INRIA

Project-Team flowers

Flowing Epigenetic Robots and Systems : Developmental and Social Robotics

Bordeaux - Sud-Ouest

Theme : Robotics

Activity Report

2010

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2. Overall Objectives

2.1. Introduction

Can a robot learn like a child? Can it learn new skills and new knowledge in an unknown and changing environment? How can it discover its body and its relationships with the physical and social environment? How can its cognitive capacities continuously develop without the intervention of an engineer? What can it learn through natural social interactions with humans?

These are the questions that are investigated in the FLOWERS research team at INRIA Bordeaux Sud-Ouest. Rather than trying to imitate the intelligence of adult humans like in the field of Artificial Intelligence, we believe that trying to reconstruct the processes of development of the child's mind will allow for more adaptive, more robust and more versatile machines. This approach is called developmental robotics, or epigenetic robotics, and imports concepts and theories from developmental psychology. As most of these theories are not formalized, this implies a crucial computational modeling activity, which in return provides means to assess the internal coherence of theories and sketch new hypothesis about the development of the human child's sensorimotor and cognitive abilities.

Our team focuses in particular on the study of developmental constraints that allow for efficient open-ended learning of novel skills. In particular, we study constraints that guide exploration in large sensorimotor spaces:

- Mechanisms of intrinsically motivated exploration and learning, including artificial curiosity;

- Mechanisms for social learning, e.g. learning by imitation or demonstration, which implies both issues related to machine learning and human-robot interaction;

- Constraints related to embodiment, in particular through the concept of morphological computation, as well as the structure of motor primitives/muscle synergies that can leverage the properties of morphology and physics;

- Maturational constraints which, coupled with the other constraints, can allow the progressive release of novel sensorimotor degrees of freedom to be explored;

We also study how these constraints on exploration can allow a robot to bootstrap multimodal perceptual abstractions associated to motor skills, in particular in the context of modelling language acquisition as a developmental process grounded in action.

Among the developmental principles that characterize human infants and can be used in developmental robots, FLOWERS focuses on the following three principles:

- **Exploration is progressive.** The space of skills that can be learnt in real world sensorimotor spaces is so large and complicated that not everything can be learnt at the same time. Simple skills are learnt first, and only when they are mastered, new skills of progressively increasing difficulty become the behavioural focus;

- **Internal representations are (partially) not innate but learnt and adaptive.** For example, the body map, the distinction self/non-self and the concept of "object" are discovered through experience with initially uninterpreted sensors and actuators;

- **Exploration can be self-guided and/or socially guided.** On the one hand, internal and intrinsic motivation systems regulate and organize spontaneous exploration; on the other hand, exploration can be guided through social learning and interaction with caretakers.

2.1.1. Research axis

The work of FLOWERS is organized around the following three axis:

- **Intrinsically motivated exploration and learning:** intrinsic motivation are mechanisms that have been identified by developmental psychologists to explain important forms of spontaneous exploration and curiosity. In FLOWERS, we try to develop computational intrinsic motivation systems and test them on robots, allowing to regulate the growth of complexity in exploratory behaviours. These mechanisms are also studied as active learning mechanisms, allowing to learn efficiently in large inhomogeneous sensorimotor spaces;

- **Natural and intuitive social learning:** FLOWERS develops interaction frameworks and learning mechanisms allowing non-engineer humans to teach a robot naturally. This involves two sub-themes: 1) techniques allowing for natural and intuitive human-robot interaction, including simple ergonomic interfaces for establishing joint attention; 2) learning mechanisms that allow the robot to use the guidance hints provided by the human to teach new skills;

- **Discovering and abstracting the structure of sets of uninterpreted sensors and motors:** FLOWERS studies mechanisms that allow a robot to infer structural information out of sets of sensorimotor channels whose semantics is unknown, such as for example the topology of the body and the sensorimotor contingencies (proprioceptive, visual and acoustic).

2.2. Highlights of the year

The Acroban humanoid robot, which building was lead by Olivier Ly, was presented at SIGGRAPH'2010 in Los Angeles, US, as a live demonstration in the Emergent Technologies section. This demonstration, showing new capabilites in terms of dynamic locomotion as well as robust and intuitive human-robot physical interaction, attracted a lot of interest both by the scientific/technological audience and by the general public on the web. Several invitations to give presentations in seminars, conferences and science museums followed. A dedicated web page with videos is available at: http://flowers.inria.fr/acroban.php.

The FLOWERS team conducted a large-scale real world experiment on human-robot social interaction in Cap Science museum in Bordeaux, France. This involved live running of the robots, interacting with visitors, for more than 25 days. This allowed both to collect stimulating scientific results and to communicate our research to the general public.

Pierre-Yves Oudeyer and Olivier Ly were invited researchers at IHES, Bures-sur-Yvette, France, for one week by Mikhail Gromov.

Adrien Baranes and Pierre-Yves Oudeyer introduced a model of competence-based intrinsic motivation coupled with maturational constraints, allowing efficient acquisition of novel skills through the use of parameterized motor primitives.

Manuel Lopes and Pierre-Yves Oudeyer guest edited a special issue of IEEE Transactions on Autonomous Mental Development on active learning and intrinsically motivated exploration in robots.

The ERC starting grant EXPLORERS project began.

FLOWERS was part of an accepted ANR project (MACSi), leaded by University Paris VI/ISIR, which will start in 2011.

3. Scientific Foundations

3.1. Scientific Foundations

Research in artificial intelligence, machine learning and pattern recognition has produced a tremendous amount of results and concepts in the last decades. A blooming number of learning paradigms - supervised, unsupervised, reinforcement, active, associative, symbolic, connectionist, situated, hybrid, distributed learning... - nourished the elaboration of highly sophisticated algorithms for tasks such as visual object recognition, speech recognition, robot walking, grasping or navigation, the prediction of stock prices, the evaluation of risk for insurances, adaptive data routing on the internet, etc... Yet, we are still very far from being able to build machines capable of adapting to the physical and social environment with the flexibility, robustness, and versatility of a one-year-old human child.

Indeed, one striking characteristic of human children is the nearly open-ended diversity of the skills they learn. They not only can improve existing skills, but also continuously learn new ones. If evolution certainly provided them with specific pre-wiring for certain activities such as feeding or visual object tracking, evidence shows that there are also numerous skills that they learn smoothly but could not be "anticipated" by biological evolution, such as for example learning to drive a tricycle, using an electronic piano toy or using a video game joystick. On the contrary, existing learning machines, and robots in particular, are typically only able to learn a single pre-specified task or a single kind of skill. Once this task is learnt, for example walking with two legs, learning is over. If one wants the robot to learn a second task, for example grasping objects in its visual field, then an engineer needs to re-program manually its learning structures: traditional approaches to task-specific machine/robot learning typically include engineer choices of the relevant sensorimotor channels, specific design of the reward function, choices about when learning begins and ends, and what learning algorithms and associated parameters shall be optimized.

As can be seen, this makes a lot of important choices from the engineer, and one could hardly use the term "autonomous" learning. On the contrary, human children do not learn following anything looking like that process, at least during their very first years. Babies develop and explore the world by themselves, focusing their interest on various activities driven both by internal motives and social guidance from adults who only have a folk understanding of their brains. Adults provide learning opportunities and scaffolding, but eventually young babies always decide for themselves what activity to practice or not. Specific tasks are rarely imposed to them. Yet, they steadily discover and learn how to use their body as well as its relationships with the physical and social environment. Also, the spectrum of skills that they learn continuously expands in an organized manner: they undergo a developmental trajectory in which simple skills are learnt first, and skills of progressively increasing complexity are subsequently learnt.

