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Project-Team FLOWERS

Flowing Epigenetic Robots and Systems : Developmental and Social Robotics

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THEME
Robotics

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Project-Team FLOWERS

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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 being 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, guided by experience, the overall pre-determined connection structure of the brain, as well as a small set of simple innate values or preferences.
- **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, for example the topology of the body and the sensorimotor contingencies (propriocetive, visual and acoustic). This process is meant to be open-ended, progressing in continuous operation from initially simple representations to abstract concepts and categories similar to those used by humans.

2.2. Highlights

An important scientific step was reached by proposing a first formal, as well as experimental, combination of two central families of exploration and learning algorithms, which were so far studied separately in the litterature: intrinsically motivated learning of sensorimotor skills, and socially guided learning of motor skills. This was achieved through the SGIM (Socially Guided Intrinsic Motivation) algorithm. An article presenting this algorithm and associated results obtained the second best student paper award in the IEEE ICDL/Epirob conference, Frankfurt Germany [27].

The results of a major large-scale experiment on human-robot interfaces was published in one of the premier venue for human-robot interaction research, the ACM/IEEE HRI conference [29]. The goal of the experiment, which was very successful and performed out of the lab in Cap Sciences museum in Bordeaux, was to show that the design of adequate interfaces for having a non-engineer human teach new visually grounded words to a robot can improve the performances of learning significantly more than the standard improvement provided by using a sophisticated statistical inference or computer vision algorithms. This is explained by the fact that adequate interfaces allow the robot to collect training examples of a much higher quality.

The FLOWERS team, in collaboration with University Bordeaux I/Labri, has participated as a central actor of the exhibition “Mathematics: A Beautiful Elsewhere” at Fondation Cartier pour l’Art Contemporain in Paris, starting from 19th october 2011 and to be held until 18th march 2012. This installation, called “Ergo-Robots/FLOWERS Fields” was made in collaboration with artist David Lynch and mathematician Mikhail Gromov (IHES, France), and shows computational models of curiosity-driven learning, human-robot interaction as well as self-organization of linguistic conventions. This exhibition, at the crossroads of science and art, has the goal of showing to the general public (several hundred thousands visitors) the intellectual universe of some of the greatest mathematicians of our time as well as some experiments and techniques in other fields (e.g. physics, computer science, robotics) which are directly related to their scientific work. Through this exhibition, the work of the team was also widely disseminated to the general public through large audience radios, magazines and newspapers (France Inter, France Culture, RFI, Sciences et Avenir, Tangente, Financial Times, Daily Telegraph, Libération, ...). More information available at: http://flowers.inria.fr/ergo-robots.php and http://fondation.cartier.com/.

The Acroban humanoid robot, developped in collaboration with University Bordeaux I/Labri, and which features groundbreaking technologies in terms of flexible morphology (including vertebral column) and capacity for intuitive, safe and robust physical interaction with humans, was highly sollicited for live demonstrations in international venues, both academic and targeted to a wider audience. In particular, on the academic side, Acroban was demonstrated live as a focus demonstration at IEEE IROS 2011 conference in San Francisco, FET 2011 European conference in Budapest, SAME conference in Nice Sophia Antipolis, Foundation of Digital Games 2011 conference in Bordeaux. On the general public side, Acroban was demonstrated at the INNOROBO International Robot Summit in Lyon, at the Laval Virtual salon in Laval, at Fète de la Science in Cité des Sciences et de l’Industrie, during the conference “Des robots et des hommes” at Cité des Sciences et de l’Industrie in Paris. A movie for scientific mediation, explaining the science and technology related to Acroban, was made with the INRIA movie department. Those technologies were also presented and explained on various large audience national and international tv programs (CNBC, TF1, BFM TV, Euronews), radios (France Info, RFI), newspapers and magazines (Le Monde, Le Point, Le Figaro, Le Figaro Magazine, Les Echos, 20 minutes). Finally, Acroban was selected by SmartPlanet.com as one of the best robots of the year 2001 (http://www.smartplanet.fr/smart-technology/compil-2011-un-defile-de-robots-9384/).

BEST PAPER AWARD :
[27] **IEEE International Conference on Development and Learning**. S. M. NGUYEN, A. BARANES, P.-Y. OUDEYER.

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, 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" [71]. 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 [51], 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 [56] [73]. The approach of developmental robotics consists in importing and implementing concepts and mechanisms from developmental psychology [58], cognitive linguistics [44], and developmental cognitive neuroscience [54] 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 [40] [61], grounding [49], situatedness [34], self-organization [69] [62], enaction [72], and incremental learning [42].

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 [9]. 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 online active self-regulation of the growth of complexity in learning situations;
2. **social learning and guidance,** a learning mechanisms that exploits the knowledge of other agents in the environment and/or that is guided by those same agents. These mechanisms exist in many different forms like emotional reinforcement, stimulus enhancement, social motivation, guidance, feedback 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 [58], 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” [36] [48]. 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 [38] [45] [47]. 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 [46] [52] [67]. Based on this, a number of researchers have began in the past few years to build computational implementation of intrinsic motivation [9] [59] [65] [37] [53] [57] [66]. 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 [59][9] [60] [64] . 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 [43] [50] 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 and Interactive Learning

Social guidance is as important as intrinsic motivation in the cognitive development of human babies [58]. There is a vast literature on learning by demonstration in robots where the actions of humans in the environment are recognized and transfered to robots [35]. Most such approaches are completely passive: the human executes the actions and the robot learns from the acquired data. Recently, the notion of interactive learning has been introduced in [70], [39], motivated by the various mechanisms that allow humans to socially guide a robot [63]. In an interactive context the steps of self-exploration and social guidances are not separated and a robot learns by self exploration and by receiving extra feedback from the social context [70], [55][26]. In FLOWERS, we are aiming at including intrinsic motivation system in the self-exploration part thus combining efficient self-learning with social guidance [27], [31]. Another challenge is to allow for more flexible interaction protocol with the user in terms of what type of feedback is provided and how it is provided [24].

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.
- **Environment perception in intelligent vehicles.** When working in simulated traffic environments, elements of FLOWERS research can be applied to the autonomous acquisition of increasingly abstract representations of both traffic objects and traffic scenes. In particular, the object classes of vehicles and pedestrians are if interest when considering detection tasks in safety systems, as well as scene categories ("scene context") that have a strong impact on the occurence of these object classes. As already indicated by several investigations in the field, results from present-day simulation technology can be transferred to the real world with little impact on performance. Therefore, applications of FLOWERS research that is suitably verified by real-world benchmarks has direct applicability in safety-system products for intelligent vehicles.

5. Software

5.1. Perception Tools

Participants: David Filliat [correspondant], Natalia Lyubova.

5.1.1. Perception Abstraction Engine

Participants: David Filliat [correspondant], Natalia Lyubova.

PAE (Perception Abstraction Engine) is a C++ library developed to provide a uniform interface to existing visual feature detector such as SIFT, SURF, MSER, superpixels, etc... Its main goal is to be able to use these various feature detectors in a "bag of feature" approach for applications such as robot localisation and object recognition. Several approach are also implemented for the visual vocabularies, in particular the fast incremental vocabularies developed in the team.

The library provide common C++ interfaces to feature detectors, visual features and visual vocabularies. A factory approach make it possible to change the feature detectors and visual vocabularies types and parameters through configuration strings, without the need to recompile. Some applications are also included in the library, in particular topological robot localization (room recognition) and visual object recognition. An Urbi interface is also provided for these modules.

5.1.2. Incremental object discovery

Participants: Natalia Lyubova [correspondant], David Filliat.

This software makes it possible to detect, model and recognize objects in a scenario of interaction between a humanoid robot and a human teacher. It is based either on standard images, or on the kinect camera to take advantage of the depth information. The software is written in C++ and relies mainly on PAE and OpenCV.

The software implements several modules: candidate object segmentation based on motion information, keypoint-based object tracking, incremental object model construction integrating multiple features (keypoints + superpixels) and object categorisation based on mutual information with robot motors (making it possible to segment robot parts, objects and humans).

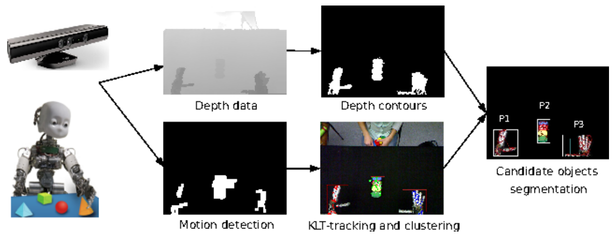

Figure 1. System Overview of the Incremental object discovery Software.

5.2. Learning Algorithms

5.2.1. Neural online learning library

Participant: Alexander GEPPERTH [correspondant].

nnLib is a C/Python-based library for the efficient simulation of neural online learning algorithms. The core user API is implemented in Python as an object-oriented hierarchy, allowing the creation of neural network layers from configuration files in a completely opaque way, as well as the adaptation of multiple parameters at runtime. Available learning algorithms are: PCA (subspace rule and stochastic gradient ascent), sparse coding, self-organizing map, logistic regression and several variants of Hebbian learning (normalized, decaying, ...). nnLib is under development and will be made available to the public under the GPL in 2012.

5.2.2. RLPark - Reinforcement Learning Algorithms in JAVA

Participant: Thomas Degris [correspondant].

RLPark is a reinforcement learning framework in Java. RLPark includes learning algorithms, state representations, reinforcement learning architectures, standard benchmark problems, communication interfaces for three robots, a framework for running experiments on clusters, and real-time visualization using Zephyr. More precisely, RLPark includes:

- Online Learning Algorithms: Sarsa, Expected Sarsa, Q-Learning, Actor-Critic with normal distribution (continuous actions) and Boltzmann distribution (discrete action), average reward actor-critic, TD, TD(λ), GTD(λ), GQ(λ), TDC
- State Representations: tile coding (with no hashing, hashing and hashing with mumur2), Linear Threshold Unit, observation history, feature normalization, radial basis functions
- Interface with Robots: the Critterbot, iRobot Create, Nao
- Benchmark Problems: mountain car, swing-up pendulum, random walk, continuous grid world

An example of RLpark running an online learning experiment on a reinforcement learning benchmark problem is shown in Figure 2.

RLPark was started in spring 2009 in the RLAI group at the university of Alberta (Canada) when Thomas Degris was a postdoc in this group. RLPark is still actively used by RLAI. Collaborators and users include Adam White (patches for bug fixes, testing), Joseph Modayil (implementation of the NAO interface, patches for bug fixes, testing) and Patrick Pilarski (testing) from the University of Alberta. RLPark has also been used by Richard Sutton, a professor and iCORE chair in the department of computing science at the University of Alberta, for a demo in his invited talk *Learning from Data* at the Neural Information Processing Systems (NIPS) 2011. Future developments include the implementation of additional algorithms (the Dyna architecture, back propagation in neural networks, ...) as well as optimizations of vector operations using GPU (with OpenCL) and additional demos. Future dissemination includes a paper in preparation for the JMLR Machine Learning Open Source Software. Documentation and tutorials are included on the http://thomasdegris.github.com/rlpark/RLPark web site. RLPark is licensed under the open source Eclipse Public License.

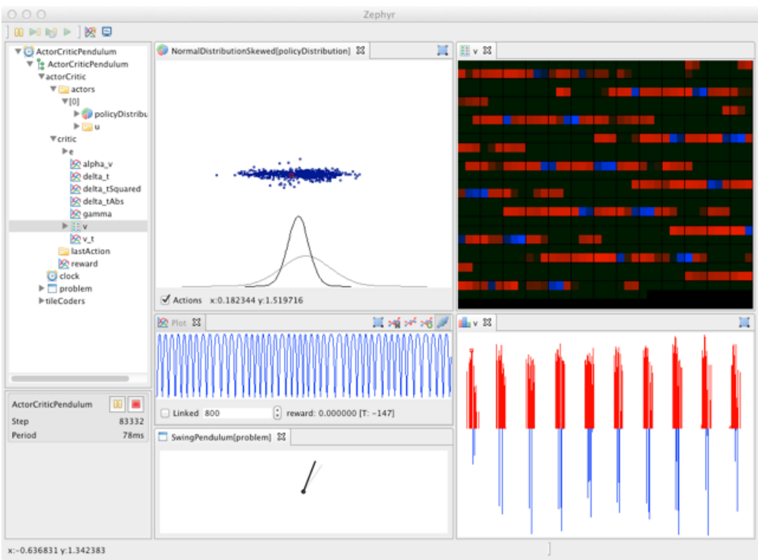

Figure 2. An example of an experiment in RLPark. Zephyr displays two views of a learned weight vector, an animation of the problem, the current policy distribution learned by the algorithm and the reward obtained by the algorithm.

5.2.3. Autonomous or Guided Explorer (AGE)

Participant: Sao Mai NGUYEN [correspondant].

The "Autonomous or Guided Explorer" program is designed for the systematic evaluation and comparison of different exploration mechanisms allowing a simulated or a real robot to learn and build models by self-exploration or social learning. Its conception allows an easy selection of different intrinsically motivated exploration or classical social learning mechanisms. Are provided algorithms such as Random Exploration, SAGG-RIAC, SGIM-D, imitation learning, learning by Observation. The program uses the new objet-oriented programming capability of Matlab, to enhance flexibility and modularity. The main program is built around objects that represent the different modules and the general architecture of such learning algorithms: action space exploration, goal space exploration, interaction with a human, robot control, model computation, but also evaluation and visualisation modules.

The software is designed to easily tune learning parameters and to be easily plugged to other robotic setups. Its object-oriented structure allows safe adaptation to different robotic setups, learning tasks where the structure of the model to learn differs, but also different action or goal spaces. This program is used by Sao Mai Nguyen of the team to compare the performance of different learning algorithms.These results were partly published in [27]. Future work will take advantage of its flexibility and implement new default robotic setups, robot control, action and goal spaces, and most of all, new types of interaction with a human.

5.2.4. NMF Python implementation

Participant: Olivier Mangin [correspondant].

This library is meant to implement various algorithms for Nonnegative Matrix Facorization in the Python programming language, on top of the Numpy and Scipy scientific libraries.

Some Pyhton NMF libraries already exist, such as the one present in the scikit-learn project. However most of them are quite limited in comparison to recent advances in these techniques (for example extension of NMF algorithms to wider families of penalties such as the beta-divergence family). On the other hand existing MATLAB software has been released by the authors of some of these algorithms but, first, code is not available for every interesting algorithm and none of those various pieces of code implements the whole set of features that one would like to use.

This project is in a very early stage and yet only for internal use in the team. It could, however be released in the future, for example integrated in the previously mentioned scikit-learn project.

