IN PARTNERSHIP WITH:
Ecole nationale supérieure des techniques avancées

Activity Report 2014

Project-Team FLOWERS

Flowing Epigenetic Robots and Systems

RESEARCH CENTER
Bordeaux - Sud-Ouest

THEME
Robotics and Smart environments

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Project-Team FLOWERS

Keywords: Developmental Robotics, Human-robot Interaction, Machine Learning, Language Acquisition, Models Of Human Cognitive Development

Creation of the Team: 2008 April 01*, updated into Project-Team:* 2011 January 01.

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2. Overall Objectives

2.1. Overall Objectives

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 sensorimotor and interaction skills in embodied systems. In particular, we study constraints that guide exploration in large sensorimotor spaces:

- Mechanisms of intrinsically motivated exploration and active learning, including artificial curiosity, allowing in particular to self-organize developmental trajectories and collect efficiently learning data;
- Mechanisms of adequately constrained optimization and statistical inference for sensorimotor skill acquisition (e.g. for optimizing motor policies in real robots);
- 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 for simplifying motor control and perception;
- 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 axis:

- **Curiosity-driven exploration and sensorimotor 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 studied as active learning mechanisms, allowing to learn efficiently in large inhomogeneous sensorimotor spaces;
- **Cumulative learning of sensorimotor skills:** FLOWERS develops machine learning algorithms that can allow embodied machines to acquire cumulatively sensorimotor skills. In particular, we develop optimization and reinforcement learning systems which allow robots to discover and learn dictionaries of motor primitives, and then combine them to form higher-level sensorimotor skills.
- **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.
- Body design and role of the body in sensorimotor and social development We study how the physical properties of the body (geometry, materials, distribution of mass, growth, ...) can impact the acquisition of sensorimotor and interaction skills. This requires to consider the body as an experimental variable, and for this we develop special methodologies for designing and evaluating rapidly new morphologies, especially using rapid prototyping techniques like 3D printing.
- **Intelligent Tutoring Systems:**FLOWERS develops methods for online personalization of teaching sequences for educational software and MOOCs. This work builds on top of online optimization methods and motivational research previously developed.

3. Research Program

3.1. Research Program

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 requires 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 link can be made to educational systems where research in several domains have tried to study how to provide a good learning experience to learners. This includes the experiences that allow better learning, and in which sequence they must be experienced. This problem is complementary to that of the learner that tries to learn efficiently, and the teacher here has to use as efficienlty the limited time and motivational resources of the learner. Several results from psychology [76] and neuroscience [10] have argued that the human brain feels intrinsic pleasure in practicing activities of optimal difficulty or challenge. A teacher must exploit such activities to create positive psychological states of flow [82].

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" [116]. 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 [89], 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 [96] [118]. The approach of developmental robotics consists in importing and implementing concepts and mechanisms from developmental psychology [101], cognitive linguistics [81], and developmental cognitive neuroscience [93] 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 [78] [107], grounding [87], situatedness [72], self-organization [114] [108], enaction [117], and incremental learning [79].

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 and represent all conceivable sensory percepts. 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 [15]. 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:

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 [101], 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. The perceptual system also gradually develops, increasing children perceptual capabilities other time while they engage in activities like throwing or manipulating objects. This make it possible to learn to identify objects in more and more complex situations and to learn more and more of their physical characteristics.

Development is therefore 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" [74] [85]. 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 [76] [82] [84]. 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 [83] [90] [113]. Based on this, a number of researchers have began in the past few years to build computational implementation of intrinsic motivation [15] [105] [111] [75] [91] [99] [112]. 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 [105][15] [106] [110]. Specific and complex problems are posed by real sensorimotor spaces, in particular due to the fact that they are both high-dimensional as well as (usually) deeply inhomogeneous. As an example for the latter issue, some regions of real sensorimotor spaces are often unlearnable due to inherent stochasticity or difficulty, in which case heuristics based on the incentive to explore zones of maximal unpredictability or uncertainty, which are often used in the field of active learning [80] [88] typically lead to catastrophic results. The issue of high dimensionality does not only concern motor spaces, but also sensory spaces, leading to the problem of correctly identifying, among typically thousands of quantities, those latent variables that have links to behavioral choices. In FLOWERS, we aim at developing intrinsically motivated exploration mechanisms that scale in those spaces, by studying suitable abstraction processes in conjunction with exploration strategies.