A grand challenge is thus to be able to build robotic machines that possess this capability to discover, adapt and develop continuously new know-how and new knowledge in unknown and changing environments, like human children. In 1950, Turing wrote that the child's brain would show us the way to intelligence: "Instead of trying to produce a program to simulate the adult mind, why not rather try to produce one which simulates the child's" [64]. Maybe, in opposition to work in the field of Artificial Intelligence who has focused on mechanisms trying to match the capabilities of "intelligent" human adults such as chess playing or natural

language dialogue [44], it is time to take the advice of Turing seriously. This is what a new field, called developmental (or epigenetic) robotics, is trying to achieve [48] [66]. The approach of developmental robotics consists in importing and implementing concepts and mechanisms from developmental psychology [50], cognitive linguistics [37], and developmental cognitive neuroscience [47] where there has been a considerable amount of research and theories to understand and explain how children learn and develop. A number of general principles are underlying this research agenda: embodiment [33] [52], grounding [42], situatedness [28], self-organization [62] [53], enaction [65], and incremental learning [35].

Among the many issues and challenges of developmental robotics, two of them are of paramount importance: exploration mechanisms and mechanisms for abstracting and making sense of initially unknown sensorimotor channels. Indeed, the typical space of sensorimotor skills that can be encountered and learnt by a developmental robot, as those encountered by human infants, is immensely vast and inhomogeneous. With a sufficiently rich environment and multimodal set of sensors and effectors, the space of possible sensorimotor activities is simply too large to be explored exhaustively in any robot's life time: it is impossible to learn all possible skills. Moreover, some skills are very basic to learn, some other very complicated, and many of them require the mastery of others in order to be learnt. For example, learning to manipulate a piano toy requires first to know how to move one's hand to reach the piano and how to touch specific parts of the toy with the fingers. And knowing how to move the hand might require to know how to track it visually.

Exploring such a space of skills randomly is bound to fail or result at best on very inefficient learning [8]. Thus, exploration needs to be organized and guided. The approach of epigenetic robotics is to take inspiration from the mechanisms that allow human infants to be progressively guided, i.e. to develop. There are two broad classes of guiding mechanisms which control exploration:

Psychologists have identified two broad classes of guiding mechanisms which control exploration:

1. **internal guiding mechanisms,** and in particular intrinsic motivation, responsible of spontaneous exploration and curiosity in humans, which is one of the central mechanisms investigated in FLOWERS, and technically amounts to achieve on-line active self-regulation of the growth of complexity in learning situations;

2. **social learning and guidance,** which exists in many different forms like emotional reinforcement or imitation, some of which being also investigated in FLOWERS;

3.1.1. *Internal guiding mechanisms.*

In infant development, one observes a progressive increase of the complexity of activities with an associated progressive increase of capabilities [50], children do not learn everything at one time: for example, they first learn to roll over, then to crawl and sit, and only when these skills are operational, they begin to learn how to stand. Development is progressive and incremental, and this might be a crucial feature explaining the efficiency with which children explore and learn so fast. Taking inspiration from these observations, some roboticists and researchers in machine learning have argued that learning a given task could be made much easier for a robot if it followed a developmental sequence and "started simple" [29] [41]. However, in these experiments, the developmental sequence was crafted by hand: roboticists manually build simpler versions of a complex task and put the robot successively in versions of the task of increasing complexity. And when they wanted the robot to learn a new task, they had to design a novel reward function.

Thus, there is a need for mechanisms that allow the autonomous control and generation of the developmental trajectory. Psychologists have proposed that intrinsic motivations play a crucial role. Intrinsic motivations are mechanisms that push humans to explore activities or situations that have intermediate/optimal levels of novelty, cognitive dissonance, or challenge [32] [38] [40]. The role and structure of intrinsic motivation in humans have been made more precise thanks to recent discoveries in neuroscience showing the implication of dopaminergic circuits and in exploration behaviors and curiosity [39] [45] [61]. Based on this, a number of researchers have began in the past few years to build computational implementation of intrinsic motivation [8][9] [59] [31] [46] [49] [60]. While initial models were developed for simple simulated worlds, a current challenge is to manage to build intrinsic motivation systems that can efficiently drive exploratory behaviour

in high-dimensional unprepared real world robotic sensorimotor spaces [9][8] [51] [58] . Specific and complex problems are posed by real sensorimotor spaces, in particular due to the fact that they are deeply inhomogeneous: for example, some regions of the space are often unlearnable due to inherent stochasticity or difficulty. In such cases, heuristics based on the incentive to explore zones of maximal unpredictability or uncertainty, which are often used in the field of active learning [36] [43] typically lead to catastrophic results. In FLOWERS, we aim at developing intrinsically motivated exploration mechanisms that scale in those spaces.

3.1.2. *Socially guided learning.*

Social guidance is as important as intrinsic motivation in the cognitive development of human babies [50]. There is a vast literature on mechanisms allowing a human to socially guide a robot towards the learning of new sensorimotor skills [54]. Yet, many existing experiments focus either on only intrinsically motivated exploration [8] [31], or only socially guided exploration with imitation, demonstration or social cheering [34] [30]. Only few attempts, such as in [63], have been tried to couple intrinsic motivation and social learning. In FLOWERS, we work on developing advanced mechanisms for coupling social learning and state-of-the-art intrinsic motivation systems.

4. Application Domains

4.1. Application Domains

- **Personal robotics.** Many indicators show that the arrival of personal robots in homes and everyday life will be a major fact of the 21st century. These robots will range from purely entertainment or educative applications to social companions that many argue will be of crucial help in our aging society. For example, UNECE evaluates that the industry of entertainment, personal and service robotics will grow from $5.4Bn to $17.1Bn over 2008-2010. Yet, to realize this vision, important obstacles need to be overcome: these robots will have to evolve in unpredictable homes and learn new skills while interacting with non-engineer humans after they left factories, which is out of reach of current technology. In this context, the refoundation of intelligent systems that developmental robotics is exploring opens potentially novel horizons to solve these problems.

- **Video games.** In conjunction with entertainment robotics, a new kind of video games are developing in which the player must either take care of a digital creature (e.g. Neopets), or tame it (e.g. Nintendogs), or raise/accompany them (e.g. Sims). The challenges entailed by programming these creatures share many features with programming personal/entertainment robots. Hence, the video game industry is also a natural field of application for FLOWERS.

5. Software

5.1. UFlow

Participants: Olivier LY, Jérôme Béchu [correspondant], Pierre-Yves OUDEYER.

We developed some new UObject to enrich the UFlow Toolbox. The UFlow Toolbox is a collection of various software modules for programming and scripting robot sensorimotor loops, aimed at allowing rapid prototyping in the FLOWERS team, and integrated in the URBI framework. URBI, developed by GOSTAI, supports the integration of heterogeneous robotic software modules. It uses a dynamic scripting language, which manages parallel and event processing. Each module, called UObject, is written in C++.

UBreve is an UObject to control a 3D simulation based on ODE and the Breve software. We developed a system of sensors and effectors to actuate the simulation. We used Breve as the 3D simulation software http://www.spiderland.org/. These simulations are used to test the developmental learning algorithm developed in the team. We created some basic experimental setups involving:

- A quadruped robot with 12 degrees of freedom;
- A fishing robot with a spinning rod that can reach a particular point of the scene;
- A simple robot with two arms to touch and move objects;

The UBreve software is based on multiple layers. We implemented a python TCP server to communicate with this UObject. Then, another connection is used between the UBreve UObject and MATLAB for example.