5.3. Software Platforms

5.3.1. JBox2D wrapper

Participant: Fabien BENUREAU [correspondant].

ProcBox2D is a wrapping of Processing and JBox2D to satisfy common robotic research needs. In order to quickly prototype research ideas, a simple and efficient simulation framework is of great use. JBox2D is a 2D rigid-body physic engine. Written in Java, it is very fast, typically allowing to compute simulation 60 times faster than real time. Mass simulations can be carried in a timely manner, and improving the process of iterating the conception and implementation of new algorithms. Processing is a graphical framework in Java, and is used to display the simulations of JBox2D. An example of a simulation rendering is visible in Figure 3.

While several libraries exist that expose the JBox2D engine to the Processing framework, they suffer from binding Processing irrevocably into the experiment description. As such, simulations without a graphical context, a situation commonly encountered on remote servers and computing clusters are impossible using these libraries. ProcBox2D was written to fill this gap. It allows the conception of experiments to be done using Processing display capability, while, later one, without modifications of the code, to execute the simulations without any dependency to Processing, on a cluster for instance. The use of Processing allows interactions with the scene via the mouse, which makes ProcBox2D a potential tool in demonstration or imitation learning experiments.

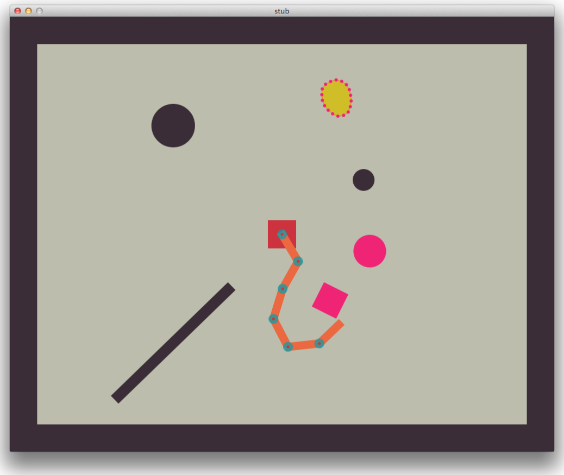

Figure 3. A JBox2D simulation rendered with Processing using ProcBox2D. A robotic arm is interaction with dynamic object (in pink and yellow); the environment contains obstacles and walls (in dark purple).

ProcBox2D also provides a sensor and controller interface. Actuated joints can be controlled in torque and velocity, and a PID controller for position control is planned. ProcBox2D implementation begun in November 2011 and was presented and made available to the team in December 2011. It is expected that it will increase productivity of researchers that previously had to work out a solution for themselves, often using in early stage of research complex and time-consuming simulation frameworks.

5.3.2. V-REPBridge

Participant: Paul FUDAL [correspondant].

V-REPBridge (formally uV-REPBridge) is a set of software tools to control V-REP through an external client; it consists of a plugin for V-REP and an API to control V-REP.
V-REP - the Virtual Robot Experimentation Platform - is a robot simulator which allows the editing and simulation of robotic systems and sub-systems. Also, it can be integrated and combined using a complete API. V-REPBridge is a way to interact with a simulation loaded through an Urbi script or a Python application. Based on network communication, V-REPBridge can be used locally (V-REP and the client on the same computer) or remotely. The V-REP simulator's main use is to perform experiments with virtual robots and environments. But, because V-REPBridge API provides classic functionality like, for example, setting position of a joint or its torque, getting sensor value, etc... an existing application built on top of V-REPBridge can be easily repurposed to use the interface of a real robots.
The development of the plugin for V-REP is made under Windows environment using the V-REP and Windows API. The plugin acts as a server to which a client can connect in order to control the simulation. The client is provided as an API written in C++. This API is available for Windows, Mac and Linux and bindings are available for UrbiScript and Python. The bindings are based on the Urbi API and the Boost Python Library.

Today, V-REPBridge is fully functional and already used in several research experiments, and provide more than 130 V-REP API functions which can be called by the client; here is an non-exhaustive list of V-REP functionalities available in the client :

- joint functionality (position, velocity, torque, etc...),
- object functionality (position, orientation, etc...),
- force sensor functionality,
- inverse kinematic and geometric functionality,
- proximity sensors functionality,
- collision detection functionality,
- minimum distance calculation functionality,
- path planning functionality,
- dynamic functionality,
- ...

V-REPBridge is also provided with an user documentation which includes some howtos (build, use), a complete list of available functions (with synopsis and parameters/returned value description) and some short examples written in Urbi and Python.
Finally, a developer documentation will be available soon to help developers who wants to implement missing V-REP calls both in the plugin and the client, or wants to implements theirs owns functions callable in the client.
The development of V-REPBridge was started at the beginning of year 2011. First release was made in February for testing and debugging foundation of the software. After this short period, time was spent expanding the software and adding new functionalities to bring a response to the needs of the team. First experiments with V-REPBridge was made for IJCAI in july (Mai NGUYEN), ICDL in august (Mai NGUYEN/Matthieu LAPEYRE) and Humanoid in october 2011 (Matthieu LAPEYRE). It was a good feedback for improving the performance and to identify potential improvements.
Work is still in progress for minor bugfixes, support of V-REP minor releases and preparation of the future version of V-REP which will run not only Windows but also on Linux and Mac OS X. A first private beta of V-REP 3 will be available at the end of january.

5.3.3. Rhoban Move Studio

Participants: Olivier Ly [correspondant], Hugo Gimbert, Jérôme Béchu, Paul Fudal.

5.3.3.1. Main software stack

RhobanMoveStudio is a software suite to easily create and control robots, Acroban, FLOWERS Fields/Robot Lamps and Ergorobots/FLOWERS Fields in particular.

This platform has already been presented last year, but it has evolved, in particular for the motor control part. The software architecture has been kept similar but performance has been improved.

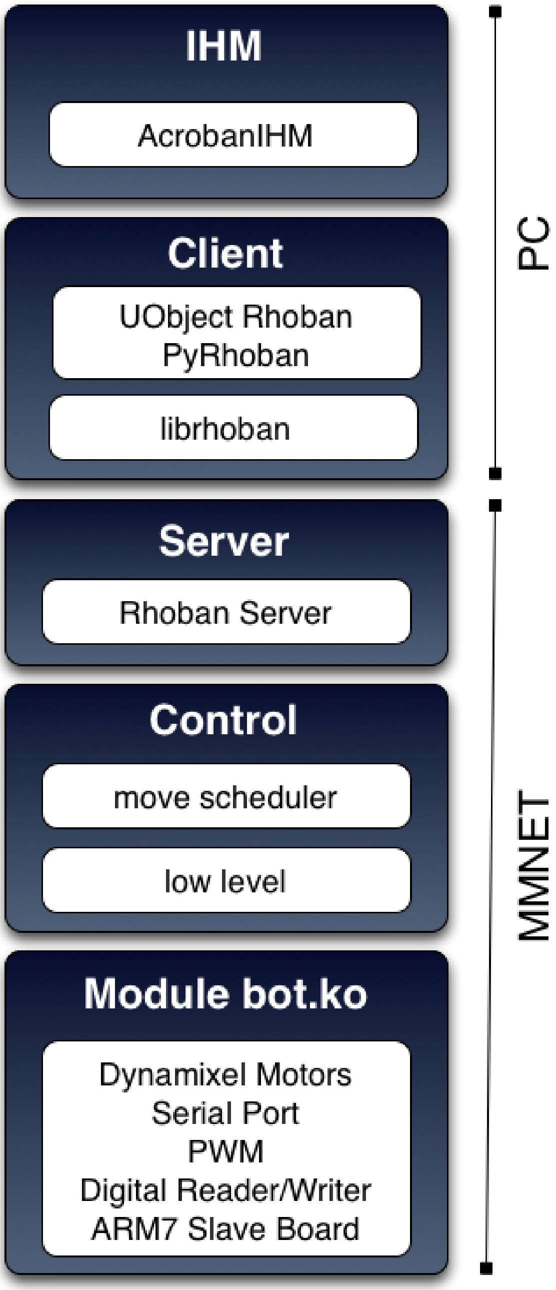

Figure 4. The complete software architecture of Rhoban Move Studio

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** The role of the module is to implement the electronic communication with devices. It enables to manage Dynamixel [1] motors, generates PWM [2] signals, uses digital readers/writers, I2C bus and more. This year the motor communication have been significantly improved and gained support fort accelerometers. This module is designed to run in root mode, to garantee execution without system interuption, as required by robotic application.
- **Low level** This set of functions is used to communicate with the module through a dedicated shared memory.
- **Move Scheduler** This library provides enables a high level specification of low level motor control loop based on graph of input/output blocks (see Section 5.3.3.2).
- **Rhoban server** This software offers access to the full API of rhoban features through a TCP Socket.
- **Librhoban** This TCP client library provides communication with the Rhoban Server and thus to the whole API. It is a dynamic library, thread safe and secure.

Except for the kernel module which is written in C ANSI, this softwares are written in C++.

5.3.3.2. Move Scheduler

Recently (October 2011) a new layer was added to the software. Its role is to enable low level motor control loops through a high level representation.

This representation introduces the concept of blocks. Each block is a computing unit with inputs and outputs. The output of a block can be the input of another one, thus forming a graph of interaction between those unit. Each block is a function (for example addition, multiplication, derivation, integration, spline generation). Special blocks are also provided for sensor inputs and motor outputs.

Graphical interface was developped to easily designed such movements. it is called *Move Scheduler Modeler*, and written in Python (PyQt). This software has import/export capabilities to XML files.

5.3.4. UFlow

Participant: Jérome Béchu [correspondant].

We developed some new UObjects 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++. We still continue to develop this collection of UObjects for the team.

5.3.4.1. USoundManager

This UObject is used to play sound. It's possible to update the sound while playing. This new version is already based on FMOD.

A new version has just been made. Based on OpenAL, this UObject has the exact same interface as the previous one expect that we include a media manager. With this functionality we load just one time the same sound (We keep it in memory a dictionnary of sounds).

5.3.4.2. URhoban

wrap the API of the librhoban (see the previous chapter). This tool is especially develop to control Bioloid motors in high frequency. With that software we can create instance of motors scanned and directly read and write features like position, torque, load, speed.

[1] Broadly used servo motor product from Robotis http://www.robotis.com
[2] Electronic signal : Pulse With Modulation

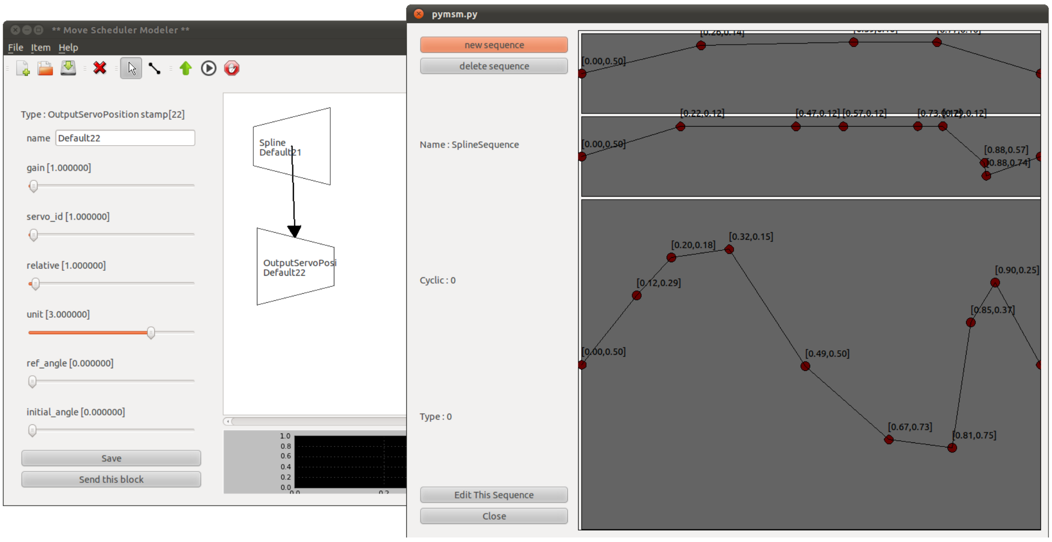

Figure 5. Move Scheduler.

5.3.4.3. UXml

is an UObject based on TinyXml. It is designed to quickly save and restore URBI List in a xml file. It is generally used to store/load paramaters like the list of motors in the ErgoRobot platform.

5.3.4.4. USmartLed

was created to use the LinkM USB Device to control RGB lights. It is based on the linkm driver (modified to support multiple USB devices). We can control intensity of each light for each primary color.

5.3.4.5. UGui

is designed to draw basic 2D primitives. A new version based on SFML was developed this year. It is used in the ErgoRobot project to run a simulation of the setup with a graphical interface.

5.3.4.6. USqlite

is an UObject to wrap functionalities of SQLite in URBI. SQLite is a software library that implements a tiny SQL database engine.

5.3.4.7. UNamingGame

is UObject used to play the Naming Game. The Naming Game is an algorithm based on communication between agents, who progressively agree meanings of words.

5.3.5. ErgoRobot/Flowers Field Software

Participants: Jérôme Béchu [correspondant], Pierre-Yves Oudeyer, Pierre Rouanet, Olivier Mangin, Fabien Benureau, Mathhieu Lapeyre.

In the context of its participation to the exhibition “Mathematics: A Beautiful Elsewhere” at Fondation Cartier pour l’Art Contemporain in Paris, starting from 19th October 2011 and to be held until 18th March 2012, the team has elaborated and experimented a robotic experimental set-up called “Ergo-Robots/FLOWERS Fields”. This set-up is not only a way to share our scientific research on curiosity-driven learning, human-robot interaction and language acquisition with the general public, but, as described in the Results and Highlights section, attacks a very important technological challenge impacting the science of developmental robotics: How to design a robot learning experiment that can run continuously and autonomously for several months?

The global scenario for the robots in the installation/experiment is the following. In a big egg that has just opened, a tribe of young robotic creatures evolves and explores its environment, wreathed by a large zero that symbolizes the origin. Beyond their innate capabilities, they are outfitted with mechanisms that allow them to learn new skills and invent their own language. Endowed with artificial curiosity, they explore objects around them, as well as the effect their vocalizations produce on humans. Human, also curious to see what these creatures can do, react with their own gestures, creating a loop of interaction which progressively self-organizes into a new communication system established between man and ergo-robots.

We now outline the main elements of the software architectures underlying this experimental setup.