3.1.2. Socially Guided and Interactive Learning

Social guidance is as important as intrinsic motivation in the cognitive development of human babies [101]. There is a vast literature on learning by demonstration in robots where the actions of humans in the environment are recognized and transferred to robots [73]. Most such approaches are completely passive: the human executes actions and the robot learns from the acquired data. Recently, the notion of interactive learning has been introduced in [115], [77], motivated by the various mechanisms that allow humans to socially guide a robot [109]. 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 [115], [94] [100].

Social guidance is also particularly important for learning to segment and categorize the perceptual space. Indeed, parents interact a lot with infants, for example teaching them to recognize and name objects or characteristics of these objects. Their role is particularly important in directing the infant attention towards objects of interest that will make it possible to simplify at first the perceptual space by pointing out a segment of the environment that can be isolated, named and acted upon. These interactions will then be complemented by the children own experiments on the objects chosen according to intrinsic motivation in order to improve the knowledge of the object, its physical properties and the actions that could be performed with it.

In FLOWERS, we are aiming at including intrinsic motivation system in the self-exploration part thus combining efficient self-learning with social guidance [103], [104]. We also work on developing perceptual capabilities by gradually segmenting the perceptual space and identifying objects and their characteristics through interaction with the user [97] and robots experiments [92]. Another challenge is to allow for more flexible interaction protocols with the user in terms of what type of feedback is provided and how it is provided [95].

Exploration mechanisms are combined with research in the following directions:

3.1.3. Cumulative learning, reinforcement learning and optimization of autonomous skill learning

FLOWERS develops machine learning algorithms that can allow embodied machines to acquire cumulatively sensorimotor skills. In particular, we develop optimization and reinforcement learning systems which allow robots to discover and learn dictionaries of motor primitives, and then combine them to form higher-level sensorimotor skills.

3.1.4. Autonomous perceptual and representation learning

In order to harness the complexity of perceptual and motor spaces, as well as to pave the way to higher-level cognitive skills, developmental learning requires abstraction mechanisms that can infer structural information out of sets of sensorimotor channels whose semantics is unknown, discovering for example the topology of the body or the sensorimotor contingencies (proprioceptive, visual and acoustic). This process is meant to be open- ended, progressing in continuous operation from initially simple representations towards abstract concepts and categories similar to those used by humans. Our work focuses on the study of various techniques for:

- autonomous multimodal dimensionality reduction and concept discovery;
- incremental discovery and learning of objects using vision and active exploration, as well as of auditory speech invariants;
- learning of dictionaries of motion primitives with combinatorial structures, in combination with linguistic description;
- active learning of visual descriptors useful for action (e.g. grasping);

3.1.5. Embodiment and maturational constraints

FLOWERS studies how adequate morphologies and materials (i.e. morphological computation), associated to relevant dynamical motor primitives, can importantly simplify the acquisition of apparently very complex skills such as full-body dynamic walking in biped. FLOWERS also studies maturational constraints, which are mechanisms that allow for the progressive and controlled release of new degrees of freedoms in the sensorimotor space of robots.

3.1.6. 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.

4. Application Domains

4.1. Applications

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 $5.4Bnto$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.

Human-Robot Collaboration. Robots play a vital role for industry and ensure the efficient and competitive production of a wide range of goods. They replace humans in many tasks which otherwise would be too difficult, too dangerous, or too expensive to perform. However, the new needs and desires of the society call for manufacturing system centered around personalized products and small series productions. Human-robot collaboration could widen the use of robot in this new situations if robots become cheaper, easier to program and safe to interact with. The most relevant systems for such applications would follow an expert worker and works with (some) autonomy, but being always under supervision of the human and acts based on its task models. 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 occurrence 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.

Automated Tutoring Systems. Optimal teaching and efficient teaching/learning environments can be applied to aid teaching in schools aiming both at increase the achievement levels and the reduce time needed. From a practical perspective, improved models could be saving millions of hours of students' time (and effort) in learning. These models should also predict the achievement levels of students in order to influence teaching practices.