UBioloid is another URBI UObject used to control uniformly several kinds of Dynamixel motors (AX12, RX28, RX64) via the MMNET Board. This software implements a TCP Protocol to set and update motors properties.

UGui is a basic graphic UObject for graphical plotting and rendering written in c++. It is based on the sfml library. This new version runs on more platforms than the previous one (OS X, Linux, Windows).

5.2. RoboDrive

Participants: Pierre Rouanet [correspondant], Pierre-Yves Oudeyer.

RoboDrive is a software which allows mobility during the interaction with a robot. By looking at the screen, the user can see what the robot is looking at. He can also drive the robot by sketching on the touch-screen using the stylus. Then, specific gestures are used to draw the attention of the robot towards new objects, and the software allows the user to associate a name to these objects. Moreover, the software allows the user to ask the robot to search and reach an object given its name/the word associated to it. Finally, the softwares provides a menu to trigger pre-programmed robot's behavior.

RoboDrive is based on an iPhone in order to use its multiple-interaction and multi-touch abilities and with the mid-term aim of making the software available to a larger audience. It is also providing interesting functionalities, such as driving the robot by litterally using the iPhone as a steering wheel (with the accelerometer). The interface has been designed based on iPhone API, making it much simpler and easy to use.
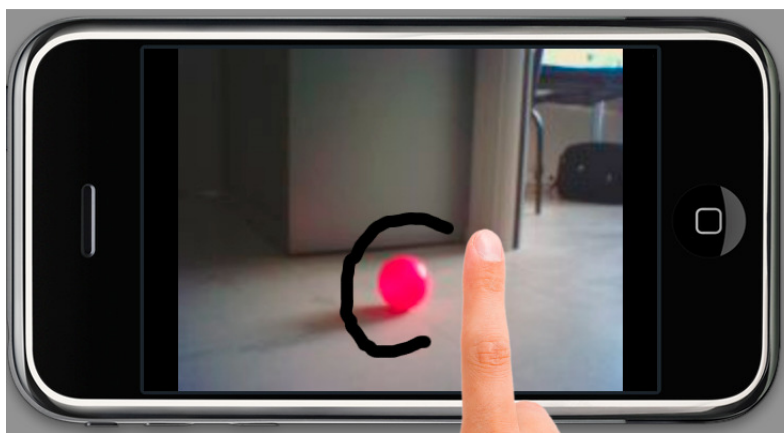

Figure 1. RoboDrive is an iPhone application that facilitates intuitive and robust human-robot teaching interactions

Users can also launch specific behavior such as "say hello", "point", "sit", etc...

As mentioned above, this software allows users to associate names with new visual objects and so the interface has been designed to allow users and especially non-expert users to really provide the robot with good learning examples. Thus, when the user wants to teach a name for a new object, he first needs to encircle the object directly on the screen which provides a rough, but still very useful, segmentation of the image.

The software was also linked to a visual recognition and machine learning framework to allow a robust and fast recognition of any object. This framework is based on the bags of visual approach where lots of visual descriptors such as SIFT of SURF descriptor are extracted from an image or here only a portion of an image. These descriptors are then clustered into words and add to a vocabulary. Then we can use statistical methods based on the frequency of these words to recognized objects.

5.3. WoZRemoteControl

Participants: Pierre Rouanet [correspondant], Fabien Danieau.

WoZRemoteControl is a software that allows users to tele-operate a robot such as the Nao robot from Aldebaran Robotics. The interface provides many feedback to the user to help them to improve the user's awareness of the situation. For instance, we displayed the video stream of the robot's camera so users can monitor what the robot is seeing. We also displayed alarm such as "the robot is falling" or "the robot is busy" to help the tele-operator to answer correctly and prevent him to trigger inadequate behaviors.

The operator can drive the robot by using the arrow-key of the keyboard as in classical first person shooter video games. Sliders can also be used to aim the robot's head (pan/tilt). A set of buttons allows the trigger of specific complex actions such as "stand up", "sit", "wave" or behavior to express emetional state as "don't undestand", "yawn", "happy", etc...

The software has been writting in python and the interface has been realised with Qt in order to be cross-platformed.

5.4. AcrobanElectronicBoard

Participants: Olivier LY [correspondant], Jérôme Béchu, Paul FUDAL.

We improved the embedded control system of the Acroban humanoid robot along several ways in order to

- Allow remote direct control of the motor.
- Embed complex computations needed by learning algorithms.

Work have been done concerning embedded electronic on the one hand, and embedded software on the other hand. Concerning electronic, we use now ARM9 technology, integrating linux operating system. We have interfaced the system in a modular way to get two configurations. First, we can now control dynamixel servo-motors via this board from a host external system (mac, pc, etc). This allow to experiment complex algorithms with a lot of freedom for development (from matlab, etc.) within a rich environment, avoiding inherent constraints of embedded systems. The second configuration aims hard realtime control (feedback loops frequency up to 100Hz). We set up a system consisting of a computation unit (the ARM9 linux board), driving a control unit (ARM7 system without operating system).

The embedded software has been upgraded along several ways also:

- Integration of low level control to the ARM9 system. This has consisted in developing a very technical piece of code (in collaboration with the LaBRI) in the low layer of linux system (a module in kernel land). This integrates to linux system all low level processing (sensor management, pwm generation, RS485 communication, etc).
- At a upper level, we set up a full *embedded* `c++` library dedicated to learning algorithm implementation. This library includes linear algebra, etc. Now, one can embed complex learning systems runing on-board.
- We also designed a new version of the embedded movement system. This work still is in development. The aim is to extend and uniformize the representation of movement.

5.5. PyBOW

Participant: Pierre Rouanet [correspondant].

PyBOW (Python Bags-Of-Words) is an interactive software for visual objects classification. It is based on the OpenCV library. You can create a classifier and train it on tagged images of objects. Then, you can present a new image of an already taught object to the classifier and ask it to guess to which tag this image correspond. The system is incremental so you can test and train at any moment.

5.6. RhobanMoveStudio

Participants: Olivier LY [correspondant], Jérôme Béchu, Paul FUDAL, Pierre-Yves OUDEYER.

RhobanMoveStudio is a complete software suite to easily create and control robots, Acroban in particular. It consists of:

- a linux kernel module embedded on an ARM9 board,
- a complete C/C++/Python API from the lowest to the highest level usable directly on the embedded system,
- an embedded server allowing interaction through a network connexion,
- an UObject Component for controlling a robot remotely using Urbi Script,
- a Java Software to diagnose the complete system of the robot (motors, sensors, embedded system, I/O, etc..)

5.6.1. Software stack

The system runs on an electronic board (based on ARM9 processor) and uses a linux distribution (OpenWrt). The sofware is composed of several layers :

- Kernel Module : This part was designed in root mode to garantee an excution without any system interuption. Actually, we allow users to manage dynamixel motors, generate PWM signals, use digital readers/writers, i2c and more.
- low level control : It is used to have a basic access to the module. We can create a new device, update it and delete it.
- mid level control : This level is based on the low level and allows the monitoring of the devices.
- high level control : It is the high level abstraction. It includes learning alogrithms and other more complex algorithms.
- rhoban server : We implemented the rhoban server to interact with each parts of the software. It is a bridge beetween the embedded software and any pc client software.

We are currently implinting some other softwares in this suite such as a java configuration tool, a C++ client api (to develop a future URBI UObject) and a basic python client (to test the software).