5.3.5.1. System components

The software architecture is organized to control the experiment at several levels, and in particular:

- **Scenes**: The organization of behavioural scenes, managing the behaviours that are allowed to each robot at particular times and in particular contexts;
- **Behaviours**: The individual behaviours of robots, also called stems, which are outlined in the next section;
- **stems**: The low-level actions and perceptin of robots while executing their behaviours, including motors control on the five physical stems, color and intensity of lights inside the stem head, production of sounds through speakers. Sensors are the kinect used to interact with visitors, and motor feedback capabilities.

In addition to that a video projector is used to display some artistic view of stem agents internal state.

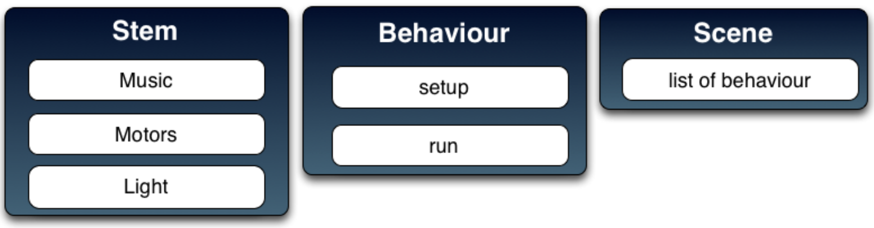

Figure 6. Three importants concepts in ErgoRobots

5.3.5.2. Behaviours

A number of innate behaviours were designed and are used by the robots as elementary behaviours of more complex behaviours, including the three following learning behaviours.

The Naming Game is a behaviour played by stems two-by-two and based on computational models of how communities of language users can self-organize shared lexicons. In the naming game, stems interact with each other in a stylised interaction. Repeated interactions lead to the development of a common repertoire of words for naming objects. More precisely, object belong to meaning spaces. Two such spaces have been implemented for the exhibition. The first one is related to object spatial categorization and the second one is related to movement categorization. The object space contains stems, some hole in walls and the interaction zone. The movement space contains representations of small dances that stem can produce and reproduce.

Object Curiosity is a behaviour in controlling intrinsically motivated exploration of the physical environnement by the stems. A small wood object is present in the reachable physical environement of the stem, attached on the top of a spring so that it is guaranteed that it comes back to its original position. The stem uses a motor primitive to act on the object and motor feedback to detect movements of the object. The robot learns through active exploration what kind of parameters motor primitive will result in touching the object.

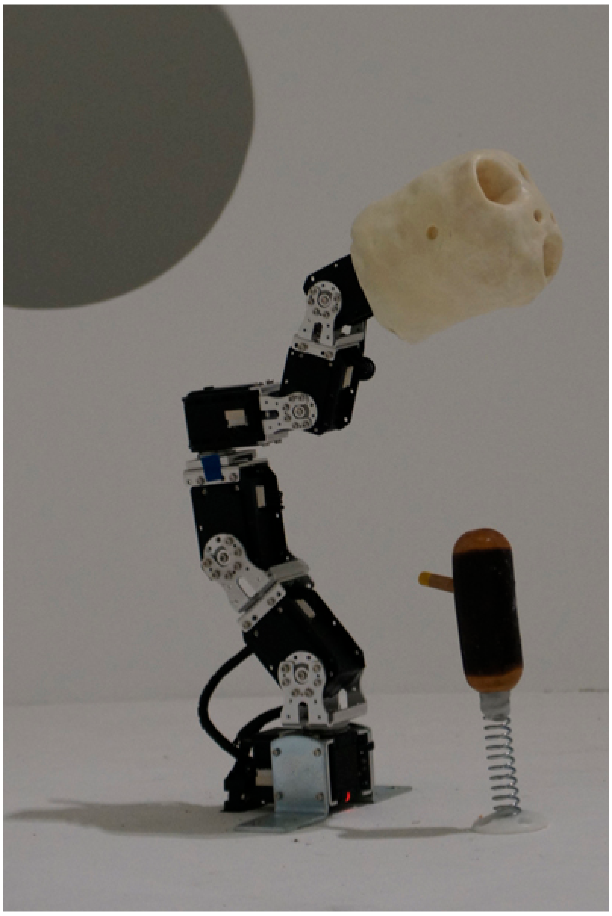

Figure 7. A Stem with the head designed by David Lynch and an Object

Birds Curiosity is a behaviour that drives robots to explore, through curiosity-driven learning, interaction with humans. One stem, generally the stem in the center, plays a sound, predicts the visitor reaction, look the interaction zone and wait the gesture of the visitor. To produce a sound the visitor have to make a gesture in space. In the next iterations, the robot chooses to produce sounds to human which produce most surprising responses from the human (i.e. the robot is "interested" to explore sound interactions which are not easily predictable by itself).. As describe in the picture, the space is split in four. Each zone corresponding with a sound.

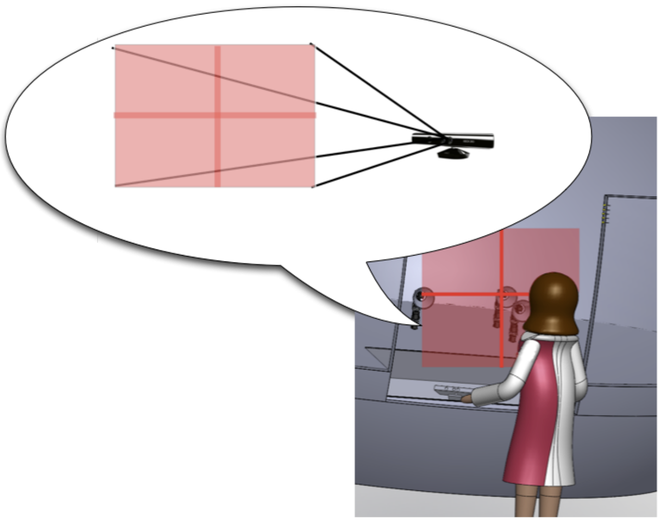

Figure 8. A virtual visitor interact with a virtual grid

5.3.5.3. Programming tools

The system is based on URBI and used some UObjects from UFlow. The most important part of the system is written in URBI script. Python and freenect [3] are used too.

The system at the startup detects motors and lights. It create dynamically a list of Stem. A Stem is one robot with 6 motors as described in hardware part.

To interact with people, we used the freenect library to interface with the kinect, with a binding to python where detection and following of gestures is made.

For the display, we display an abstract rendering of the structure inside each ErgoRobot, using a python parser to read and parse log file from the ErgoRobot system, and the Bloom/Processing software to create and display the rendering. Currently, the system has three displays, one for the naming game, another one for birds curiosity and the last one for objects curiosity.

The sound system used the UObject USoundManager. It plays sounds when required by a behaviour, it also plays word sounds in Naming Game behaviour.

The Light system used Linkm technologies. In the head of each ErgoRobot we put two lights devices. Each light device is a RGB Light. We can control the intensity of each primary color through I2C control. To control lights we used LinkM USB Device. And finally we used an UObject dedicated to communicate with the USB Device.

[3] Kinect library

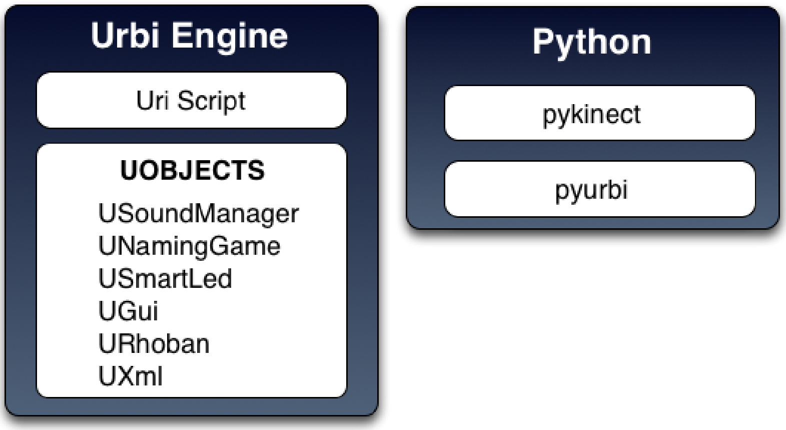

Figure 9. List of software used in ErgoRobots

5.3.5.4. Maintenance

A dedicate maintenance software is used to switch off, switch on the system. This software is written in Python (and Qt). The status of ErgoRobots is display on the graphical interface. Buttons are present too : Start, Stop, Reset and Take a video.

Recently we added a video system to have a visual feedback of motors usage and also to detect eventual problems. This is a screenshot of the application :

5.4. Visualization Tools

5.4.1. Zephyr - Visualization Platform

Participant: Thomas Degris [correspondant].

Zephyr is a software in Java and Eclipse Rich Client Platform to visualize numeric variables and data structure in real time and at different time scale. Zephyr is practical for developers because it requires only minimal changes in the code to debug: it uses Java reflexivity to automatically detect variables in the code to monitor and data structure with an associated dedicated view. Zephyr can easily be extended with new plugins because it is based on the popular Eclipse Rich Client Platform. Consequently, Zephyr takes advantage of already existing and fully operational Eclipse plugins for many of its functionalities. Finally, Zephyr is distributed with a Java python virtual machine named Jython and a lisp implementation named Clojure. An example of a Zephyr screen is shown in Figure 11.

Zephyr was started in fall 2009 in the RLAI group at the university of Alberta (Canada) when Thomas Degris was a postdoc in this group. Zephyr is still actively used by RLAI. Users include Adam White, Joseph Modayil and Patrick Pilarski from the University of Alberta. Moreover, Zephyr has been registered on the Eclipse marketplace since October 2011 where it has been downloaded a few times by anonymous users. Future dissemination includes the implementation of demos and tutorial videos. Documentation about Zephyr is included on http://thomasdegris.github.com/zephyr/. Zephyr is licensed under the open source Eclipse Public License.

5.4.2. Bloom - particle-based physical engine

Participants: Fabien BENUREAU [correspondant], Olivier Mangin [correspondant].

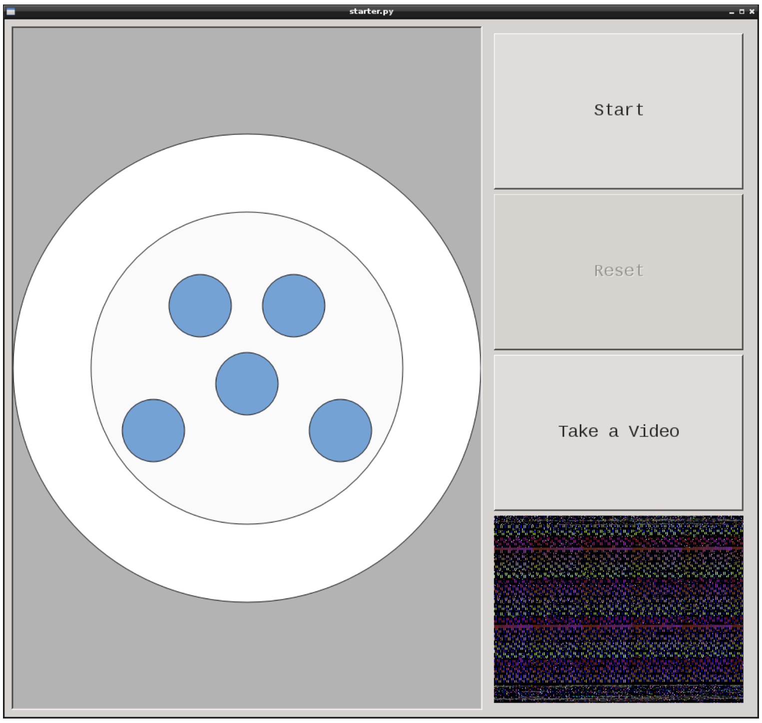

Figure 10. Maintenance Software for the ErgoRobots.

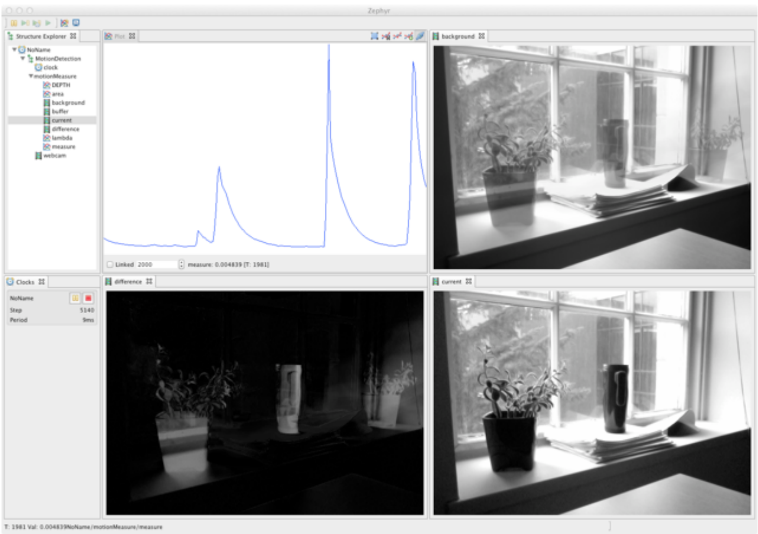

Figure 11. An example of Zephyr showing the different steps of a video processing pipeline in real-time.

Bloom is a particle-based physical engine that was coded for the Ergorobot exhibition. Written in a matter of days in September 2011, Bloom is based on Processing and coded in Java. It is currently running all of the projected visualisation of the Ergorobot installation. Bloom greatest strength is to provide an intuitive and lightweight tool to display of complex and dynamic information, such a the morphology of a robot vocabulary, as shown in Figure 12. As such, it should permit to examine the state of complex data structure in real-time during experiment, getting insights and allow detection and tracking of issues in algorithms being developed. Bloom is a great complement in research work to the use of charts and graphs. Bloom has since be made available and presented to the team in December 2011.

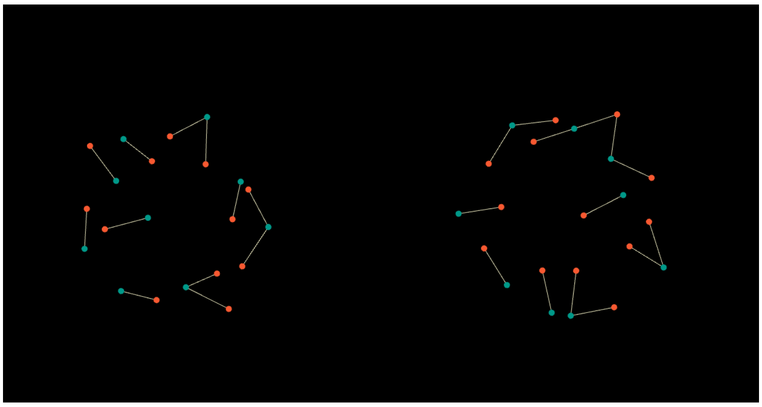

Figure 12. The vocabulary of 2 interacting robots of the ErgoRobot installation. The blue particles represent meanings, while the orange ones represent words. The strength of association between them is represented by the length of the edges linking them (shorter is stronger). It easy to spot the presence of synonyms and of difference of topology in the vocabulary of the two robots.