5. New Software and Platforms

5.1. Perception Tools

Participants: David Filliat [correspondant], Louis-Charles Caron, Alexander Gepperth.

5.1.1. Of 3-D point cloud

Participants: Louis-Charles Caron [correspondant], Alexander Gepperth, David Filliat.

This software scans the 3-D point cloud of a scene to find objects and match them against a database of known objects. The process consists in 3 stages. The segmentation step finds the objects in the point cloud, the feature extraction computes discriminating properties to be used in the classification stage for object recognition.

The segmentation is based on simple assumptions about the geometry of an indoor scene and the movement of a wheeled mobile robot. The floor plane coefficients are known a priori and are used to eliminate from the point cloud all points that are close to this plane and have a normal perpendicular to it. The floor plane coefficients also allow the detection of walls. Successive RANSACs are run to find planes that are perpendicular to the floor plane, and contain a large number of points. With these large structural regions removed, the only points remaining in the point cloud are the objects in the scene. These objects are separated by clustering the points based on a distance criteria. Close-by points are considered to form a single object.

Objects are characterized by their shape, texture. The texture information is encoded as a histogram that apprioximates the form of the distribution of color values in the object. A separate histogram is built for the red, green and blue channels. The shape of an object is encoded by computing thousands of randomly chosen Surflet-pair relation features and compiing them into a histrogram of occurrence.

The classification is done by a 3-layer feed-forward neural network. The network is trained on a dataset of point clouds of 53 objects. After training, the neural network is run on the features computed from each object detected in the segmentation stage [86].

5.1.2. PEDDETECT: GPU-accelerated person detection demo

Participant: Alexander Gepperth [correspondant].

PEDDETECT implements real-time person detection in indoor or outdoor environments. It can grab image data directly from one or several USB cameras, as well as from pre-recorded video streams. It detects mulitple persons in 800x600 color images at frame rates of >15Hz, depending on available GPU power. In addition, it also classifies the pose of detected persons in one of the four categories "seen from the front", "seen from the back", "facing left" and "facing right". The software makes use of advanced feature computation and nonlinear SVM techniques which are accelerated using the CUDA interface to GPU programming to achieve high frame rates. It was developed in the context of an ongoing collaboration with Honda Research Institute USA, Inc.

5.1.3. A Python OptiTrack client

Participant: Pierre Rouanet [correspondant].

This python library allows you to connect to an OptiTrack from NaturalPoint (http://www.naturalpoint.com/optitrack/). This camera permits the tracking of 3D markers efficiently and robustly. With this library, you can connect to the Motive software used by the OptiTrack and retrieve the 3D position and orientation of all your tracked markers directly from python.

5.2. Datasets

5.2.1. Assemblies of objects for the 3rd hand project

Participants: Yoan Mollard [correspondant], Thibaut Munzer, Manuel Lopes.

The 3rd hand project aims to develop a semi-autonomous robot assistant that acts as a third hand of a human worker. Especially, both should be able to undertake assembly tasks together, in a cooperative way. In order to analyse assembly tasks we recorded 6 datasets of two objects being assembled by a human. The experiment setup has the form of a single user assembling simple furnitures (a chair and a bench) composed by several distinct parts (seating, back, legs). Each part is tracked thanks to an Optitrack system and a set of reflective markers during the whole assembly. The experimental setup records the absolute poses of each part (position and orientation) and relative poses of each couple of objects.

5.3. Learning algorithms

5.3.1. KidLearn

Participants: Manuel Lopes [correspondant], Benjamin Clement, Pierre-Yves Oudeyer, Didier Roy.

The KidLearn software provides an Intelligent Tutoring System that optimizes teaching sequences based on the estimated level of each particular student. Two algorithms, RiARiT and ZPDES have been developped and are described in [37], [39] and [38]. We updated the Game of Money that we developped last year wich allows students between 7-8 years to learn how to use money. It still includes 3 main components: i) a webserver that handles the requests and stores the experiments in a databased; ii) a GUI that provides the interface for the game; and iii) the optimization software.