5.6.2. RhobanConfigurationTool

RhobanConfigurationTool is Java software/applet used to diagnose a robot; so, it's possible to verify if all the motors are operational, if a sensor work well, if the system is over-loaded or not, etc... The choice of Java was made because it is a multi-platform runtime available on several commons environment (Windows, Linux, Mac OS X) so the user doesn't have to install any dependencies (except the Java runtime) to run the software as a stand-alone application or a web-brower Java applet.

This software provides different configuration panels according of the different parts of a robot system. As an example, there is a panel (figure 3) for global system functionality (load average, memory stat, console), and an other (figure 4) used to test and set all motors.
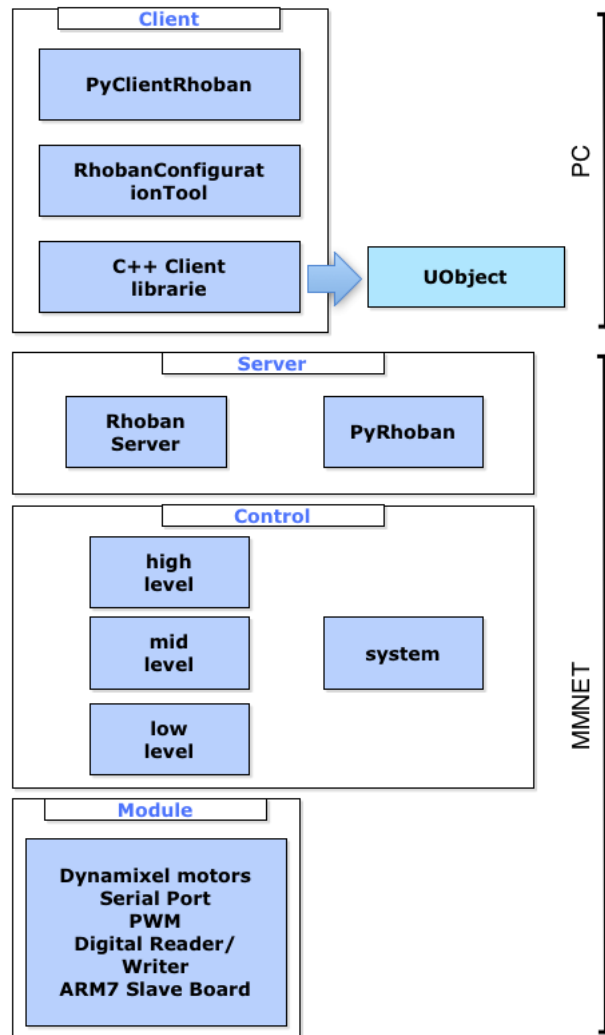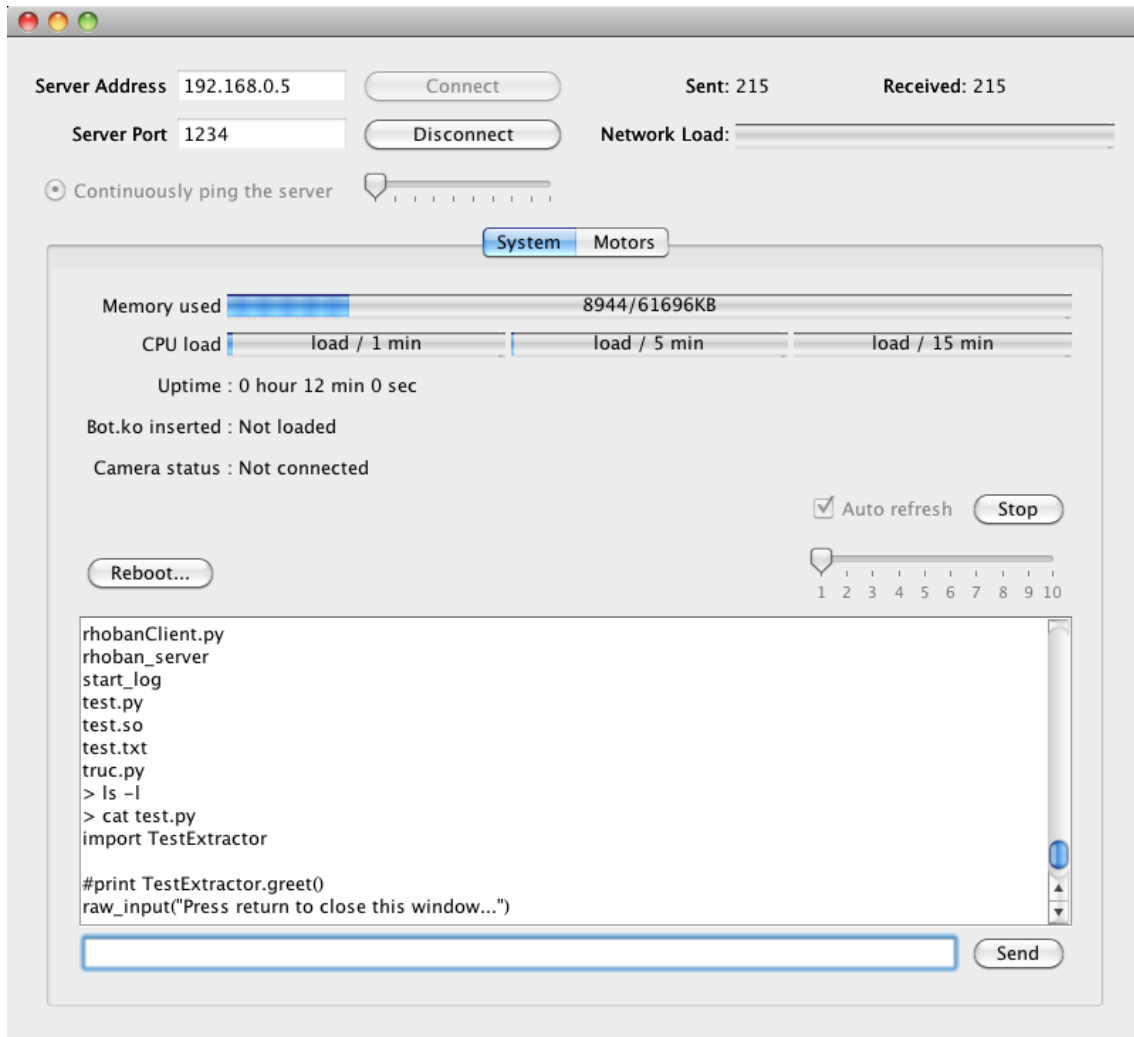
Figure 2. RhobanConfigurationTool system panel