5.5. Hardware

5.5.1. The Ergo-Robots Hardware Platform

Participants: Jerome BECHU [correspondant], Fabien BENUREAU, Haylee FOGG, Hugo GIMBERT, Matthieu LAPEYRE, Olivier LY, Olivier MANGIN, Pierre-Yves OUDEYER, Pierre ROUANET.

ErgoRobots is a hardware platform for showcasing a number of curiosity and learning behaviours for the public to interact with. The platform can also have future uses inside the lab for experiments that require more than one robot to complete. Although this system is entirely new this year, a very different previous version existed with the name FLOWERSField. It consists of five ErgoRobots, a control system, an interaction system, a display system, a sound system and a light system. There is an external system which monitors the ErgoRobots which contains a control system, a power system, a surveillance system and a metric capture system. This system went live on October 19 2011 without lights which will be added in late December.

The Ergo-Robot system: The robots themselves are each composed of six motors (see figure). Currently, the heads of the robots have been created in wax by David Lynch and the entire system is displayed at Fondation Cartier inside a large egg shaped orb as shown in the following diagram. The control system module contains both an MMNET1002 control board with an UART-RS485 breakout board which communicates with a ubuntu Linux PC via an ethernet cable. The mment board communicates with the motors, but all other ErgoRobot systems communicate with the PC directly. The sound system is currently externally provided and communicates with the PC. The light system is a series of two or three BlinkM RGB leds placed inside each ErgoRobot head that are controlled through two LinkM USB devices directly with the computer. A kinect placed in front of the system operates as the means for the public to interact with the platform and communicates directly through USB to the PC. The display system is currently an externally provided projector that projects visualisations of the field's current state behind the ErgoRobots.

The external system: This system allows anyone that is monitoring the system to externally control the ErgoRobots system. The PC with which the software control takes place is a Ubuntu Linux system which communicates with the ErgoRobot control system via an ethernet cable. The ErgoRobot harware system can be managed by an external power system which includes a 15.5V bench top power supply for the ErgoRobot motors, an external 12V plug in adapter for the mment board, an external 5V plug in adapter for the LED lights which are all controlled via an emergency stop button. The maintenance system can be located out of direct view of the ErgoRobot field as it has a surveillance system: a kinect that can display the current state of the field. More surveillance is conducted through a metric capture system that communicates with the ErgoRobots to obtain various state values of the ErgoRobots through the motor sensors and other data. This surveillance is not entirely in place as of 2011 and will be implemented in early 2012.

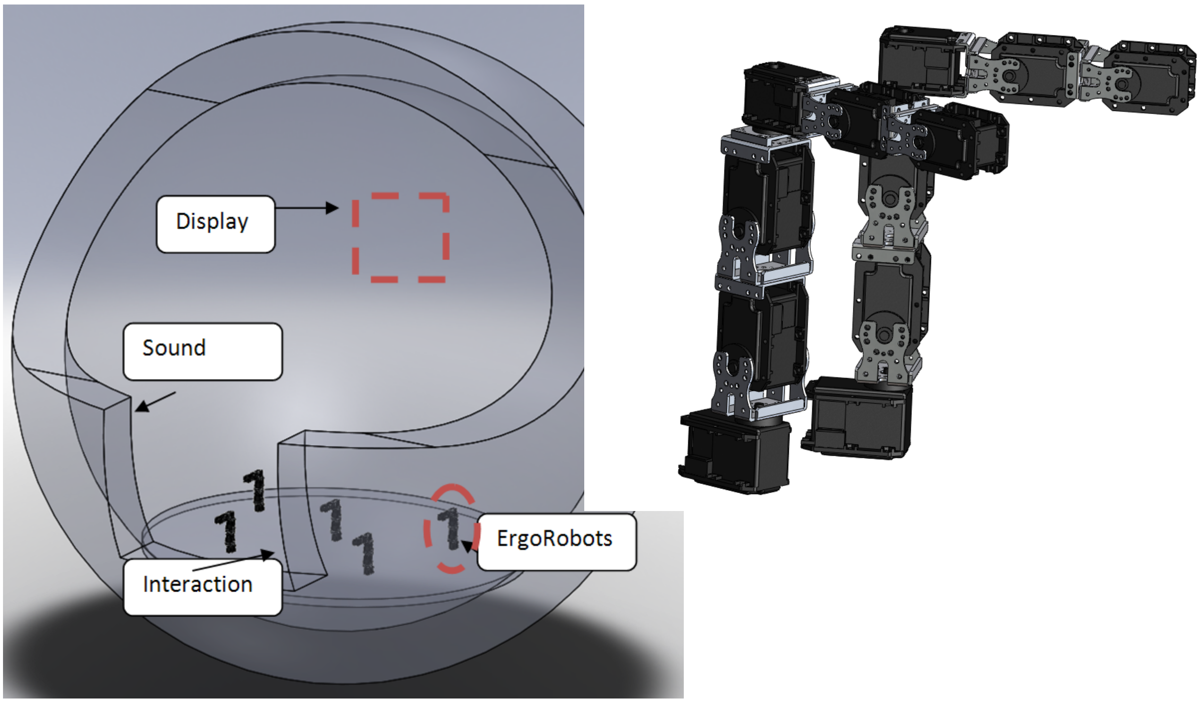

Figure 13. Ergo-Robots

5.5.2. Flowers Field/Robot Lamps

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

We continued to develop the FLOWERS FIELDS/Robot Lamps experimental set-up, see Figure 14. This set-up 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/Robot Lamps, 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 year, a major update of the platform consisted in shifting the whole servomotor technology to the RX Robotis Series, allowing much more robustness and sophistication of control. The software was adapted to these new motors, requiring indeed a new mode of control together with a new electronic board. This installation was demonstrated in march 2011 at the INNOROBO International Summit on Personal Robotics in Lyon.

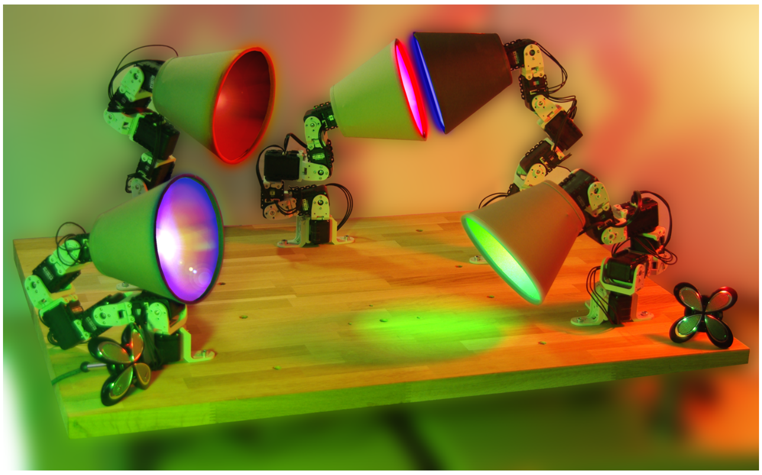

Figure 14. Flowers Fields/Robot Lamps

5.5.3. Humanoid Robot Torso

Participant: Haylee FOGG [correspondant].

The Humanoid Robot Torso is a hardware platform that is intended for use in the lab for either experiments or demonstrations. It consists of a humanoid robot that contains just a torso, arms and head. It is entirely new this year, but it has been updated once during the year. The previous version was inspired by Acroban and consisted of 20 degrees of freedom. The update began in November of 2011 where 3 degrees of freedom was removed from the spine and one degree of freedom was removed from the head.

The Torso has two arms. At the time of writing one arm consists of a three fingered claw that is controlled by a single motor, and the other is just a flat push mechanism. The arm with the claw contains seven degrees of freedom (including 'grip') and the other only five. The torso itself has two degrees of freedom. The head is soon to consist of an iPhone for the face and a separate usb camera for the 'eyes' with the ability to move in two degrees (pitch and roll) in early 2012.

The hardware is both robotis Dynamixel RX-28 and R-64 motors attached together with standard robotis frames and a substance called polymorph. Polymorph is used to attach a series of springs and elastic to many of the degrees of freedom to increase smoothing and absorb backlash of the motors. Polymorph was added in November 2011 to replace the previous versions metal that was tooled in the lab.

A method for controlling the motors of the Torso will be under review in 2012.

6. New Results

6.1. Autonomous Development of Representations

6.1.1. *Open-ended bootstrapping of new sensorimotor representations*

Participant: Alexander Gepperth.

We have explored a novel approach to the open-ended development of internal representations in autonomous agents, addressing in particular the transfer of knowledge between different modalities or abstraction levels. We propose a self-organized neural learning paradigm termed PROPRE (projection-prediction) that is driven by *predictability*: competitive advantages are given to those feature-sensitive elements that are inferable from activity in a *reference representation*, which may be innate or previously formed by learning. For generating and adapting the new *induced representations*, PROPRE implements a bi-directional interaction of clustering ("projection") and inference ("prediction"), the key ingredient being an easy-to-compute online measure of predictability, by which the projection step is encouraged to favor sensitivity to predictable clusters. We demonstrated the potential of this paradigm by several simulation experiments with synthetic inputs. We showed that induced representations are indeed significantly more sensitive to predictable stimuli, that they are continuously being adapted to changing input statistics and that the behavior under severe resource constraints is favorable.

6.1.2. *The contribution of context information to object detection in intelligent vehicles*

Participants: Alexander Gepperth, Michael Garcia Ortiz.

In this work package, we explored the potential contribution of multimodal context information to object detection in an "intelligent car". The used car platform incorporates several sophisticated processing subsystems, both for the detection of objects from local visual patterns as well as for the estimation of global scene properties, e.g., the shape of the road area, or the 3D position of the ground plane (sometimes denoted "scene context" or just "context"). Annotated data recorded on this platform is publicly available as the "HRI RoadTraffic" vehicle video dataset, which formed the basis for this investigation.

In order to quantify the contribution of context information, we investigated whether it can be used to infer object identity with little or no reference to local patterns of visual appearance. Using a challenging vehicle detection task based on the "HRI RoadTraffic" dataset, we trained selected algorithms to estimate object identity from context information *alone*. In the course of our performance evaluations, we also analyzed the effect of typical real-world conditions (added noise, high dimensions, environmental variation) on context model performance.

As a principal result, we showed that the learning of context models is feasible with all tested algorithms, and that object identity can be estimated from context information with similar accuracy as by relying on local pattern recognition methods. We also found that the use of *basis function representations* (also known as "population codes") allows the simplest (and therefore most efficient) learning methods to perform best in the benchmark, suggesting that the use of context is feasible even in systems operating under strong performance constraints.

6.1.3. *Discovering object concept through developmental learning*

Participants: Natalia Lyubova, David Filliat.

The goal of this work is to design a visual system for a humanoid robot. Taking inspiration from childs' perception and following the principles of developmental robotics, the robot should detect and learn objects from interactions with people and from experiments it performs with objects, avoiding the use of image databases or of a separate training phase. In our model, all knowledge is therefore iteratively acquired from low-level features and builds up hierarchical object models, which are robust to changes in the environment, background and camera motion.

In our scenario, people in front of the robot are supposed to interact with objects to encourage the robot to focus on them. We therefore assume that the robot is attracted by motion and we segment possible objects based on clustering of the optical flow. Additionally, the depth information from a Kinect is used to filter visual input, considering the constraints of the robot's working area and to refine the object contours obtained from motion segmentation.

The appearance of objects is encoded following the Bag of Visual Words approach with incremental dictionaries. We combine several complementary features to maximize the completeness of the encoded information (SURF descriptor and superpixels with associated colors) and construct pairs and triples of these features to integrate local geometry information. These features make it possible to decide if the current view has been already seen or not. A multi-view object model is then constructed by associating recognized views and views tracked during object motion.

This system is implemented on the iCub humanoid robot, which detects objects in the visual space and characterizes their appearance, their relative position and their occurrence statistics. Ten objects were presented in the current experiment; each of them was manipulated by a person during 1-2 minutes. Once the vocabulary reached a sufficient amount of knowledge, the robot was able to reliably recognize human hands and most of objects.

6.1.4. Scaling-up Knowledge for a Cognizant Robot

Participants: Thomas Degris, Joseph Modayil.

A cognizant robot is a robot with a deep and immediately accessible understanding of its interaction with the environment—an understanding that the robot can use to flexibly adapt to novel situations. Such a robot will need a vast amount of situated, revisable, and expressive knowledge to display flexible intelligent behaviors. Instead of relying on human-provided knowledge, we consider the case where an arbitrary robot can autonomously acquire pertinent knowledge directly from everyday interaction with the environment. We study how existing ideas in reinforcement learning theory can be used to formalize knowledge and use reinforcement learning techniques to enable a robot to maintain and improve its own knowledge. We consider robot performing a continual learning process that scales-up knowledge acquisition to cover a large number of facts, skills and predictions. This knowledge has semantics that are grounded in sensorimotor experience and can then be used for more abstract process such as planning. We see the approach of developing more cognizant robots as a necessary key step towards broadly competent robots.

Paper being published: *Scaling-up Knowledge for a Cognizant Robot* accepted at Designing Intelligent Robots: Reintegrating AI, AAAI Spring Symposium 2012.

6.1.5. Learning parallel combinations of motor primitives from demonstration and linguistic guidance with non-negative matrix factorization

Participants: Olivier Mangin, Pierre-Yves Oudeyer.

We have elaborated and experimented a novel approach to joint language and motor learning from demonstration. It enables discovery of a dictionary of motor and linguistic primitives, that can be combined in parallel to represent training data as well as novel skills in the form of combinations of known skills. These methods and the results of our experiments participate in addressing two main issues of developmental robotics: 1) symbol grounding for language learning; 2) achieving compositionality in motor-learning from demonstration, which enables re-using knowledge and thus scaling to complex tasks. In particular, we are intereseted in learning motor primitives active in parallel, a less explored way of combining such primitives. To address these challenges we have explored and studied the use of nonnegative matrix factorization to dicover motor primitives from histogram representations of data acquired from real demonstrations of dancing movements. Initial results were presented in [30] and further results are presented in an article under review.

6.2. Learning Algorithms for Autonomous Robots: Concepts and Algorithms

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

Participants: Adrien Baranès, Pierre-Yves Oudeyer.