Graphical interfaces in ITS can have unwanted side effects. For this reason, the interface was entirely designed with the help of a didactician, with several specific design choices motivated by pedagogical, motivational and attention requirements. For example, the interface, shown in Figure 1. is such that:

- display is as clear and simple as possible;
- there is no chronometer, so that students are not put under time pressure;
- coins and banknotes have realistic visual appearance, and their relative sizes are respected;
- costumer and merchant are represented to indicate clearly the role of the student;
- text quantity is kept to minimum;

Four principal regions are defined in the graphical interface, as shown in Figure 1, on the left picture. The first is the wallet location where users can pick and drag the money items and drop them on the repository location to compose the correct price. The object and the price are present in the object location.

We performed a more developed and complete user study than last year, considering 5 different schools in the Bordeaux metropolitan area. We had a total of 400 students between 7 and 8 years old. We divided them into 4 groups, with one control group where student does not use the software and 3 groups where exercises are proposed using : a) a predefined sequence; b) ZPDES; c) RiARiT. To measure student learning, students pass pre-test few days before using the interface, and a post test fews days after using the interface. The control group pass the pre and post test at the same time that others but without using the interface between. The results of this study have been presented in [69].

Figure 1. Interface with two exemple of type of exercises, Left: customer/one object, Right : merchant/two objects

5.3.2. DMP-BBO Matlab library

Participant: Freek Stulp [correspondant].

The dmp_bbo (Black-Box Optimization for Dynamic Movement Primitives) Matlab library is a direct consequence of the insight that black-box optimization outperforms reinforcement learning when using policies represented as Dynamic Movement Primitives. It implements several variants of the PI^{BB} algorithm for direct policy search. It is currently being used and extended by several FLOWERS members (Manuel Lopes, Clément Moulin-Frier) and external collaborators (Jonas Buchli, Hwangbo Jemin of ETH Zurich). In the context of the DIGITEO-funded project "PrActIx" , CEA LIST has now started using this library. In 2014, parts have been made real-time safe for use on the Meka Humanoid robot. This has been fundamental in achieving the results for [65], [64].

5.3.3. Self-calibration BCI - Matlab library

Participants: Jonathan Grizou [correspondant], Iñaki Iturrate, Luis Montesano, Manuel Lopes, Pierre-Yves Oudeyer.

The Matlab software implements the algorithms described in [45]. Downloadable from https://github.com/jgrizou/lfui.

It allows a robot to be instructed a new task by a human using communicative signals initially totally unknown to the robot. It is was extended and improved in the context of EEG-based brain-machine interfaces (BMIs) [44].

It results in a BCI based control of sequential tasks with feedback signals that do not require any calibration process. As a by-product, the method provides an unsupervised way to train a decoder with the same performance than state-of-the-art supervised classifiers, while keeping the system operational and solving, with a lower performance during the first steps, the unknown task. The algorithm has been tested with online experiments (fig. 2), showing that the users were able to guide from scratch an agent to a desired position.

To improve the efficiency of the algorithm, we introduced a new planning method that uses the uncertainty in the signal-target estimation. This planner is inspired by exploration methods with exploration bonuses that allow guiding to reduce the uncertainty in an efficient way. We showed that trying to follow the best hypothesis does not explore the space significantly to reduce uncertainty and thus identify the correct task. Only through an approach that plans how to reduce the uncertainty multiple steps ahead are we sure that the agent will reach states that can only be explained by the correct hypothesis.

5.3.4. DyNAMoS: parallel multi-process simulation of distributed neural architectures

Participants: Alexander Gepperth [correspondant], Mathieu Lefort.