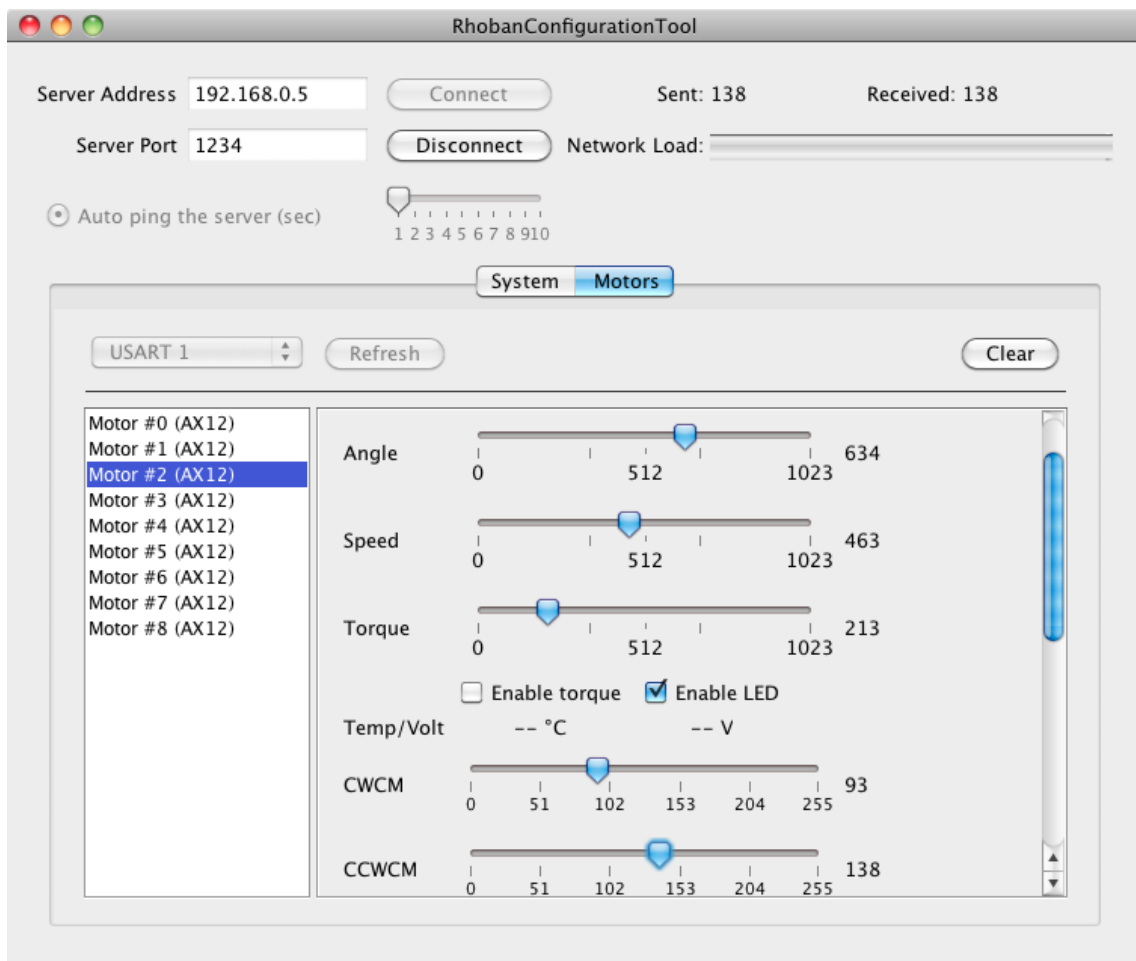*Figure 3. RhobanConfigurationTool system panel*

Figure 4. RhobanConfigurationTool motors panel

5.7. The Exploration Explorer 2

Participant: Adrien Baranès [correspondant].

The "Exploration Explorer 2" is a Matlab toolbox designed for the systematic evaluation and comparison of different exploration mechanisms allowing a simulated or a real robot to self-determine its future actions. Its conception allows an easy selection of different intrinsically motivated exploration mechanisms provided by the toolbox, and the tuning of numerous corresponding parameters. Several default sensorimotor spaces are also provided, with their corresponding visualizations systems, allowing an easy evaluation of statistical results relating the evolution of performances of each algorithm. Moreover, the software is designed to be easily plugged to other robotic setups.

5.8. uV-REPBridge

Participants: Paul FUDAL [correspondant], Matthieu LAPEYRE.

uV-REPBridge is a set of softwares which allows to control V-REP through Urbi scripts; it consists of a plugin for V-REP and a UObject component for Urbi.

V-REP - the Virtual Robot Experimentation Platform - is robot simulator which allows to edit and simulate robotic systems and sub-systems. Also, it can be integrated and combined using a complete API.

Urbi, Universal Robot Body Interface, is an open source cross-platform software platform in C++ used to develop applications for robotics and complex systems. Urbi is based on the UObject distributed C++ component architecture. It also includes the Urbi script orchestration language which is a parallel and event-driven script language. UObject components can be plugged into Urbi script and appear as native objects that can be scripted to specify their interactions and data exchanges. UObjects can be linked to the Urbi script interpreter, or executed as autonomous processes in "remote" mode.

uV-REPBridge is a way to interact with a robot simulation loaded with Urbi. Based on network communication, it's possible to use this software locally (V-REP and Urbi on the same computer) or remotely. So, it's possible to do experiences with a virtual robot and environment instead of using a real robot. Also, because uV-REPBridge provides classic functionality like, for example, setting position of a joint or its torque, getting sensor value, etc... it will be very easy to adapt an existing Urbi script controlling a real robot to use it through V-REP.

The development is made under a Windows environment using the V-REP and Windows API for the plugin and the UObject API with Boost for the UObject Component. The development of software has just begun at the end of the past year and will be finalized soon.

5.9. Flowers Field

Participants: Olivier LY, Jérôme Béchu [correspondant], Pierre-Yves OUDEYER, Fabien BENUREAU.

FLOWERS FIELDS is a robotic installation that explores new forms and new functions of robotics. When we think of robots, we traditionally have in mind either humanoid robots that look like humans and are supposed to do similar things as humans, or industrial robotic arms which should work in factories. On the contrary, the future may come with unforeseen kinds of robots that may enter our everyday homes: for examples, as houses become themselves intelligent with domotics, we could imagine that furnitures themselves could become robots. Chairs, tables, televisions, or lamps may become robots. In FLOWERS FIELDS, we show robotic lamps which move like living entities, with their own moods and their own system of interaction. They can be thought to be in houses partly as aesthetic objects, and partly for their social presence. Indeed, not only their movements and sounds are life-like, but they are sensible to human presence and can become interested in looking and interacting with people through those movements and sounds. In the future, we could imagine additionally that these robot lamps could serve as a friendly interface with the numeric world: for example, some gestures may be used towards the lamps to tell their hifi system to play a given song in your library. This installation was demonstrated at two INRIA INDUSTRIE DAYS and Cite des sciences (Paris, FRANCE).

We upgraded the version of Flowers Fields from URBI 1.5 to URBI 2.0. This new version is fully object oriented.

6. New Results

6.1. The SAGG-RIAC algorithm: competence based active learning of motor skills

Participants: Adrien Baranès, Pierre-Yves Oudeyer.

We have introduced the Self-Adaptive Goal Generation - Robust Intelligent Adaptive Curiosity (SAGG-RIAC) algorithm as an intrinsically motivated goal exploration mechanism which allows a redundant high-dimensional robot to efficiently and actively learn to control its own body. The main idea is to push the robot to perform babbling in the goal/operational space, as opposed to motor babbling in the actuator space, by self-generating goals actively and adaptively in regions of the goal space which provide a maximal competence improvement for reaching those goals. Then, a lower level active motor learning algorithm, inspired by the SSA algorithm, is used to allow the robot to locally explore how to reach a given self-generated goal. We have achieved experiments in both simulated and real robots, in various sensorimotor space (learning the inverse kinematics of a redundant arm with unknown geometry, learning quadruped walking with CPG's), showing that 1) exploration in the goal space can be a lot faster than exploration in the actuator space for learning the control of a redundant robot; 2) selecting goals based on the maximal improvement heuristics is statistically significantly more efficient than selecting goals randomly. These results were partly published in [21].

6.2. Maturationally-Constrained Competence-Based Intrinsically Motivated Learning

Participants: Adrien Baranès, Pierre-Yves Oudeyer.