We have continued to develop and experiment the Self-Adaptive Goal Generation - Robust Intelligent Adaptive Curiosity (SAGG-RIAC) algorithm as an intrinsically motivated goal exploration mechanism which allows high-dimensional redundant robots with various body schemas to efficiently and actively learn motor skills in their task space. The main idea is to push the robot to perform active babbling in the low- dimensional goal/task space, as opposed to motor babbling in the high-dimensional actuator space (possibly defined with motor primitives), by self-generating goals actively and adaptively in regions of the task space which provide a maximal competence improvement for reaching those goal states. Then, a lower level active motor learning algorithm is used to drive the robot to locally explore how to reach a given self-generated goal. We have conducted systematic experiments with high-dimensional continuous sensorimotor spaces related to different robotic setups such as a highly-redundant robotic arm, a quadruped, and an arm controlling a fishing rod with a flexible wire and show that 1) exploration in the task space can be a lot faster than exploration in the actuator space for learning inverse models in redundant robots; 2) selecting goals based on the maximal improvement heuristics creates developmental trajectories driving the robot to progressively focus on areas of increasing complexity and is statistically significantly more efficient than selecting goals randomly, as well as more efficient than different standard active motor babbling methods. These results were published in [13], [15], [17] and a journal publication is in preparation.

6.2.2. SGIM-D: Bootstrapping Intrinsically Motivated Learning with Human Demonstration

Participants: Mai Nguyen, Pierre-Yves Oudeyer.

We have studied the coupling of internally guided learning and social interaction, and more specifically the improvement owing to demonstrations, of the learning by intrinsic motivation. We have designed Socially Guided Intrinsic Motivation by Demonstration (SGIM- D), an algorithm for learning the mapping between high dimensions in continuous, non-preset, highly redundant environments. We have shown through a robot learning experiment involving a high-dimensional sensorimotor space related to fishing skills that SGIM-D efficiently combines the advantages of social learning and intrinsic motivation to gain a wide repertoire while being specialised in specific subspaces. An article presenting aspects of this work was awarded the second best student paper award in IEEE ICDL/Epirob 2011 [27].

6.2.3. Maturationally-Constrained Competence-Based Intrinsically Motivated Learning

Participants: Adrien Baranès, Pierre-Yves Oudeyer.

We have continued to develop computational models of the coupling of intrinsic motivations and physiological maturational constraints, showing that both mechanisms may have complex bidirectional interactions allowing the active control of the growth of complexity in motor development which directs an efficient learning and exploration process. The coupling relies on the Self- Adaptive Goal Generation - Robust Intelligent Adaptive Curiosity algorithm (SAGG-RIAC) that instantiates an intrinsically motivated goal exploration mechanism for motor learning of inverse models. Then, we have introduced a functional model of maturational constraints inspired by the myelination process in humans, and showed how it can be coupled with the SAGG-RIAC algorithm, forming a new system called McSAGG-RIAC2. We have then conducted systematic experiments to evaluate qualitative and, more importantly, quantitative properties of these systems when applied to the learning of the forward and inverse kinematic of an unknwn robotic arm of up to 60 dimensions, the learning of walking in a 12DOF quadruped controlled with 24 dimensions motor synergies, and learning the control of a fishing rod involving a flewible/rope component. These results were published in [13], [15], [17] and a journal publication is in preparation.

6.2.4. Actor-Critic for Parallel Learning

Participants: Thomas Degris, Matha White, Richard Sutton.

Parallel learning is necessary for a robot to learn multiple tasks in parallel while executing a behavior in the environment not necessarily directly related to the tasks to learn. In previous existing work, an interesting class of learning algorithms for control are actor–critic. First, these algorithms can be used with high-dimensional action space. Second, they also sometimes provide computational models for biological decision-making systems. At FLOWERS, we work on new actor–critic algorithms suitable for parallel learning, with theoretical guaranties, applicable and practical to use with robots, and formulated in the general framework of reinforcement learning.

6.2.5. Curiosity for Parallel Learning of Predictions and Tasks from the Continuous Interaction of a Robot with its Environment

Participants: Thomas Degris, Adam White, Pierre-Yves Oudeyer.

On one hand, a robot needs a wide variety of knowledge to fully interact with its environment. On the other hand, a robot, like humans or animals, can only perform one behavior at a time in the real world to learn this vast amount of knowledge. A solution to scale up learning while keeping the interaction time with the real world realistic is to learn multiple elements of knowledge simultaneously in parallel. The Horde architecture proposes a set of demons each learning about new policies (i.e. skills) and predictions about these skills (i.e. partial models) off-policy simultaneously. The number of demons learning in parallel is limited only by memory and processing power, and not by the fact that there is only one sensorimotor interaction with the environment to learn from. At FLOWERS, we investigate the question of what the behavior policy of the robot should be to speed-up learning of the demons. Our goal is to test if the Horde scales-up to complex humanoid robots and if, driven by intrinsic motivations, it can autonomously learn building blocks of knowledge for future, more complex, behaviors.

6.2.6. Optimal Teaching on Sequential Decision Tasks

Participants: Manuel Lopes, Maya Cakmak.

A helpful teacher can significantly improve the learning rate of an autonomous learning agent. Teaching algorithms have been formally studied within the field of Algorithmic Teaching. These give important insights into how a teacher can select the most informative examples while teaching a new concept. However the field has so far focused purely on classification tasks. In this paper we introduce a novel method for optimally teaching sequential decision tasks. We present an algorithm that automatically selects the set of most informative demonstrations and evaluate it on several navigation tasks. Next, we present a set of human subject studies that investigate the optimality of human teaching in these tasks. We evaluate examples naturally chosen by human teachers and found that humans are generally sub-optimal. Then based on our proposed optimal teaching algorithm we try to elicit better teaching from humans. We do this by explaining the intuition of the teaching algorithm in an informal language prior to the teaching task. We found that this improves the examples elicited from human teachers on all considered tasks. This shows that a simple modification the instructions given to human teachers, has the potential of greatly improving the performance of the agent trained by the human [41].

6.2.7. Inverse Coordinated Reinforcement Learning

Participants: Manuel Lopes, Jonathan Sprauel.

Inverse Coordinated Reinforcement Learning

We extended of inverse reinforcement learning to the multi-agent case. Under this formalism a team of agents can learn a task goal, encoded as a reward function, by observing another team executing that task. Our agents behave using local information and limited communication following the coordinated reinforcement learning framework. We show that a team behavior can be learned using this formalism and how well this mechanism can deal with changing initial conditions and number of agents [68].

6.3. Motor Learning and Morphological Computation

6.3.1. Morphological Computation in Acroban the Humanoid: Balance Control and Dynamic Walking

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

We have continued to elaborate and experiment 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; 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. 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. These results were presented in [25]. A dedicated web page with videos is available at: http://flowers.inria.fr/acroban.php.

6.3.2. Maturational constraints for motor learning in high-dimensions: the case of biped walking

Participants: Matthieu Lapeyre, Pierre-Yves Oudeyer, Olivier Ly.

We have elaborated and began to experiment a new developmental approach to motor learning in very high-dimensions, applied to learning biped locomotion in humanoid robots. This approach relies on the formal modeling and coupling of several advanced mechanisms inspired from human development for actively controlling the growth of complexity and harnessing the curse of dimensionality: 1) Maturational constraints for the progressive release of new degrees of freedoms and progressive increase their explorable ranges; 2) Motor synergies; 3) Morphological computation; 4) Social Guidance. An experimental setup involving a simulated version of the Acroban Humanoid robot, based on the V-REP simulator, has been elaborated, and initial encouraging results were obtained. These results are presented in [23].

6.3.3. Acroban v2: improving morphological computation with dampers

Participant: Olivier Ly.

Theoretical studies and experiments concerning in particular dynamics of passive walkers drove us to design, construct and continue to experiment 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 chocks. Indeed, during the gait, the unstability is mainly due to chock 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 which are 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 makes is 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 chocs in a significant maner. Experiment shows that stability of the whole structure is greatly improved especially during locomotion.

6.4. HRI and Robot Language Teaching

6.4.1. Intuitive and Robust Physical Human-Robot Interaction with Acroban

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

We have experimented and shown how the humanoid robot Acroban allows whole-body robust, natural and intuitive physical interaction with both adults and children. These physical human-robot interaction are made possible through the combination of several properties of Acroban: 1) it is whole-body compliant thanks to variable impedance control and also thanks to the use of elastics and springs; 2) it has a bio-inspired vertebral column allowing more flexibility in postural and equilibrium control; 3) it is light- weight; 4) it has simple low-level controllers that leverage the first three properties. Moreover, the capabilities for physical human-robot interaction that we show are not using a model of the human, and in this sense are “model free”: 1) the capability of the robot to keep its equilibrium while being manipulated or pushed by humans is a result of the intrinsic capability of the whole body to absorb unpredicted external perturbations; 2) the capability of leading Acroban by the hand is an emergent human-robot interface made possible by the self-organizing properties of the body and its low-level controllers and was observed a posteriori only after the robot was conceived and without any initial plan to make this possible. Finally, an originality of Acroban is that is is made with relatively low-cost components which lack of precision is counterbalanced with the robustness due to global geometry and compliance. These results were presented in [28]. A dedicated web page with videos is available at: http://flowers.inria.fr/acroban.php.

6.4.2. A Real World User Study of Different Interfaces for Teaching New Visually Grounded Words to a Robot

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

We have continued to elaborate and experiment an integrated system based on a combination of advanced Human-Robot Interaction, visual perception and machine learning methods that allows non-expert users to intuitively and robustly teach new visually grounded words to robots. This system is based on the state-of-the-art bags of words technique but focuses on different mediator based interfaces that we can propose to the users. Indeed, we argue that by focusing on interaction we could help users to collect good learning examples and thus improve the performance of the overall learning system. We compared four different interfaces and their impact on the overall system through a real world study where we asked participants to show and teach a robot names for five different objects. Three interfaces were based on mediator objects such as an iPhone, a Wiimote and a laser pointer and provided the users with different kinds of feedback of what the robot is perceiving. The fourth interface was gesture based with a Wizard-of-Oz recognition system included in order to compare our mediator interfaces with a more natural interaction. We showed that the interface may indeed strongly impact the quality of the learning examples collected by users, especially for small objects. More precisely, we showed that interfaces such as the iPhone interface do not only give feedback about what the robot is perceiving but also drive users to pay attention to the learning examples they are collecting. Thus, this interface allows non-expert users to intuitively and easily collect almost as good learning examples as expert users trained for this task and aware of the different visual perception and machine learning issues. Finally, we showed that the mediator based interfaces were judged as easier to use than the a priori more natural gestures based interface. This work was presented in [29].

6.4.3. Language Acquisition as a Particular Case of Context-Dependant Motor Skills Acquisition

Participants: Thomas Cederborg, Pierre-Yves Oudeyer.

Imitation learning, or robot programing by demonstration, have made important advances in recent years. We have proposed to extend the usual contexts investigated to also include linguistic expressions. We have proposed a modification to existing algorithms within the imitation learning framework so that they can handle learning from the demonstration of several unlabelled tasks (or motor primitives) without having to inform the imitator of what task is being demonstrated or what the number of tasks is, which then allows directly for relatively complex language learning. A mechanism for detecting wether or not linguistic/speech input is relevant to the task has also been proposed. 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 learns a word by knowing that 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. To demonstrate this ability to find the relevance of speech 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). A simulated experiment demonstrates that an imitator can indeed find the number of tasks it has been demonstrated, discover what demonstrations are of what task, for which of the tasks speech is relevant and successfully reproduce those tasks. This work is presented in a publication under review.

6.4.4. Robot Learning by Imitation of Internal Cognitive Operations in the Context of Language Acquisition

Participants: Thomas Cederborg, Pierre-Yves Oudeyer.

We have examined the problem of learning socio-linguistic skills through imitation when those skills involve both observable motor patterns and internal unobservable cognitive operations. This approach is framed in a research program trying to investigate novel links between context-dependent motor learning by imitation and language acquisition. More precisely, the paper presents an algorithm for learning how to respond to communicative/linguistic actions of one human, called an interactant, by observing how another human, called a demonstrator, responds. The response of the demonstrator, which depends on the context, including the signs of the interactant, is assumed to be appropriate and the robotic imitator uses these observations to build a general policy of how to respond to interactant actions. In this paper the communicative actions of the interactant is hand signs, and the learnt behavior consists of how to respond to the hand signs of a small and simple sign language, both in terms of adequately focusing attention on the right part of the scene, and in terms of responding physically. As a response to two continuous signs of the interactant, the demonstrator focuses on one out of three objects, and then performs a movement in relation to the object focused on. An algorithm is proposed based on a similarity metric between demonstrations, and a simulated experiment is presented where the unseen “focus on object” operation and the hand movements are successfully imitated, including in situations where there are no demonstrations. This work has been pubished in [21]

6.4.5. Learning Simultaneously New Tasks and Feedback Models in Socially Guided Robot Learning

Participants: Manuel Lopes, Thomas Cederborg, Pierre-Yves Oudeyer.

We have developped a system that allows a robot to learn simultaneously new tasks and feedback models from ambiguous feedback in the context of robot learning by imitation. We have considered an inverse reinforcement learner that receives feedback from a user with an unknown and noisy protocol. The system needs to estimate simultaneously what the task is, and how the user is providing the feedback. We have further explored the problem of ambiguous protocols by considering that the words used by the teacher have an unknown relation with the action and meaning expected by the robot. This allows the system to start with a set of known symbols and learn the meaning of new ones. We have presented computational results that show that it is possible to learn the task under a noisy and ambiguous feedback. Using an active learning approach, the system is able to reduce the length of the training period. [24], [26].

6.5. Hardware

6.5.1. Ergo-Robots/FLOWERS Fields: Towards Large-Scale Robot Learning Experiments in the Real World

Participants: Jérome Béchu, Fabien Bénureau, Haylee Fogg, Paul Fudal, Hugo Gimbert, Matthieu Lapeyre, Olivier Ly, Olivier Mangin, Pierre Rouanet, Pierre-Yves Oudeyer.

