knowledge alone is insufficient to satisfactorily model the potential controls on deposit formation using the available information in continent-scale information systems. The BRGM is interested by the understanding of the formation of ore deposits (precious and base metals) and the contribution to the exploration and discovery of new occurrences using artificial neural networks and specially artificial neural networks which are able to construct a revised model for knowledge extraction. We have applied our new algorithms (*cf.* § 6.3) on this problem.

7.2.2. *Ministry Grant "New analytic methodologies and sensors" SAWCapt*

Participant: Dominique Martinez.

Because of the simplicity and compactness of hardware implementation, spiking neurons are very appealing for addressing embedded systems for robotics or portable low-power smart sensors in vision or olfaction. The objective of the SAWCapt project is to develop a spiking neural network capable of solving the non-selectivity problem encountered in gas sensors and to consider its use for designing an electronic nose featuring small size and low cost of fabrication. This research project, in collaboration with the Laboratoire de Physique des Milieux Ionisés et Applications in Nancy, will develop and broaden knowledge in both software implementation of olfactory neuromorphic systems and pattern recognition algorithms as well as hardware implementation of smart sensing applied to an electronic nose.

7.2.3. *Ministry Grant Systèmes Complexes pour les Sciences Humaines et Sociales*

Participant: Arnaud Tonnelier.

Our studies in theoretical neuroscience address the dynamics at the cellular and network level. In order to investigate the related cognitive functions, we are interested in modeling the psychological processes and revealing the underlying neural substrate. In a recent paper [12], the fundamental question of space and time dependencies is studied using a mathematical model. In this multidisciplinary project, in collaboration with M.D. Giraudo (MCF, UMR Mouvement et Perception) and V. Kostrubiec (MCF, Adaptation percepto-motrice et Apprentissage, Toulouse), we investigate the dynamic phenomena in the memory representation. We plan to study emergent states using both modeling and experiments.

7.2.4. Convention with the Museum of La Villette

Participant: Jean-Charles Lamirel.

This project deals with intelligent access to the collections of the museum, with the interest to multiply user's views on these collections and also to led historians and administrators to discover unexpected links between the objects exposed in the collections. The central idea we apply for that goal is the coupling of two different classification methods both for visualizing the collection of objects, for constructing viewpoints on these objects, for constructing object subsets with variable level of granularity, and lastly for highlighting correlation between some of the properties of the objects. This approach represents a collaboration between the Cortex team and the Orpailleur team who deals with the Galois lattice classification technique. The work of this year consisted in finalizing the multi-criteria classification approach on 3-dimensional representations of the object of the collections. The goal of this new approach, that as been initiated last year, is to dynamically highlight relation between the objects depending on the current view a user has of an object at a given time.

7.2.5. Ministry Grant RNTL: Project LIRENET

Participant: Jean-Charles Lamirel.

The domain of application of this project is the domain of electronic encyclopaedia. It consists in providing an electronic encyclopaedia with on-line capabilities of integration of information issued from the Web. Such knowledge will thus act as complementary knowledge on areas that have been already queried by users. It will be then be dynamically classified in the reference model used by the encyclopaedia for its own knowledge. The starting date of this project will be at end of 2005. The project will make use of all our recent research developments in supervised and unsupervised classification.

7.3. European initiatives

7.3.1. Project IST MirrorBot

Participants: Frédéric Alexandre, Hervé Frezza-Buet, Olivier Ménard, Nicolas Rougier, Julien Vitay.

This project from the European initiative FET (Future Emergent Technology) gathers INRIA-Lorraine, Sunderland University, Parma University, Ulm University and the Cognition and Brain Sciences Unit in Cambridge. Its main topic is biologically inspired multimodal neuronal learning for an autonomous robot acting on, perceiving, and representing the world, as described in (*cf.* § 6.1).

More information is available at http://www.his.sunderland.ac.uk/mirrorbot/.

7.3.2. NoE GOSPEL

Participant: Dominique Martinez.

GOSPEL (General Olfaction and Sensing Projects on a European Level) is a Network of Excellence (NoE) under funding of the European Commission in the 6th framework programme.

The aim of GOSPEL is to structure the European research in the field of Artificial Olfaction with the declared goal of establishing Europe as a world leader in this field. The leadership shouldn't be limited just to the scientific understanding, as it happened many times in the past, but expand into the technological development and commercial exploitation.

More information is available at http://www.gospel-network.org.

7.3.3. IST Project EICSTES

Participants: Jean-Charles Lamirel, Shadi Al Shehabi.

The goal of this project is to set up both indicators and methods for the analysis of the Web data. The data that are managed in the framework of the project concern the Web pages of the institutional Web sites as well as the log files associated to the different servers and services provided by the institutions. The project covers a large scope of competence because it enhances collaborations between statisticians, social scientists and computer scientists. The MicroNOMAD-MultiSOM method (*cf.* § 5.4) is one of the two reference methods of the project. After increasing the genericity of MicroNOMAD-MultiSOM method in order to adapt it to the context of the project, we have shown that it is particularly adapted for data analysis based on the textual content of Web pages. We have worked with social scientists in order to relate the results of co-links analysis obtained with the other reference method of the project with the results of thematic analysis obtained by our method. A second task we have participated in this project is to establish a state of the art of the different methods of visualisation that are available for the information analysts. The panel of studied methods should be large and therefore not only concern neural methods. The project successfully finished this year.

7.4. International cooperation

7.4.1. European Project SAT-At-ONCE

Participants: Jean-Charles Lamirel, Randa Kassab.