The progressive biological maturation of infants' brain, motor and sensor capabilities, introduces numerous important constraints on the learning process. Indeed, at birth, all the sensorimotor apparatus is neither precise enough, nor fast enough, to allow infants to perform complex tasks. The low visual acuity of infants, their incapacity to efficiently control distal muscles, and to detect high-frequency sounds, are examples of constraints reducing the complexity and limiting the access to the high-dimensional and unbounded space where they evolve. Maturational constraints play an important role in learning, by partially determining a developmental pathway. Numerous biological reasons are part of this process, like the brain maturation, the weakness of infants' muscles, or the development of the physiological sensory system. A particularly important family of maturational constraint induced by the brain is due to **myelination**. Related to the evolution of a substance called myelin, (which is) usually called white matter, the main impact of myelination is to help the information transfer in the brain by increasing the speed at which impulses propagate along axons (connections between neurons). We have focused on the myelination process for several reasons, this phenomenon being responsible for numerous maturational constraints, affecting the motor development, but also the visual or auditive acuity, by making the number of degrees-of-freedom, and the resolution of sensori-motor channels increase progressively with time, all of this effecting the efficiency and progression of learning. We have studied the coupling of intrinsic motivation with those physiological maturational constraints, arguing that both mechanisms may have complex bidirectional interactions allowing to actively control the growth of complexity in motor development. On top of the self-adaptive goal generation algorithm (SAGG), instantiating an intrinsically motivated goal exploration mechanism for motor learning of inverse models, we have introduced a functional and formal model of maturational constraints inspired by the myelination process in humans, and showed how it can be coupled with the SAGG algorithm, forming a new system called McSAGG. We then have conducted experiments to evaluate qualitative properties of these systems when applied to learning a reaching skill with an arm with initially unknown kinematics. These results were partly published in [22].

6.3. Morphological computation in Acroban the humanoid and physical human-robot interaction

Participants: Olivier Ly, Pierre-Yves Oudeyer, Matthieu Lapeyre, Jérôme Béchu, Paul Fudal, Haylee Fogg.

We realized substantial advancement with the humanoid platform Acroban and its use to study various scientific topics. Our goal was to study three main issues: 1) Compliance and semi-passive dynamics in the framework of dynamic walking in humanoid robots and more generally its impact in terms of semi-passive interactive motor primitives and their robustness to unknown external perturbations; 2) the advantage of a bio-inspired multi-articulated vertebral column in the dynamics of these motor primitives; 3) Intuitive and compliant physical human-robot interaction. The platform uses mechatronic components that allow us to adjust dynamically the compliance of actuators, which combines with the intrinsic mechanical compliance of the structure due to the use of elastics and springs. We have explored how these capabilities can allow us to enforce morphological computation in the design of robust dynamic locomotion. Compliance also allows us to design semi-passive motor primitives using the torso as a system of accumulation/release of potential/kinetic energy. The platform is also considered in the context of physical human-robot interaction. We have shown that is possible to produce robust and playful whole-body physical interaction with humans, and yet based on standard affordable components. This is made possible by the combination of adequate morphology and materials, full-body compliance, semi-passive and self-organized stable dynamics, as well as the possibility to experiment new motor primitives by trial-and-error thanks to light-weightedness. In addition to opening new technological avenues for the future of personal robotics, we also show how a complex analogical human-robot interface allowing a human to "lead the robot by the hand" can spontaneously emerge thanks to morphological computation. Finally, we have begun to study the strong positive emotional reactions that Acroban triggers, with children in particular, in spite of its metallic non-roundish visual appearance, and we propose the hypothesis of the "Luxo Jr. Effect". These results have been partially presented in SIGGRAPH'2010, and several related articles are submitted. A dedicated web page with videos is available at: http://flowers.inria.fr/acroban.php.

6.4. Acroban v2: improving morphological computation with dampers

Participant: Olivier Ly.

Furthermore, theoretical studies and experiments concerning in particular dynamics of passive walkers drove us to design and build a new version of Acroban. This new version has two goals both fitting in the study of the impact of morphology in the behaviour of the robot:

- experiment deep structural modifications of the morphology, in order to avoid as much as possible inelastic schocks. Indeed, during the gait, the unstability is mainly due to schock at the landing of the foot.
- improve the global ratio weight/power of the robot in order to get more dynamic movements.

Indeed, this new version uses RX-28 motors which are lighter than the RX-64 motors used in the first version of Acroban. The robot is smaller and lighter. First experiments show that the obtained ratio weight/power is better than the first version. Movements of the robot, and in particular amplitude of locomotion movements, are not limited by torque now. Second, we have experimented plastic materials to design the structure in order to make it naturally flexible comparing to the metal used in the first version. This way, we improve the natural compliance of the robot. Finally, and this is probably the most important change, we used *non actuated linear joints* in the hip and in the spline. To control these linear joints, instead of servo-motors, we use *dampers*. This kind of design is new in humanoid robotic. While bringing new control problems (because of the non-controled joints which makes the robot semi-passive), this design softens schocks in a significant maner. Experiment shows that stability of the whole structure is greatly improved especially during locomotion.

6.5. Incremental Local Online Gaussian Mixture Regression for Imitation Learning of Multiple Tasks

Participants: Thomas Cederborg, Pierre-Yves Oudeyer, Adrien Baranès.

Imitation learning in robots, also called programming by demonstration, has made important advances in recent years, allowing humans to teach context dependant motor skills/tasks to robots. We have proposed to extend the usual contexts investigated to also include acoustic linguistic expressions that might denote a given motor skill, and thus we target joint learning of the motor skills and their potential acoustic linguistic name. In addition to this, a modification of a class of existing algorithms within the imitation learning framework has been made so that they can handle the unlabeled demonstration of several tasks/motor primitives without having to inform the imitator of what task is being demonstrated or what the number of tasks are, which is a necessity for language learning, i.e; if one wants to teach naturally an open number of new motor skills together with their acoustic names. Finally, a mechanism for detecting whether or not linguistic input is relevant to the task has also been proposed, and our architecture also allows the robot to find the right framing for a given identified motor primitive. With these additions it becomes possible to build an imitator that bridges the gap between imitation learning and language learning by being able to learn linguistic expressions using methods from the imitation learning community. In this sense the imitator can learn a word by guessing whether a certain speech pattern present in the context means that a specific task is to be executed. The imitator is however not assumed to know that speech is relevant and has to figure this out on its own by looking at the demonstrations: indeed, the architecture allows the robot to transparently also learn tasks which should not be triggered by an acoustic word, but for example by the color or position of an object or a gesture made by a human in the environment. To demonstrate this ability to find the relevance of speech, we have made experiments where non linguistic tasks are learnt along with linguistic tasks and the imitator has to figure out when speech is relevant (in some tasks speech should be completely ignored and in other tasks the entire policy is determined by speech). These simulated experiments also demonstrated that the imitator can indeed find the number of tasks that has been demonstrated to it, discover what demonstrations are of what task, which framing is associated to which tasks, and for which of the tasks speech is relevant and finally successfully reproduce those tasks when the corresponding context is detected. An initial description of some of the techniques associated with this work is in [23]. Further publications are under review.

6.6. A Real World User Study of Different Interfaces for Teaching New Visual Objects to a Robot

Participants: Pierre Rouanet, Fabien Danieau, Pierre-Yves Oudeyer, David Filliat.