In the context of its participation to the exhibition "Mathematics: A Beautiful Elsewhere" at Fondation Cartier pour l'Art Contemporain in Paris, starting from 19th October 2011 and to be held until 18th March 2012, the team has elaborated and experimented a robotic experimental set-up called "Ergo-Robots/FLOWERS Fields". This set-up is not only a way to share our scientific investigations with the general public, but attacks a very important technological challenge impacting the science of developmental robotics: How to design a robot learning experiment that can run continuously and autonomously for several months? Indeed, developmental robotics takes life-long learning and development as one of its central objective and object of study, and thus shall require experimental setups that allow robots to run, learn and develop for extended periods of time. Yet, in practice, this has not been possible so far due to the unavailability of platforms adapted at the same time to learning, exploration, easy and versatile reconfiguration, and extended time of experimentation. Most experiments so far in the field have a duration ranging from a few minutes to a few hours. This is an important obstacle for the progress of developmental robotics, which would need experimental set-ups capable of running for several months. This is exactly the challenge explored by the Ergo-Robots installation, which we have approached by using new generations of affordable yet sophisticated and powerful off-the-shelf servomotors (RX Series from Robotis) combined with an adequately designed software and hardware architecture, as well as processes for streamlined maintainance. The experiment is now running for five months, six days a week, in a public exhibition which has strong constraints over periods of functionning and no continual presence of dedicated technicians/engineers on site. The experiment involveds five robots, each with 6 degrees of freedoms, which are endowed with curiosity-driven learning mechanisms allowing them to explore and learn how to manipulate physical objects around them as well as to discover and explore vocal interactions with humans/the visitors. The robots are also playing language games allowing them to invent their own linguistic conventions. A battery of measures has been set up in order to study the evolution of the platform, with the aim of using the results (to be described in an article) as a reference for building future robot learning experiments on extended periods of time, both within the team and in the developmental robotics community. More information available at: http://flowers.inria.fr/ergo-robots.php and http://fondation.cartier.com/.

7. Contracts and Grants with Industry

7.1. Contracts with Industry

Honda: Alexander Gepperth conducted a 6-month research contract with Honda Research Institute America, Inc. on pedestrian pose classification in 2011.

7.2. Grants with Industry

7.2.1. Pal Robotics:

Freek Stulp is collaborating with Pal Robotics in Barcelona to implement and evaluate the use of Dynamic Motion Primitives on the commercial mobile platform 'REEM'. A particular focus of this project is to compare the respective advantages of motion primitives and sampling-based motion planning approaches in the context of human-robot interaction. We intend to submit this work to the International Journal of Robotics Research, for a special issue on "Motion Planning for Physical Robots". Pal Robotics is supporting Freek Stulp by co-financing travel costs for regular project meetings in Barcelona.

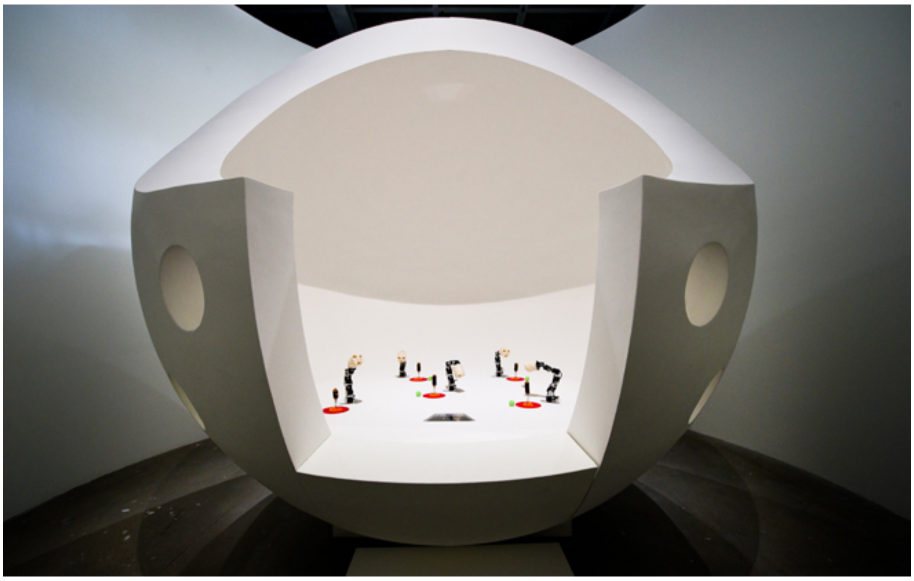

Figure 15. Installation of Ergo Robots at Foundation Cartier.

7.2.2. Fondation Cartier pour l'Art Contemporain:

The team has been collaborating with Fondation Cartier pour l'Art Contemporain in the context of the elaboration of the exhibition "Mathematical: A Beautiful Elsewhere" (http://fondation.cartier.com), to be held from October 2011 to March 2012, as well as with artist David Lynch, to build the robotic installation/experiment Ergo-Robots/FLOWERS Fields. This robotic installation illustrates, as well as allows to experiment in a realistic setup on the long term, computational models of curiosity-driven learning, human-robot interaction and language formation. Fondation Cartier participated to the funding of this experiment/installation. A dedicated web page is available at: http://flowers.inria.fr/ergo-robots.php

8. Partnerships and Cooperations

8.1. Regional Initiatives

8.1.1. CRA ARAUI

A Conseil Régional d'Aquitaine Project (ARAUI, 2011-) began, coordinated by Manuel Lopes entitled *Apprentissage Automatique en Robotique pour l'Adaptation aux Utilisateurs a Travers L'Interaction*. It will fund 50% of a 3 years PhD student and funding of 5500 euros for equipment.

The objective of ARAUI is the creation of robots that initiate autonomously the execution of frequent tasks after learning about the user's preferences through repeated interactions. Particularly these robots will act as personal companions or helpers and will be able to perform shared tasks with humans.

The long-term view of this project is that of a robot that comes out of the box with general purpose motor and sensory skills and then is adapted to each user's preferences and needs to achieve autonomous behavior. The major challenge is how to equip machines with such adaptability and learning capabilities. Until now machines are programmed by skilled engineers to perform a specific task and learning new tasks is not possible. Even in a restricted industrial setting the need for robots that can be more easily re-programmed to new tasks and environments has lead to research programs on flexible manufacturing that consider frequent changes in tasks and close (physical) interactions with human operators.

8.1.2. CRA DEVROB

The Conseil Régional d'Aquitaine Project (DEVROB, 2008-) continued, involving Pierre Rouanet and Pierre-Yves Oudeyer. The funding contributes with 50% funding for a 3 years PhD student. The objective of DEVROB is to study, elaborate and experiment human-robot interfaces that allow a non-engineer human to teach intuitively and robustly new visually grounded words to a robot.

8.1.3. CRA ACROBATE

The Conseil Régional d'Aquitaine Project (ACROBATE, 2009-) continued, involving Thomas Cederborg and Pierre-Yves Oudeyer. The funding contributes with 50% funding for a 3 years PhD student. The objective of ACROBATE is to study mechanisms and models that can allow a robot to learn in a unified manner context-dependant motor skills and linguistic skills through interactions with humans.

8.1.4. ADT Acrodev

The ADT project (Acrodev, 2010-) continued, involving Paul Fudal, Haylee Fogg, Olivier Ly and Pierre-Yves Oudeyer. The INRIA ADT funds two engineers for two years. The objective of Acrodev is on the one hand to build up re-usable software architectures for embedded control of Acroban-like robots, and on the other hand to explore novel morphologies in particular for the feet, hands and head of Acroban-like robots.

8.1.5. Collaboration with Institut de Neurosciences Cognitives et Integratives d'Aquitaine

A collaboration began with Jean-René Cazalets, Christophe Halgand and Etienne Guillaud from Institut de Neurosciences Cognitives et Integratives d'Aquitaine, Bordeaux. The goal is to compare properties of the postural balance, and its relation to morphology and distributed control, in humans and in the humanoid Acroban, which vertebral column and postural control shares several fundamental features with the human vertebral column, and using the "Plateforme d'analyse de la motricité" available at the Institut de Neurosciences Cognitives et Integratives d'Aquitaine. This collaboration involves Matthieu Lapeyre, Olivier Ly and Pierre-Yves Oudeyer.

8.2. National Initiatives

8.2.1. ANR MACSi

An ANR Project (MACSi, ANR Blanc 0216 02), coordinated by ISIR/Univesity Paris VI (Olivier Sigaud), on developmental robotics (motor learning, visual learning, and exploration algorithms on the ICub robot) continued. The MACSi project is a developmental robotics project based on the iCub humanoid robot and the Urbi open source software platform. It is funded an as ANR Blanc project from 2010 to 2012. The project addresses four fundamental challenges, led by four partners:

- How can a robot learn efficient perceptual representations of its body and of external objects given initially only low-level perceptual capabilities? Challenge leader : INRIA-ENSTA-ParisTech FLOWERS (Paris).
- How can a robot learn motor representations and use them to build basic affordant reaching and manipulation skills? Challenge leader : ISIR-UPMC-Paris 6 (Paris). ISIR hosts the iCub humanoid robot on which the achievements will be evaluated.
- What guidance heuristics should be used to explore vast sensorimotor spaces in unknown changing bodies and environments? Challenge leader : INRIA-ENSTA-ParisTech FLOWERS (Bordeaux).

- How can mechanisms for building efficient representations/abstractions, mechanisms for learning manipulation skills, and guidance mechanisms be integrated in the same experimental robotic architecture and reused for different robots? Challenge leader : GOSTAI company (Paris).

Web site: http://macsi.isir.upmc.fr/

8.3. European Initiatives

8.3.1. Collaborations in European Programs, ERC

Program: ERC Starting Grant

Project acronym: EXPLORERS

Project title: Exploring Epigenetic Robotics: Raising Intelligence in Machines

Duration: 12/2009-11/2014

Coordinator: Pierre-Yves Oudeyer

Abstract: In spite of considerable and impressive work in artificial intelligence, machine learning, and pattern recognition in the past 50 years, we have no machine capable of adapting to the physical and social environment with the flexibility, robustness and versatility of a 6-months old human child. Instead of trying to simulate directly the adult's intelligence, EXPLORERS proposes to focus on the developmental processes that give rise to intelligence in infants by re-implementing them in machines. Framed in the developmental/epigenetic robotics research agenda, and grounded in research in human developmental psychology, its main target is to build robotic machines capable of autonomously learning and re-using a variety of skills and know-how that were not specified at design time, and with initially limited knowledge of the body and of the environment in which it will operate. This implies several fundamental issues: How can a robot discover its body and its relationships with the physical and social environment? How can it learn new skills without the intervention of an engineer? What internal motivations shall guide its exploration of vast spaces of skills? Can it learn through natural social interactions with humans? How to represent the learnt skills and how can they be re-used? EXPLORERS attacks directly those questions by proposing a series of scientific and technological advances: 1) we will formalize and implement sophisticated systems of intrinsic motivation, responsible of organized spontaneous exploration in humans, for the regulation of the growth of complexity of learning situations; 2) intrinsic motivation systems will be used to drive the learning of forward/anticipative sensorimotor models in high-dimensional multimodal spaces, as well as the building of reusable behavioural macros; 3) intrinsically motivated exploration will be coupled with social guidance from non-engineer humans; 4) an information-theoretic framework will complement intrinsically motivated exploration to allow for the inference of body maps; 5) we will show how learnt basic sensorimotor skills can be re-used to learn the meaning of early concrete words, pushing forward human-robot mutual understanding. Furthermore, we will setup large scale experiments, in order to show how these advances can allow a high-dimensional multimodal robot to learn collections of skills continuously in a weeks-to-months time scale. This project not only addresses fundamental scientific questions, but also relates to important societal issues: personal home robots are bound to become part of everyday life in the 21st century, in particular as helpful social companions in an aging society. EXPLORERS' objectives converge to the challenges implied by this vision: robots will have to be able to adapt and learn new skills in the unknown homes of users who are not engineers. The ERC EXPLORERS is a central scientific driver of the FLOWERS team.

8.4. Exterior research visitors

Marc Toussaint from Free University of Berlin, jointly with Tobias Lang, visited INRIA as *Professeur Invités*, see details of the collaboration below.

8.5. International Initiatives

8.5.1. INRIA International Partners

- Luis Montesano, **University of Zaragoza, Spain**. Manuel Lopes collaborated with Luis Montesano on active learning approaches for grasping point learning. Results were published in Robotics and Autonomous Systems [16].
- Francisco Melo **Instituto Superior Técnico, Portugal**. Manuel Lopes collaborated with Francisco Melo on the development of active learning for inverse reinforcement learning. Recent developments consider the extension to more cues available to the learner and sampling complexity on the algorithm.
- José Santos-Victor, **Instituto Superior Técnico, Portugal**. Manuel Lopes collaborated with José Santos-Victor on the extension of affordances models to higher levels of representations, e.g. relational models.
- Maya Cakmak, Andrea Thomaz, **Georgia Tech, USA**. Manuel Lopes collaborated with Maya Cakmak on the development of optimal teaching algorithms for sequential decision problems (modeled as markov decision processes). The algorithm provides optimal demonstrations for systems that learn using inverse reinforcement learning. The joint work considers not only the algorithmic aspects but also a comparison with human behavior and the possibility of using insights from the algorithm to elicit better teaching behavior on humans [41].
- Marc Toussaint, Tobias Lang, **Free University of Berlin, Germany**. Manuel Lopes and Pierre-Yves Oudeyer are collaborating with FUB in the unification of exploration algorithms based on intrinsic motivation with methods for exploration in reinforcement learning such as R_{max}. We intend to develop a general framework for exploration in non-stationary domains. Another project consider how to learn efficient representation for robotic hierarchical planning.
- Jacqueline Gottlieb, **Columbia University, New-York, US**. Adrien Baranes, Pierre-Yves Oudeyer and Manuel Lopes began a collaboration with Jacqueline Gottlied, neuroscientist at Columbia University and specialist of visual attention and exploration in monkeys. An experimental set-up with brain imaging and behavioural observations of monkeys, and made to evaluate new families of computational models of visual attention and exploration (some of which developped in the team around the concept of intrinsic motivation) is being elaborated. Adrien Baranes will go in postdoc at Jacqueline Gottlieb's laboratory through a FullBright grant, and experiments shall begin next year.
- Louis ten Bosch, **Radboud University, The Netherlands**. Pierre-Yves Oudeyer and David Filliat continued to work with Louis ten Bosch on the modelling of multimodal language acquisition using techniques based on Non-Negative Matrix Factorization. We showed that these techniques can allow a robot to discover audio-video invariants starting from a continuous unlabelled and unsegmented flow of low-level auditory and visual stimuli.A journal article is in preparation.
- Paul Vogt (**Tillburg University, The Netherlands**), Linda Smith (**Indiana University, Bloomington, US**), Aslo Ozyurek (**Max Planck Institute for Psycholinguistics, Nijmegen, The Netherlands**), Tony Belpaeme (**University of Plymouth, UK**). Pierre-Yves Oudeyer began collaboration with partners of the NWO SCMSC project to set up a research network on modeling of social cognition and symbolic communication.
- Michael Gienger from **Honda Research Institute Europe**. Alexander Gepperth collaborated with Principal Scientist Dr.Michael Gienger from Honda Research Institute Europe GmbH about robotic grasping: this activity will result in a jointly supervised internship ("stage de fine d'études") and a publication.
- Ursula Korner from Honda Research Institute Europe. Alexander Gepperth collaborated with Senior Scientist Ursula Korner from Honda Research Institute Europe GmbH on the topic of "Biologically motivated models of robotic memory acquisition and consolidation using the PROPRE algorithm". This activity has resulted in the submission of a conference publication to the European Symposium on Neural Networks (ESANN) 2012 and will result in additional journal publications as well as the creation of a robotic demonstration system.