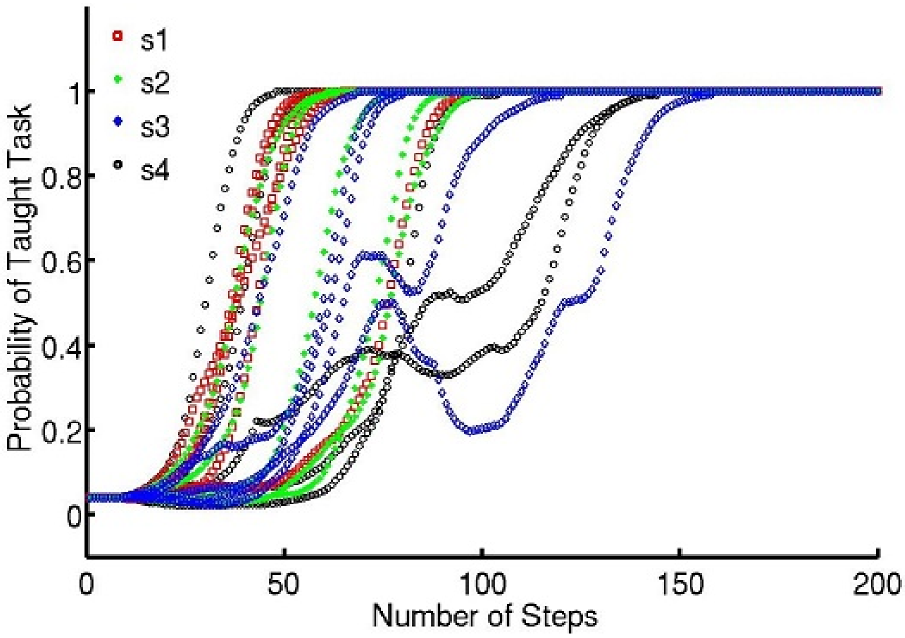

Figure 2. Results from the online BCI experiment for identifying the task. Evolution of the probability of the taught task for each subject and run

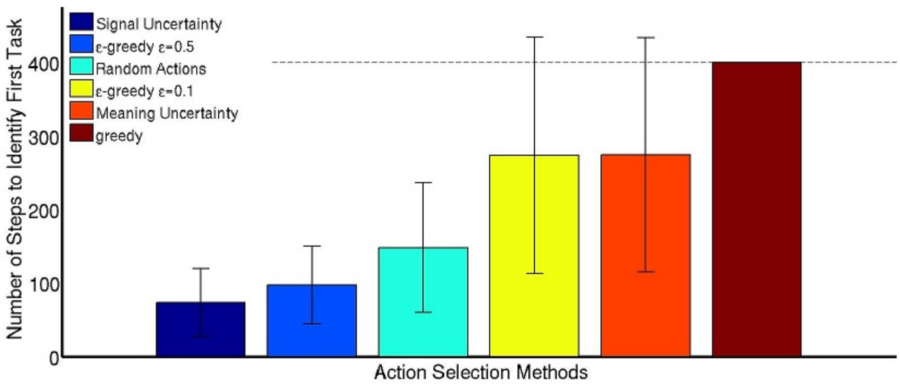

Figure 3. Comparison between different exploration methods. Planning wrt. uncertainty in noth task and signal space is the most efficient method

This simulation software comes in the form of a PYTHON module and allows a user to define and simulate complex neural architectures while making use of the parallelism inherent to modern multi-core processors. A special focus lies on on-line learning, processing inputs one by one, in contrast to batch processing of whole databases at a time.

The connectivity of an architecture, as well as neural dynamics and learning rules, are defined by editing simple text-based configuration files. A simple instantiation of a pre-defined simulator class together with the name of the configuration file launches the simulation. Users can provide continuous input to the architecture, as well as inspect and visualize all elements of the simulation, by subclassing the simulator class and redefining the appropriate methods in a clean and Pythonic way. DyNAMoS can be, and is in fact meant to be, extended by user-defined learning methods and dynamics models, which is possible through a well-documented interface all such functions must respect. DyNAMoS distributes computation across multiple processes that are spawned dynamically, possibly on multiple computers, which communicate by TCP/IP or Linux interprocess communication depending on whether they are on the same computer. All aspects of multi-process handling and communication are completely hidden from the user who may merely specify which neural map is executed on which physical process if he wishes to.

This software has been used to speed up computations and provides a common platform for implementing online and incremental learning algorithms. Up to now, we have included linear and logistic regression, various versions of self-organizing maps, MLP and LWPR. It will be made available on GitHub in 2015 after final tests have been concluded.

5.3.5. pyStreamPlayer: synchronized replay of multiple sensor recordings and supplementary data

Participant: Alexander Gepperth [correspondant].