Social robotics have recently known an important development and in particular these robots are predicted to arrive in every home in the next few years. Yet, an important challenge to solve is to allow these robots to discover their environment so they could adapt themselves to more robustly and efficiently evolve in it. We argue that users should be able to help their robot to achieve this ability: i.e. by teaching it names for the visual objects present in its close environment so it could later on recognize them. We already developed an integrated framework based on state of the art algorithms such as the visual bag-of-words to tackle this problem [56]. While our system deals with the visual perception and machine learning challenges, it especially focused on the human-robot interaction issues as we argue that the design of the interface may strongly impact the quality of the learning examples collected by the users and thus on the performance of the whole system. We already proposed different interfaces based on mediator objects such as an iPhone, a Wiimote and a Wiimote coupled with a laser pointer [57] [55][26][27]. We developed a new interface based on gestures where users directly guide the robot through hand or arm gestures. As gesture recognition is still a hard task, we used a Wizard-of-Oz framework where a human (the Wizard) was remotely controlling the robot accordingly to the different gestures he saw. Yet, the wizard only sees the interaction through the robot eyes and thus is restricted to the visual apparatus of the robot which is much limited than the human eye. To really evaluate these different interfaces and especially their impact on the entire system, we designed a large scale user study in a sciences museum in Bordeaux. This study was carefully designed in order to evaluate users in real world conditions. Furthermore, this study took place outside of the laboratory to recruit non-expert users, unfamiliar with robotics. The goal of this study was to ask participants to show and teach different visual objets to a social robot so we can collect the learning examples they gathered with the different interfaces. They also had to answer questionnaires so we can evaluate their user's experience. However, as teaching objects to a robot is

still an unusual and artificial task, we designed the experiment as a robotic game and embedded the task into a scenario in order to justify it and immerse the participants. Designing the study as a game also allows us to reproduce a daily life area and stressless environment. 107 users participated to our study and we showed that with simple interfaces such as the Wiimote or the Gestures interfaces that do not provide any feedback to the users, users tend to collect only 50% of good learning examples. Then, we showed that specifically designed interfaces as the Laser and the iPhone interfaces really significantly improve the quality of the learning example gathered. In particular, the visual feedback provided by the iPhone interface improves strongly the quality of the learning examples and allows users to naturally eliminate almost all the bad learning examples. We also showed that the Gestures interface which apriori seems more natural than the other interfaces was in fact judged as less intuitive and harder to use than the other interfaces. To us, it shows that as actual social robots have specific sensorimotor spaces, the classical human-human interaction can not be directly reused in human-robot interaction but new kind of interfaces should be developed to help the human and the robot communicate. Publications on this study have been accepted and will be presented in HRI 2011.

6.7. A bag-of-features framework for incremental learning of speech invariants in unsegmented audio

Participants: Olivier Mangin, David Filliat, Pierre-Yves Oudeyer.

We have introduced a computational framework that allows a machine to bootstrap flexible autonomous learning of speech recognition skills. Technically, this framework enables a robot to incrementally learn to recognize speech invariants from unsegmented audio streams and with no prior knowledge of phonetics. To achieve this, we imported the bag-of-words/bag-of-features approach from recent research in computer vision, and adapt it to incremental developmental speech processing. We evaluated positively an implementation of this framework on a complex speech database reused from the ACORNS FP7 european FET project. This work was described in [25].

6.8. Multimodal self-supervised acquisition of language from unsegmented audio-video streams

Participants: Louis ten Bosch, David Filliat, Pierre-Yves Oudeyer.

Through the visit of invited researcher Louis ten Bosch, from Radboud University, Holland, we have developed a computational framework which allows a machine to learn to recognize new acoustic words and new visual objects, as well as their associations, from initially unsegmented flow of audio and video and no initial knowledge of phonetics or global object shapes. This allows to reproduce some of the properties of human infant language acquisition in their first years. The techniques behind rely on the one hand on the use of non-negative matrix factorization techniques, and on the other hand on the use of audio and video encoding based on bag-of-words local representations (histograms of local spectral descriptors for audio and SIFT for videos). Based on observations of unsegmented and unlabelled associations between acoustic waves, potentially comprising several words in a sentence, and images, potentially comprising several visual objects, non-negative matrix factorizations allows to find sparse decompositions of the audio-video flow which allow the machine to reconstruct and find later an image containing the object denoted by an acoustic wave or the feature of the acoustic wave of a word given an image of it. Furthermore, we have been able to use incremental versions of non-negative matrix factorization in this setup. An article describing those techniques and experiments is being written.

6.9. FLOWERS FIELDS

Participants: Jérôme Béchu, Olivier Ly, Pierre-Yves Oudeyer.

We contined the design, evaluation and demonstrations of the FLOWERS FIELDS installation. This is a robotic installation that explores new forms and new functions of robotics. When we think of robots, we traditionally have in mind either humanoid robots that look like humans and are supposed to do similar things as humans, or industrial robotic arms which should work in factories. On the contrary, the future may come with unforeseen kinds of robots that may enter our everyday homes: for examples, as houses become themselves intelligent with domotics, we could imagine that furnitures themselves could become robots. Chairs, tables, televisions, or lamps may become robots. In FLOWERS FIELDS, five robotic lamps mounted on a table move like living entities, with their own moods and their own system of interaction. They can be thought to be in houses partly as aesthetic objects, and partly for their social presence. Indeed, not only their movements and sounds are life-like, but they are sensible to human presence and can become interested in looking and interacting with people through those movements and sounds. This installation was demonstrated at two Rencontres INRIA INDUSTRIE in Bordeaux (with the Aerospace industries and with the healthcare industries), as well as in Cité des Sciences et de l'Industrie in Paris.

7. Contracts and Grants with Industry

7.1. ANR

An ANR Project (MACSi, ANR Blanc 0216 02), coordinated by ISIR/Univesity Paris VI, on developmental robotics (motor learning, visual learning, and exploration algorithms on the ICub robot), was obtained on the "appel blanc" call. It will fund a 2 year for a postdoc position.

7.2. ERC

The ERC starting grant EXPLORERS 240007 achieved its first year and is a central driver of the whole team.

7.3. Industry

The team is part of the ROMEO2 FUI project proposal, coordinated by Aldebaran Robotics, and submited at the end of 2010.

7.4. Exterior research visitors

Louis ten Bosch, researcher at Radboud University, the Netherlands, visited FLOWERS for three months as an invited researcher in the context of starting grant ERC EXPLORERS. He was previously coordinator of FET European project ACORNS on speech acquisition. His visit in the lab was the opportunity to combine his expertise in speech acquisition and non-negative matric factorization techniques with our expertise in image processing and developmental learning. This resulted in a new frameword for bootstrapping multimodal language acquisition from unlabelled unsegmented audio-video streams as described in the results section.

7.5. National Initiatives

Collaboration with ENSTA Cognitive robotics lab., headed by David Filliat, which continued and in particular organized itself around joint work with Louis ten Bosch (invited professor) on multimodal language acquisition and the setting up of the ANR Blanc MACSi project.

Collaboration with IHES (Institut des Hautes Etudes Scientifiques IHES), and in particular Mickhail Gromov, has begun around two scientific topics: intrinsically motivated exploration and learning, and morphological computation (Acroban). Pierre-Yves Oudeyer and Olivier Ly were invited twice to give presentations and spend some time at IHES. The setting up of a formal larger scale joint project is ongoing.

8. Dissemination

8.1. Diffusion and animation of the scientific community

8.1.1. Editorial boards

Pierre-Yves Oudeyer has worked as Editor of the IEEE CIS AMD Newsletter, and member of the IEEE CIS Technical Committee on Autonomous Mental Development.

Pierre-Yves Oudeyer has worked as Associate Editor of IEEE Transactions on Autonomous Mental Development.

Pierre-Yves Oudeyer has worked as Associate Editor of Frontiers in Neurorobotics (Frontiers Foundation).

Pierre-Yves Oudeyer has worked as Associate Editor of International Journal of Social Robotics (Springer).