- Michael Garcia Ortiz, **Laboratory for Cognitive Robotics (CoR-Lab) in Bielefeld, Germany**. Alexander Gepperth collaborated with Michael Garcia Ortiz, a PhD student from the Laboratory for Cognitive Robotics (CoR-Lab) in Bielefeld, Germany, on the exploitation of scene context for object detection in intelligent vehicles. This collaboration resulted in the submission of a journal publication to the journal "Neurocomputing".
- Martha White, Patrick Pilarski, Joseph Modayil, Adam White, and Richard Sutton, **University of Alberta, Canada**. Thomas Degris is collaborating with Martha White, Patrick Pilarski, Joseph Modayil, Adam White, and Richard Sutton from the Reinforcement Learning and Artificial Intelligence group at the University of Alberta on new learning algorithms for robots. One paper is in the process of being published, two others are work in progress. Moreover, via the University of Alberta, Thomas Degris uses for his research a cluster belonging to the Alberta Ingenuity Centre for Machine Learning, and a cluster from Westgrid (http://www.westgrid.ca/), a member of the High Performance Computing consortia in Canada.
- Stefan Schaal, **University of Southern California (Los Angeles, USA)**. Freek Stulp is continuing his collaborative work with Prof. Stefan Schaal of the University of Southern California (Los Angeles, USA), and founding director of the Max-Planck-Insitute for Intelligent Systems (Tübingen, Germany). This project aims at combining algorithms from evolutionary optimization and direct reinforcement learning to achieve adaptive exploration for life-long learning in a developmental robotics context. We intend to submit this work the the International Conference on Intelligent Robots and Systems as well as the International Conference on Development and Learning.

8.5.2. Visits of International Scientists

- Marc Toussaint, Technical University Berlin, Germany (november 2011)
- Tobias Lang, Technical University Berlin, Germany (november 2011)
- Luis Montesano, University of Zaragoza, Spain (november 2011)
- Yukie Nagai, Osaka University, Japan (march 2011)
- Jan Peters, TU Darmstadt, Germany (september 2011)
- Robert Damper, University of Southampton, UK (may 2011)
- Stefano Nolfi, University La Sapienza, Roma, Italy (may 2011)
- Jacqueline Gottlieb, Columbia University, US (december 2011)
- Thomas Degris, University of Alberta, Canada (may 2011)
- Thierry Chaminade, Mediterranean Institute for Cognitive Neuroscience (INCM), CNRS - Aix-Marseille Universite) (may 2011)
- Ludovic Marin, University of Montpellier, France, (may 2011)
- Robin Salesse, University of Montpellier, France, (may 2011)
- Olivier Sigaud, University Paris VI (may 2011)

8.5.3. Participation In International Programs

8.5.3.1. NWO project: Socio-Cognitive Mechanisms of Symbolic Communication

SCMSC is a project funded by NWO (Netherlands Organization for Scientific Research) on Socio-Cognitive Mechanisms of Symbolic Communication, and coordinated by Paul Vogt (Tillburg University). This project aims to study the socio-cognitive mechanisms of symbolic communication. In contrast to other species, humans have the capacity to communicate symbolically (i.e. using forms that are either arbitrary or conventionalised) in an open fashion (i.e. with a very large repertoire of symbols). It is widely accepted that our ability to communicate symbolically has both cognitive and social roots. In recent years, traditional approaches from humanities to study symbolic communication, such as linguistics and psychology, have been complemented by computational approaches. However, interactions between researchers from the humanities with computer modellers have been few and far between, perhaps due to a lack of mutual understanding of what each field can contribute to the other.

In this project, we will set up a structural research network to improve cross fertilization between researchers from different disciplines by exchanging knowledge and experiences, and join forces to study communication multidisciplinary. This way, we aim to improve each other's research methods and investigate unifying properties of the socio-cognitive mechanisms underlying symbolic communication. To achieve this, we propose to start up an open structural research network in which we will organise two workshops, apply for joint research funding, set up an online repository of publications, educational and other materials, and publish an edited collection.

Partners are Paul Vogt (Tillburg University, The Netherlands), Linda Smith (Indiana University, Bloomington, US), Pierre-Yves Oudeyer (INRIA-ENSTA-ParisTech, France), Aslo Ozyurek (Max Planck Institute for Psycholinguistics, Nijmegen, The Netherlands), Tony Belpaeme (University of Plymouth, UK). Web site: http://ilk.uvt.nl/~paul/scmsc/SCMSC/Home.html.

9. Dissemination

9.1. Animation of the scientific community

9.1.1. 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 for IEEE Transactions on Autonomous Mental Development, Frontiers in Neurorobotics (Frontiers Foundation), 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.

9.1.2. Steering committees

Pierre-Yves Oudeyer has worked as member of the Steering Committee of the International Conference on Epigenetic Robotics, and participated to the setting up of the first joint conference with IEEE ICDL, i.e. the IEEE ICDL/Epirob conference that was held in Frankfurt, Germany.

Manuel Lopes participated in the steering committee of the IEEE TC on Robot Learning.

9.1.3. Conference Organization

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

Manuel Lopes participated in the organization of the Machine Learning Summer School, Bordeaux, September, 2011.

9.1.4. Program Committees

Freek Stulp was on the program committee of the IEEE International Conference on Development and Learning/Epigenetic Robotics.

Pierre-Yves Oudeyer was a member of the following program committees: IEEE ICDL-EPIROB 2011; HRI 2011 Workshop on "The role of expectations in intuitive human-robot interactions"; Ecal satellite workshop on Alife Approaches to Artificial Language Evolution, 2011.

Manuel Lopes was an associated editor for: International Conference on Robotics and Automation (ICRA'11), International Conference on Intelligent Robotics Systems (IROS'11). He is a program committee member for Neural Information Processing Systems (NIPS'11) and Robotics: Science & Systems (RSS'11).

David Filliat was a member of the program committee of ECMR 2011 (European conference on Mobile Robots)

9.1.5. Journal Reviews

Freek Stulp reviewed articles for the journals: IEEE Transactions on Robotics and Robotics and Automous Systems.
Pierre-Yves Oudeyer reviewed papers for the journals: IEEE Transactions on Robotics, IEEE Transactions on Autonomous Mental Development,
Manuel Lopes reviewed for the journals: IEEE Transactions on Robotics, IEEE Transactions on Autonomous Mental Development, Robotics and Autonomous Systems and Advanced Robotics.
Alexander Gepperth reviewed articles for the journals: IEEE Transactions on Intelligent Vehicles and Neural Processing Letters.
David Filliat reviewed papers for the journals: International Journal of Robotics and Automation, IEEE Transactions on Autonomous Mental Development, Robotics and Autonomous Systems.

9.1.6. Conference Reviews

Alexander Gepperth reviews articles for the International Conference on Neurally Inspired Processing (ICONIP) and the ACM/IEEE HRI conference.
Freek Stulp has reviewed papers for the IEEE IROS 2011 conference, IEEE ICDL/Epirob, IEEE ICRA, IEEE-RAC Humanoids.
David Filliat was reviewer for IEEE International Conference on Robotics and Automation (ICRA), IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), Advanced Concepts for Intelligent Vision Systems (ACIVS), IEEE International Conference on Development and Learning (ICDL), International Conference On Advanced Robotics, Human Robot Interaction (HRI).
Pierre-Yves Oudeyer was reviewer for IEEE ICDL-EPIROB 2011; Ecal satellite workshop on Alife Approaches to Artificial Language Evolution, 2011.
Olivier Mangin has reviewed papers for the IEEE IROS 2011 conference.
Pierre Rouanet has reviewed papers for the IEEE 2012 ICRA conference, IEEE 2011 IROS conference and IEEE HRI 2011 workshop "Expectations in intuitive HRI".
Thomas Cederborg has reviewed papers for the 2012 IEEE International Conference on Robotics and Automation (ICRA).

9.1.7. PhD Jury

Pierre-Yves Oudeyer was rapporteur in the PhD jury of Sylvain Koos, for its PhD entitled “L’approche par transférabilité : une réponse aux problèmes de passage à la réalité, de généralisation et d’adaptation” and defended at ISIR/University Paris VI, France.
Pierre-Yves Oudeyer participated to the PhD jury of Clément Moulin-Frier, for its PhD entitled “Rôle des relations perception-action dans la communication parlée et l’émergence des systèmes phonologiques : étude, modélisation computationnelle et simulations” and defended at University of Grenoble, France.
David Filliat was rapporteur in the PhD jury of Thomas Feraud, for its PhD entitled ”Rejeu de chemin et localisation monoculaire : Application du Visual SLAM sur carte peu dense en environnement extérieur contraint” defended at LASMEA, Université Blaise Pascal, Clermont-Ferrand, France, on December, 9th.
Manuel Lopes acted as member of the advising committee for the PhD thesis of: Pedro Sequeira entitled ”Biologically-inspired Mechanisms to Enhance Learning in Autonomous Agents”, Instituto Superior Técnico, Lisbon, Portugal, and Salomon Ramire entitled ”Active Vision in the Peripersonal Space for Humanoid Robots”, University of Plymouth, England.

9.1.8. Expertise

Pierre-Yves Oudeyer was expert for the European Commission for review and evaluations of several FP7 projects and calls. Pierre-Yves Oudeyer participated to a jury for recruiting a “Chaire d’Excellence” Maitre de Conférence in Université Cergy-Pontoise. He was also reviewer for ANR project call “Contint”, participated to the jury for recruiting CR1 and CR2 researchers in INRIA Bordeaux, and was a member of Commission de Développement Technologique, INRIA Bordeaux Sud-Ouest.
Manuel Lopes participated in the Cost-Gtri: Groupe de travail des relations internationales du comite d’orientation scientifique et technologique.

Thomas Degris reviewed a project proposal in Reinforcement Learning for the The Netherlands Organisation for Scientific Research (NWO).

9.2. Teaching

Master : Robotique de Comnpagnie, 12 heurs. M2, ENSTA - Paris Tech (Manuel Lopes).

Doctorat : Direct and Inverse Reinforcement Learning, 12h, Machine Learning Summer School, Bordeaux, 2011 (Manuel Lopes).

Master : Robotique Mobile, 24 heures. M2, ENSTA - ParisTech (David Filliat).

Master : Vision pour la robotique, 12 heures. M2, Université Pierre et Marie Curie (David Filliat).

Master : Localisation et navigation en robotique, 12 heures. M2, Université Pierre et Marie Curie (David Filliat).

License : Introduction à Matlab, 21 heures. L3, ENSTA - ParisTech (David Filliat).

License : Projet informatique, 21 heures. L3, ENSTA - ParisTech (David Filliat).

License : Mathématiques, 64 heures - Université Bordeaux 1 (Olivier Mangin)

Licence 2 : Graphe, Langage, Cryptologie, 21 heures. Pôle Universitaire Francais de HoChiMinh ville (Sao Mai Nguyen).

PhD & HdR:

HdR: Pierre-Yves Oudeyer defended his HdR, entitled "Developmental constraints on the evolution and acquisition of sensorimotor and social skills", at University of Bordeaux, 18 May, 2011.

HdR : David Filliat, Navigation, Perception et Apprentissage pour la robotique, University Pierre et Marie Curie, 12 Juillet 2011.

PhD: Adrian Baranes defended his PhD thesis, entitled "Motivations Intrinsèques et Contraintes Maturationnelles pour l'Apprentissage Sensorimoteur", at University of Bordeaux, on 13th december 2011.

PhD in progress : Natalia Lyubova, A developmental approach to perception for a humanoid robot, started nov 2010 (superv. David Filliat).

PhD in progress : Matthieu Lapeyre, Developmental constraints for biped humanoid walking, started oct. 2010 (superv. Pierre-Yves Oudeyer and Olivier Ly).

PhD in progress : Pierre Rouanet, Mediator interfaces for language teaching in human-robot interaction, started oct. 2008 (superv. Pierre-Yves Oudeyer).

PhD in progress : Mai Nguyen, Bootstrapping Intrinsically Motivated Learning with Human Demonstration, started oct. 2010 (superv. Pierre-Yves Oudeyer).

PhD in progress : Fabien Bénureau, Cumulative, hierarchical and intrinsically motivated learning of robot skills, started oct. 2010 (superv. Pierre-Yves Oudeyer).

PhD in progress : Jonathan Grizou, Fluid simultaneous learning of task and feedback models, started oct. 2011 (superv. Manuel Lopes and Pierre-Yves Oudeyer).

PhD in progress : Olivier Mangin, Learning of sensorimotor primitives with Non-Negative Matrix Factorization, started oct. 2010 (superv. Pierre-Yves Oudeyer).

PhD in progress : Thomas Cederborg, A unified view of context-dependant skill learning and language acquisition, started oct. 2009 (superv. Pierre-Yves Oudeyer).

9.3. Invited talks

Pierre-Yves Oudeyer:

- (Keynote talk) 6th May 2011, “Developmental constraints for open-ended robot learning”, AAMAS 2011, Taipei, Taiwan.
- (Keynote talk) 15th April 2011, “Mechanisms and Constraints for Open-Ended Learning in Developmental Robotics”, 2011 IEEE Symposium on Artificial Life, Paris, France.
- (Keynote talk) 24th March 2011, “Artificial intelligence: innate vs. acquired”, Robolift 2011, Lyon, France.
- 6th december 2011, “Developmental approaches to sensorimotor and linguistic learning in robotics”, INRIA Workshop on Statistical Learning, Institut Henri Poincaré, Paris, France.
- 1st december 2011, “On Self-Organization and Developmental Mechanisms in the Origins of Speech and Action Systems”, Symposium on Language Acquisition and Language Evolution, Stockholm University, Royal Academy of Sciences, Stockholm, Sweden.
- 17th march 2011 “Où vont les robots, quelques défis de la robotique personnell’e”, Séminaire national sur l’enseignement de l’informatique au lycée, Formation IA-PR, ENS Lyon.