This Python software is intended to facilitate the application of machine learning algorithms by avoiding to work directly with an embodied agent but instead with data recorded in such an agent. Assuming that non-synchronous data from multiple sensors (e.g., camera, Kinect, laser etc.) have been recorded according to a flexible format defined by the pyStreamPlayer architecture, pyStreamPlayer can replay these data while retaining the exact temporal relations between different sensor measurements. As long as the current task does not involve the generation of actions, this software allows to process sensor data as if it was coming from an agent which is usually considerably easier. At the same time, pyStreamPlayer allows to replay arbitrary supplementary information such as, e.g., object information, as if it was coming from a sensor. In this way, supervision information can be stored and accessed together with sensory measurements using an unified interface. pyStreamPlayer has been used to facilitate real-world object recognition tasks, and several of the major databases in this field (CalTech Pedestrian database, HRI RoadTraffic traffic objects database, CVC person database, KITTI traffic objects database) have been converted to the pyStreamPlaer format and now serve as a source of training and test data for learning algorithms.

pyStreamPlayer has been integrated into a ROS node as well, allowing th replay and transmission across networks of distributed processes.

5.3.6. Multimodal: framework around the NMF algorithm for multimodal learning

Participant: Olivier Mangin [correspondant].

The python code provides a minimum set of tools and associated libraries to reproduce the experiments in [98], together with the choreography datasets. The code, publicly available at https://github.com/omangin/multimodal, under the new BSD license, is primarily intended for reproduction of the mulimodal learning experiment mentioned above. It has already been reused in several experimentations by other member of the team and is expected to play an important role in further collaborations. It is also expected that the public availability of the code encourages further experimentation by other scientists with data coming from other domains, thus increasing both the impact of the aforementioned publication and the knowledge on the algorithm behaviors. The nonnegative matrix factorization algorithm used in the experiments is also available as a third party extension to http://scikit-learn.org.

5.3.7. *Explauto: an autonomous exploration library*

Participants: Clément Moulin-Frier [correspondant], Pierre Rouanet.

Explauto is a framework developed to study, model and simulate curiosity-driven learning and exploration in virtual and robotic agents. The code repository is available at: https://github.com/flowersteam/explauto.

This library provides high-level API for an easy definition of:

- Virtual and robotics setups (Environment level)
- Sensorimotor learning iterative models (Sensorimotor level)
- Active choice of sensorimotor experiments (Interest level)

It is crossed-platform and has been tested on Linux, Windows and Mac OS. It has been released under the GPLv3 license.

Explauto's scientific roots trace back from Intelligent Adaptive Curiosity algorithmic architecture [15], which has been extended to a more general family of autonomous exploration architecture by [3] and recently expressed as a compact and unified formalism [102]. The library is detailed in [60].

This library has been used in many experiments including:

- the control of a 2D simulated arm
- the exploration of the inverse kinematics of a poppy humanoid (both on the real robot and on the simulated version)
- accoustic model of a vocal tract

5.3.8. *Explorers Framework*

Participants: Benureau Fabien [correspondant], Pierre-Yves Oudeyer.

The Explorers framework is aimed at creating, testing and comparing autonomous exploration strategies for sensorimotor spaces in robots. The framework is largely strategy-agnostic, and is aimed as expressing motor babbling, goal babbling and intrinsically motivated exploration algorithms, among other. It is also able to express strategies that feature transfer learning, such as the reuse algorithm we introduce in [34].

At the center of the framework, an explorer receives observations and provides motor commands for the environment to execute.

We can then easily express a typical goal babbling architecture (the feedback update is not pictured).

Here, the explorer interacts with the environment, rather than the inverse model. Such an architecture allows to filter motor commands that are proposed by the inverse model, and eventually to select another goal if the motor command is not satisfactory or possible to execute. The framework is organized in a modular way. This allows to create flexible hierarchical architectures made of several, atomic or themselves composite, exploration strategies.

The framework has been released this year under the *OpenScience* license (http://fabien.benureau.com/openscience.html), and made available on github (https://github.com/humm/explorers). Using provided examples, users can easily modify the exploration parameters and investigate for instance the differences between motor and goal babbling exploration strategies.