The goal of the SAT-At-ONCE project is to propose a unified user-oriented environment for accessing to multiple satellite services. Our role in this project is to set-up a personalised user-filtering system for a specific service of Web contents delivery. The LORIA part of this project is achieved in cooperation with the Maia team. The SAT-At-ONCE project started officially in September 2004. It is now in its finalization phase. The resulting filtering system that we have proposed is based both on analysis of common behaviour of user's groups (collaborative filtering) and on analysis of individual behaviour of each user (content-based filtering). Moreover, the system is able to adapt to an overall evolution of the Web content by providing users with new proposal concerning upcoming Web sites. The Cortex team has played a major role in the construction of individual user's profiles by the use of techniques based on novelty detection and intelligent adaptive relevance feedback. The team has also played an important role in Web data contents analysis and validation of upcoming Web site proposals. The produced system is now in its evaluation phase.

7.4.2. PAI Procore with Hong Kong

Participant: Dominique Martinez.

The PAI Procore will last from January 2004 until december 2005 with EE Dept. Hong Kong University of Science and Technology (HKUST) on the topic “Electronic Nose Microsystem based on an array of gas sensors and advanced pattern recognition algorithms”.

The overall aim of this joint research project is to investigate advanced and robust pattern recognition algorithms applied to electronic nose applications.

7.4.3. Common project with Tunisia

Participants: Frédéric Alexandre, Khaled Ben Khalifa, Laurent Bougrain, Bernard Girau, Nizar Kerkeni.

We are working with the faculty of medicine in Monastir on physiological signal interpretation (EEG, EMG, EOG). On the one hand, we have developed a connectionist system able to discriminate vigilance states with a good accuracy. We have laid emphasis this year on artefact detection. This system has been implemented on an FPGA, to get a light and easy-to-wear system. On the other hand, we are working with physiologist physicians to better understand sleep and associated pathologies. Accordingly, we have studied the human expertise on the topic [24] and we have tried this year to discriminate the different stages of sleep with self organizing maps [35], [4].

7.4.4. Joint venture INRIA-NSC Taiwan

Participant: Jean-Charles Lamirel.

The domain of application of this project is the analysis of gene-sickness interactions through the use of textual information analysis [40]. The information to be analysed takes the form of full text reports, each one being issued from a specific biological experiment. The role of the Cortex team is to provide flexible methods of data analysis and knowledge extraction in order to solve the gene-sickness interactions problem relatively to such kind of data. This problem is mainly characterized by the high dimensionality of the generated data description space. Our approach is thus all together based on the MicroNOMAD-MultiSOM model, on the recently developed MultiGAS model and on the methods of similarity computation in the highly multidimensional spaces developed in our team. We are currently working on the operational implementation of a model that will be itself integrated in a more general platform of bioinformatics.

7.4.5. Joint venture with Dalian university

Participant: Jean-Charles Lamirel.

The domains of application of this project are the scientometrics and the webometrics domains. It consists in setting up and supervising a new research team in these domains. This project is in a starting phase at the University of Technology of Dalian (DUT), China. The collaboration will include high level teaching, research exchange and PhD student research project management. On the Cortex side, the focus will be put on the use of the recent research results of the team in the domains of unsupervised clustering, knowledge extraction and hyperbolic visualization. A first teaching session has been already achieved this year [39], [38]. New teaching sessions will be achieved in the beginning of the year 2006 in parallel with the start of student research projects. This joint venture also implies a complementary collaboration with the University of Social Sciences in Berlin.

8. Dissemination

8.1. Leadership within the scientific community

- Head of the Network Grand-Est for Cognitive Science; member of the piloting committee of the CNRS UMS RISC (F. Alexandre)
- Reviewing for journals: Neural computation, Sensors and Actuators B (D. Martinez); European Physical Journal B, SIAM J. Appl. Math. (A. Tonnelier); IEEE Systems, Man and Cybernetics - Part B (F. Alexandre); Journal of Applied Research and Technology (B. Girau).
- Member of program comittee: TAIMA'05, CAP'05 (F. Alexandre)
- Session Chair for session “Signal Processing” at BioMED 2005 (IASTED conference, feb. 2005, F. Alexandre); for the 10th ISSI-COLLNET Conference, Stockholm, July 2005 (J.C. Lamirel); for session "Neuromorphic Hardware" at IJCNN'05 (Cesar Torres).
- Invited talk at ISOEN (International Symposium on Olfaction and Electronic Nose), Barcelone, 13-15 April 2005 (D. Martinez) [43], 7th colloque of the french neurosciences society, lille, 17-20 May 2005 (F. Alexandre) [22]; TAIMA'05 (F. Alexandre) [23], 2 talks at Scientometrics, November, Dalian, China (J.C Lamirel) [39], [38].
- expertise for the Netherlands Organisation for Scientific Research (NWO, the Dutch research council) and for the European Science Foundation (F. Alexandre)

8.2. Teaching

- Courses given at different levels (DEA, DESS, IUT, Licence-Maîtrise) in computer science in Nancy and Strasbourg by most team members;
- Member of PhD defense committees (F. Alexandre, D. Martinez, J.C. Lamirel);
- Co-supervision of PhD in Tunisia (J.-C. Lamirel, F. Alexandre).

8.3. Miscellaneous

- Participation to a one hour long documentary film for french TV in a series “Sciences and Philosophy” entitled “The sciences of the mind” (January 2005, F. Alexandre); live demonstration of a behaving robot during the news on french TV (France3) during “Fête de la Science” in October 2005 (J. Vitay).
- Participation to a public “café scientifique” about artificial intelligence (F. Alexandre, October 2005)
- Participation to an exposition of cognitive software development (L. Bougrain and M. Tonnelier) to present our software (*cf.* § 5.3).

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