Manuel Lopes

- ”Social Learning with Inverse Reinforcement Learning”, ICML workshop on New Developments in Imitation Learning, USA, 2011.
- ”Social Learning with Inverse Reinforcement Learning’, Daghstuhl Exploration and Curiosity in Robot Learning and Inference, Germany, 2011.

Olivier Ly:

- 13th october 2011, “Acroban the humanoid”, SAME Conference, Nice Sophia-Antipolis, France.
- 24th march 2011, “Acroban the humanoid”, INNOROBO Conference, Lyon France.

9.4. Communication towards the general public

9.4.1. Popular Science Articles

Oudeyer, P-Y. (2011) Curiosity and Languages, in Catalogue of the Exhibition “Mathematics: A Beautiful Elsewhere”, Fondation Cartier pour l’Art Contemporain, Paris, France.
Oudeyer, P-Y. (2011) Curiosité et Langages, extrait du catalogue de l’exposition « Mathématiques : Un Dépaysement Soudain », Fondation Cartier pour l’Art Contemporain, Paris, France.
Oudeyer, P-Y. (2011) GX-29 n’est pas un object comme les autres, Hors-Série Sciences et Avenir "Qu’est-ce-que l’homme", Décembre 2012.

9.4.2. Museum exhibitions, science festivals and general public presentations and demonstrations

16th December 2011: "Prix de la Vocation Scientifique et Technique des Filles": Mai Nguyen was sponsor of a winner of this award that encourages young high-school graduates to go into scientific fields. The organisation of a visit of the research institute and the laboratory will take place in the following months.

30 november 2011, Animation for childs, Fondation Cartier pour l’Art Contemporain, Paris (Jérôme Béchu, Matthieu Lapeyre and Marie Sanchez)

21 - 23 October 2011, Scientific mediation about ErgoRobot, Mathématiques un dépaysement soudain, Fondation Cartier pour l’Art Contemporain, Paris (Jérome Béchu, Fabien Bénureau, Haylee Fogg, Matthieu Lapeyre, Olivier Mangin, Pierre-Yves Oudeyer, Pierre Rouanet)

14-16 october 2011, Public demonstartion of Acroban, Fête de la Science, Cité des Sciences et de l'Industrie, Paris (Paul Fudal and Matthieu Lapeyre)

13th october 2011: Public presentation and demonstration “Le robot Acroban”, Conférence SAME, Nice Sophia-Antipolis, France (Olivier Ly and Paul Fudal).

29th june 2011: Public presentation and demonstration of robot “Acroban”, Digital Games International Conference, Bordeaux, France (Paul Fudal, Matthieu Lapeyre, Pierre Rouanet, Jérome Béchu).

8th august 2011, Public demonstration of Acroban, ECALL'11 Workshop, Paris (Matthieu Lapeyre and Pierre Rouanet).

8th august 2011: Public presentation and demonstration “Le robot Acroban”, Workshop AAALE at ECAL'11, Paris, France (Matthieu Lapeyre and Pierre Rouanet).

18th june 2011, Demonstration of Acroban and Nao, visit of the association "Jeunes Science Bordeaux" in our laboratory, Bordeaux (Pierre Rouanet and Matthieu Lapeyre).

May 2011: The European Future Technologies Conference and Exhibition (Fet11) was held between the 4th and 6th May 2011 in Budapest, Hungary. The team had the opportunity to demonstrate Acroban at their stand. The audience was typically members of the cutting edge technology field and had a good representation of both research and research departments of industry. (Haylee Fogg, Adrien Baranes and Olivier Ly)

April 2011: Laval Virtual in Laval, France was a virtual reality exhibition held in France between the 6th and 10th April. The team brought FLOWERS Field and Acroban along to the exhibition and were greeted with great enthusiasm. Members of the public had access to the final two days of this exhibition which provided very different feedback from the previous days and exhibition in Laval. Most of the previous guests were members of various technology and robotic fields and reacted quite differently from those of the public. Both Acroban and FLOWERS Field were well received by all. (Jérôme Béchu, Pierre Rouanet, Jérémy Laviole and Haylee Fogg)

March 2011: Innorobo (International Summit of Personal Robotics) in Lyon, France aimed at gathering both industry and research teams who develop in the area of service robotics in order to show to the general public as well as to build up industrial partnerships during an exhibition which was held between the 23rd and 25th March. The team had the opportunity to present FLOWERS Field and Acroban. Acroban attracted a lot of interest from both the general and specialist public, as well as from various media. This was also the first time that the updated version of FLOWERS Field had been presented, and the added functionality of interactivity with the audience was a big hit; this included being able to select various flower behaviours through an iPad interface and also interact with the flowers through a special behaviour where flowers followed the path of the interactor's hand through a Kinect. (Jérôme Béchu, Pierre Rouanet, Paul Fudal, Olivier Ly, Haylee Fogg and Pierre-Yves Oudeyer)

5th febuary 2011, Promotion for scientific studies, Salon Aquitec, Bordeaux (Matthieu Lapeyre and Olivier Mangin).

21th january 2011: Public presentation and demonstration of iDrive, rencontres INRIA-Industrie "nouveaux services mobiles" , Nice Sophia-Antipolis, France (Jérôme Béchu and Pierre Rouanet).

9.4.3. Press

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

9.4.3.1. TV

September 2011, **CNBC**, "Acroban the humanoid" (Interview of Olivier Ly).

March 2011, **BFM TV**, "Ces robots qui vont changer nos vies" (explains Acroban).

March 2011, **TF1**, “Des robots au service des homees" (features Acroban).

March 2011, **La Chaine Techno**, “JTech: Acroban le robot français « bon marché » présenté à Innorobo » (Interview of Pierre-Yves Oudeyer).

9.4.3.2. Radio

November 2011, **France Inter**, "En direct de la Fondation Cartier: Les mystères des mathématiques, et les robots et la curiosité", 3D Le Journal, émission de Stéphane Paoli (Interview de Pierre-Yves Oudeyer)

November 2011, **RFI**, "Les maths en ont leur certificats artistique à la Fondation Cartier", by Isabelle Artus (explanation of Ergo-Robots).

July 2011, **France Inter**, "Robots, Invasion Imminente ?", On verra ça demain, émission de Daniel Fiévet (Interview de Pierre-Yves Oudeyer).

May 2011, **France Culture**, "L'apprentissage des robots", On prolonge l'émission avec l'INRIA, émission de Xavier de la Porte (Interview de Pierre-Yves Oudeyer)

March 2011, **France Info**, Emission de Marc Fauvel (Interview de Pierre-Yves Oudeyer)

March 2011, **France Info**, Chronique de Jérome Collomban, "Les robots sont de sortie à Lyon" (explains Acroban)

March 2011, **RFI**, Chronique de Dominique Desaunay, "Acroban, le nouvel androide"

9.4.3.3. Magazines

December 2011, **Sciences et Avenir**, "GX-29 n'est pas un objet comme les autres", Hors-Série "Qu'est-ce-que l'homme ?" (text of Pierre-Yves Oudeyer).

December 2011, **Tangente**, "Robots et mathématiques", Hors-Série sur l'exposition "Mathématiques: un Dépaysement Soudain" (Interview of Pierre-Yves Oudeyer).

October 2011, **Sciences et Avenir**, "L'apprentissage de la curiosité", Hors-Série sur l'exposition "Mathématiques: un Dépaysement Soudain" (Interview of Pierre-Yves Oudeyer).

October 2011, **Wallpaper** (Art magazine), "Mathematics exhibition at Fondation Cartier, in Paris".

March 2011, **Le Point**, "La robotique s'empare des sciences humaines" (explanation of robot models of cognition)

March 2011, **L'Usine Nouvelle**, "Un compagnon très très sensible" (explanation of Acroban)

9.4.3.4. Newspapers

November 2011, **Libération**, "David Lynch, La loi du silencio".

November 2011, **Financial Times**, "Twin Peaks of Maths and Arts".

October 2011, **The Saturday Telegraph**, "Art plus maths: do they add up?".

October 2011, **The Times**, "Maths and Arts? Go Figure".

April 2011, **LeMonde.fr**, video on human-robot interfaces and the use of Nao by research labs.

March 2011, **20 minutes**, "Acroban, le robot qui va apprendre comme un enfant".

March 2011, **Direct Matin**, "Acroban, le robot français qui apprend comme un enfant".

March 2011, **Les Echos**, "Mon robot nettoie ma maison".

March 2011, **Nouvel Obs**, "Acroban, le robot qui apprend par lui-même".

March 2011, **Le Progrès**, "Ces robots qui vont changer notre vie quotidienne".

March 2011, **Les Nouvelles**, (Canada), "Des chercheurs français développent Acroban, le robot qui apprend par lui-même" .

March 2011, **Le Matin**, (suisse), "Les robots se plient en quatre pour nous" .

March 2011, **Charente Libre**, "Prendre un robot par la main".

March 2011, **Le Figaro**, "Les robots font leur show".

March 2011, **Les Echos Judiciaires**, "Nouvelles technologies, des chercheurs bordelaise à la pointe de la robotique".

March 2011, **Le Dauphine**, “Les robots dernière génération débarquent”.

9.4.3.5. Web

November 2011, **Slate**, "L’art de la formule", par Jean-Michel Frodon.

October 2011, **ArtsScienceFactory**, "Les Ergo-Robots arrivent", et éditorial sur l’expo "Mathématiques, un dépaysement soudain", par Jean-Michel Frodon.

March 2011, **Futura Sciences**, “Des robots convergent vers Lyon pour le salon Innorobo . . . ”.

March 2011, **MSN News** “Les robots font leur show: Acroban”.

March 2011, **http://Wired.co.uk**, “There is no point making robots look and act like humans”.

March 2011, **Bizzen IT and Business**, "Robotter til sjov, hjælp og til absolut ingenting".

March 2011, **Tom’s guide**, "Acroban the humanoid robot".

March 2011, **Journal du Geek**, “Acroban, le premier robot que l’on peut prendre par la main”.

March 2011, **Famili.fr**, “Un bébé robot”.

10. Bibliography

Major publications by the team in recent years

[1] A. Baranes, P.-Y. Oudeyer. *RIAC: Robust Intrinsically Motivated Exploration and Active Learning*, in "IEEE Trans. on Auto. Ment. Dev.", 2009, vol. 1, n^{o} 3, p. 155-169.

[2] J. Buchli, F. Stulp, E. Theodorou, S. Schaal. *Learning Variable Impedance Control*, in "International Journal of Robotics Research", 2011, vol. 30, n^{o} 7, p. 820-833, http://ijr.sagepub.com/content/early/2011/03/31/0278364911402527.

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[4] T. Degris, O. Sigaud, P. Wuillemin. *Learning the Structure of Factored Markov Decision Processes in Reinforcement Learning Problems*, in "Proceedings of the 23rd International Conference on Machine learning (ICML)", 2006, p. 257–264.

[5] A. Gepperth, S. Rebhan, S. Hasler, J. Fritsch. *Biased competition in visual processing hierarchies: a learning approach using multiple cues*, in "Cognitive Computation", March 2011, vol. 3, n^{o} 1, http://hal.archives-ouvertes.fr/hal-00647809/en/.

[6] M. Lopes, T. Cederborg, P.-Y. Oudeyer. *Simultaneous Acquisition of Task and Feedback Models*, in "Development and Learning (ICDL), 2011 IEEE International Conference on", Germany, 2011, p. 1 - 7 [*DOI :* 10.1109/DEVLRN.2011.6037359], http://hal.inria.fr/hal-00636166/en.

[7] M. Lopes, F. Melo, L. Montesano. *Active learning for reward estimation in inverse reinforcement learning*, in "Machine Learning and Knowledge Discovery in Databases", 2009, p. 31–46.

[8] L. Montesano, M. Lopes, A. Bernardino, J. Santos-Victor. *Learning Object Affordances: From Sensory–Motor Coordination to Imitation*, in "Robotics, IEEE Transactions on", 2008, vol. 24, n^{o} 1, p. 15–26.

[9] P.-Y. OUDEYER, F. KAPLAN, V. HAFNER. *Intrinsic Motivation Systems for Autonomous Mental Development*, in "IEEE Transactions on Evolutionary Computation", 2007, vol. 11, n^{o} 1, p. 265–286.

[10] P.-Y. OUDEYER. *Self-Organization in the Evolution of Speech*, Studies in the Evolution of Language, Oxford University Press, 2006.

[11] P.-Y. OUDEYER. *On the impact of robotics in behavioral and cognitive sciences: from insect navigation to human cognitive development*, in "IEEE Transactions on Autonomous Mental Development", 2010, vol. 2, n^{o} 1, p. 2–16, http://hal.inria.fr/inria-00541783/en/.

[12] F. STULP, S. SCHAAL. *Hierarchical Reinforcement Learning with Motion Primitives*, in "11th IEEE-RAS International Conference on Humanoid Robots", 2011.

Publications of the year

Doctoral Dissertations and Habilitation Theses

[13] A. BARANES. *Motivations Intrinsèques et Contraintes Maturationnelles pour l'Apprentissage Sensorimoteur*, Université Bordeaux I/INRIA, December 2011, Thèse de Doctorat de Adrien Baranès, http://hal.inria.fr/hal-00653308/en.

[14] D. FILLIAT. *Navigation, perception et apprentissage pour la robotique*, Université Pierre et Marie Curie - Paris VI, July 2011, Habilitation à Diriger des Recherches, http://hal.inria.fr/tel-00649692/en.

[15] P.-Y. OUDEYER. *Developmental constraints on the evolution and acquisition of sensorimotor and social skills*, Université Bordeaux I/INRIA, 2011, Habilitation à diriger des recherches, http://hal.inria.fr/hal-00652129/en.

Articles in International Peer-Reviewed Journal

[16] L. MONTESANO, M. LOPES. *Active learning of visual descriptors for grasping using non-parametric smoothed beta distributions*, in "Robotics and Autonomous Systems", 2011, p. 26-AUG-2011 [*DOI :* 10.1016/J.ROBOT.2011.07.013], http://hal.inria.fr/hal-00637575/en.

International Conferences with Proceedings

[17] A. BARANES, P.-Y. OUDEYER. *The Interaction of Maturational Constraints and Intrinsic Motivations in Active Motor Development*, in "ICDL - EpiRob", Frankfurt, Germany, August 2011, http://hal.inria.fr/hal-00646585/en.

[18] E. BATTESTI, S. BAZEILLE, D. FILLIAT. *Qualitative localization using vision and odometry for path following in topo-metric maps*, in "European Conference on Mobile Robotics (ECMR)", Sweden, 2011, p. 303-308, http://hal.inria.fr/hal-00652479/en.

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