Pierre-Yves Oudeyer has worked as member of the editorial board of the book series Advances in Interaction Studies, John Benjamins Publishing Company.

Manuel Lopes acted as steering comittee member of the IEEE Technical Comitte on Robot Learning and as invited editor for the IEEE Transactions on Autonomous Mental Development

8.1.2. Conference Organization

Pierre-Yves Oudeyer was part of the organizing committee of IEEE International Conference on Development and Learning 2010, University of Michigan, Ann Arbor, USA.

Pierre-Yves Oudeyer participated in the coordination of the joint international event IEEE ICDL-Epirob 2011, which will be held in Frankfurt, Germany, in 2011.

8.1.3. Special Issues

Manuel Lopes and Pierre-Yves Oudeyer co-organized a special issue of IEEE Transactions on Autonomous Mental Development on Active Learning and Intrinsically Motivated Exploration in Robots.

8.1.4. Program Committees/Conference Reviews

Pierre-Yves Oudeyer was a member of the following program committees: IEEE International Conference on Development and Learning 2010; 9th International Conference on Epigenetic Robotics, 2010; ICRA 2011 (International Conference on Robotics and Automation); 11th International Conference on Simulation of Adaptive Behavior, Paris, France.

Manuel Lopes acted as Associated Editor for the IEEE International Conference on Robotics and Automation 2011 and reviewed papers for the HRI 2011.

8.1.5. Journal Reviews

Pierre-Yves Oudeyer reviewed papers for the journals: IEEE Transactions on Robotics, IEEE Transactions on Autonomous Mental Development.

Manuel Lopes reviewed papers for Machine Learning Journal, and for the Systems Man and Cybernetics journal.

8.1.6. Other

Pierre-Yves Oudeyer was expert for the European Commission for review and evaluations of several FP7 projects and calls.

8.2. Invited talks

Pierre-Yves Oudeyer:

- (9th december 2010) The challenges of developmental robotics, INRIA Colloquium, Paris, France.
- (23rd november 2010) with Olivier Ly: "Morphological computation in the acquisition of dynamic walking in biped humanoids", Séminaire de biologie mathématique de l'IHES, Bures-Sur-Yvette, France.
- (18th november 2010) Un robot peut-il apprendre comme un enfant? Conférences du Centre Ha 32, cycle "Jeu, enjeux, hors-jeux".
- (6th november 2010) Où vont les robots? Quelques défis de la robotique personnelle, Cité des Sciences et de l'Industrie, journée "Des robots et des hommes", Paris, France. Video PodCast.
- (28th october 2010) Panel session on "Fueling the creativity of young researchers", ICT 2010, European Commission, Brussels, Belgium.
- (27th june 2010) Developmental Constraints on Active Learning for the Acquisition of Motor Skills in High-Dimensional Robots, RSS 2010 Workshop "Towards Closing the Loop: Active Learning for Robotics", Zaragoza, Spain.
- (15th june 2010) On Self-Organization and Developmental Mechanisms in the Origins of Novel Behavioral and Cognitive Structures: Computational Robotic Models and Experiments, IHES (Institut des Hautes Etudes Scientifiques), Séminaire de Biologie.
- (13th april 2010) La robotique développementale et sociale, séminaire du LAAS, Toulouse, France.
- (29th march 2010) Open-ended (re-)search in evolutionary and developmental systems, Workshop on evolutionary algorithms - Challenges in Theory and Practice, Bordeaux, France.
- (17th february 2010) Un robot peut-il apprendre comme un enfant? Robot Wednesday - Apprendre comme un enfant pour un robot, Paris.

Olivier Ly:

- (8th december 2010) Overview of Acroban Robot. Groupe de travail CNRS GDR Robotique, GT7 - Robotique Humanoide. University Paris 6.
- (29th november 2010) Demonstration of Acroban. Journée "Innovons-Ensemble". Enseirb, Bordeaux.
- (23rd november 2010) with Pierre-Yves Oudeyer: "Morphological computation in the acquisition of dynamic walking in biped humanoids", Séminaire de biologie mathématique de l'IHES, Bures-Sur-Yvette, France.
- (15th october 2010) Voyage au pays des robots. MajecStic 2010. Bordeaux.

8.3. Teaching

Pierre-Yves Oudeyer gave a 23 hours course on Social and Entertainment Robotics to third year engineering students of ENSTA, Paris.

8.4. Communication towards the general public

8.4.1. *Museum exhibitions, science festivals and general public presentations*

January 2010 - Demonstration of FLOWERS FIELDS, Acroban and IDrive human-robot interfaces at Rencontres INRIA Industrie "The aerospace industries: Modeling and secure systems" (Jérôme Béchu, Olivier Ly, Pierre Rouanet, Pierre-Yves Oudeyer).

April 2010 - December 2010: Continuous regular demonstrations (25 days in total) of robots to the general public in the Science Museum in Bordeaux (Cap Sciences). Experiments lead by Fabien Danieau and Pierre Rouanet.

April 2010 - Demonstration of FLOWERS FIELDS and IDrive human-robot interfaces at Rencontres INRIA Industrie "Digital industries for healthcare" (Jérôme Béchu, Pierre Rouanet).

July 2010 - Demonstration of Acroban at SIGGRAPH'2010 Emerging Technologies, Los Angeles, USA (Olivier Ly, Jérôme Béchu, Pierre Rouanet).

Sept. 2010 - Demonstration of Acroban, Nao and human-robot interfaces at the French Science Festival, Cap Sciences event (Place de la Victoire), Bordeaux, France (the whole team).

Sept. 2010 - Demonstration and presentation to several classes college students for the Science Festival, at INRIA Bordeaux, France (the whole team).

6th November 2010 - Demonstration of Acroban and FLOWERS FIELDS in Cité des Sciences et de l'Industrie in Paris, during the public event "Des robots et des hommes", Paris, France (Olivier Ly, Jérôme Béchu, Fabien Danieau, Pierre-Yves Oudeyer).

6th November 2010 - Public presentation "Où vont les robots? Quelques défis de la robotique personnelle", Journée "Des robots et des hommes", Cité des Sciences et de l'Industrie, Paris, France (Pierre-Yves Oudeyer).

6th Novembre 2010 - Public presentation "Le robot Acroban", Journée "Des robots et des hommes", Cité des Sciences et de l'Industrie, Paris, France (Olivier Ly).

8.4.2. *Press*

Web links to the following press items are available on http://flowers.inria.fr/press.php.

TV, 3rd August 2010, **Euronews**, Meet the robots (on Acroban at SIGGRAPH'2010, Los Angeles, USA).

Newspaper, August 2010, **Sud-Ouest**, "Tout l'été, essayez Nao le robot télécommandé" (on public demonstration of robots at Cap Sciences by Pierre Rouanet and Fabien Danieau).

Newspaper, Sept. 2010, **Sud-Ouest**, "Les chercheurs tentent l'opération séduction" (on public demonstration of robots by the whole team for the French science festival in Bordeaux).

Radio, april 2010, **Radio Trafic FM**, "La robotique personnelle" (Interview of Pierre Rouanet and Fabien Danieau).

Radio, 3rd december 2010, **France Inter**, "La tête au carré" (Interview of Pierre-Yves Oudeyer).

30th july 2010, **Engadget.com**, "Acroban, the childlike robot you want to punch".

4th august 2010, **Wired.com/GadgetLab**, "Holographic displays, Robot eyes hint at your interactive future" (on Acroban at SIGGRAPH'2010, Los Angeles, USA).

August 2010, **Computer Graphics World**, Siggraph 2010 Emerging technologies summary.

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