5.3.9. *PyQMC: Python library for Quasi-Metric Control*

Participant: Steve Nguyen [correspondant].

PyQMC (https://github.com/SteveNguyen/pyqmc) is a python library implementing the control method described in http://dx.doi.org/10.1371/journal.pone.0083411 It allows to solve discrete markovian decision processes by computing a Quasi-Metric on the state space. This model based method has the advantage to be goal independant and thus can produce a policy for any goal with relatively few recomputation. New addition to this method is the possibility of online learning of the transition model and the Quasi-Metric.

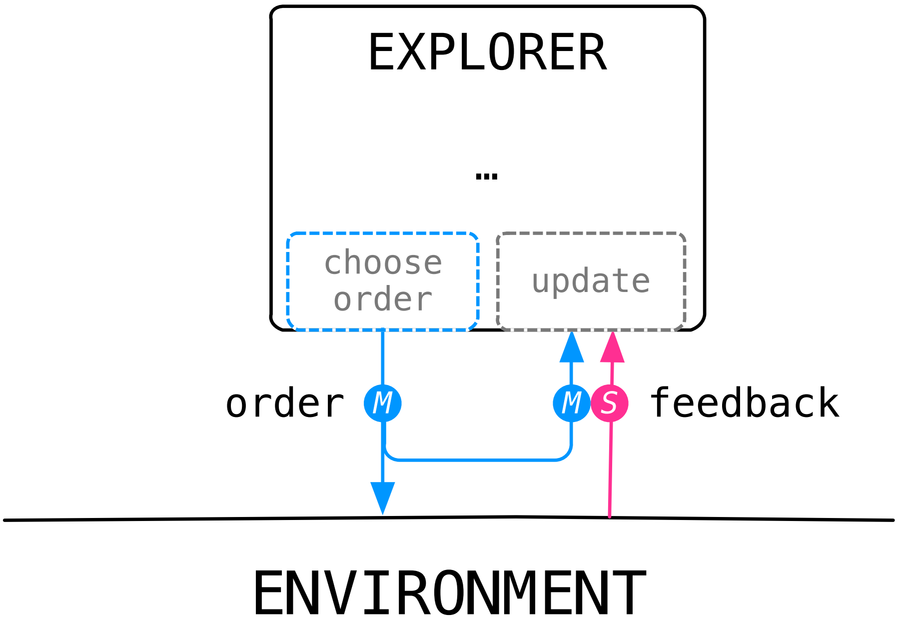

Figure 4.

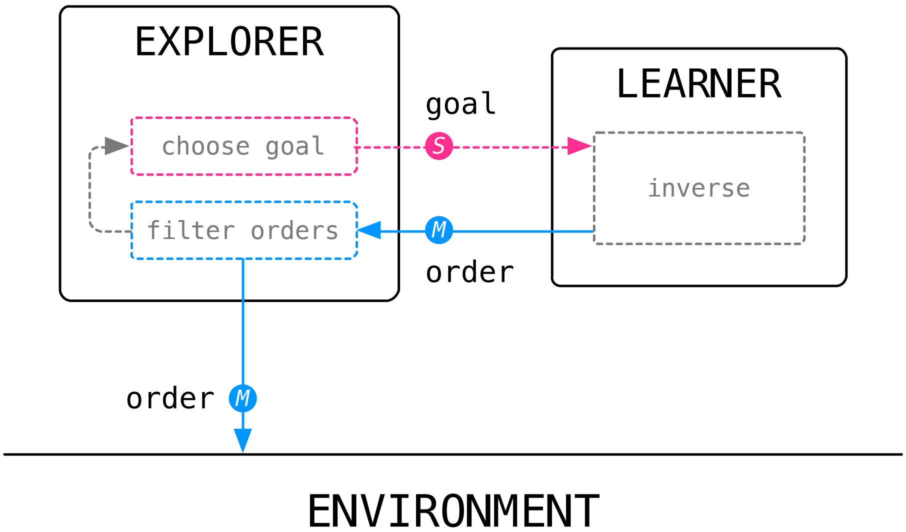

Figure 5.

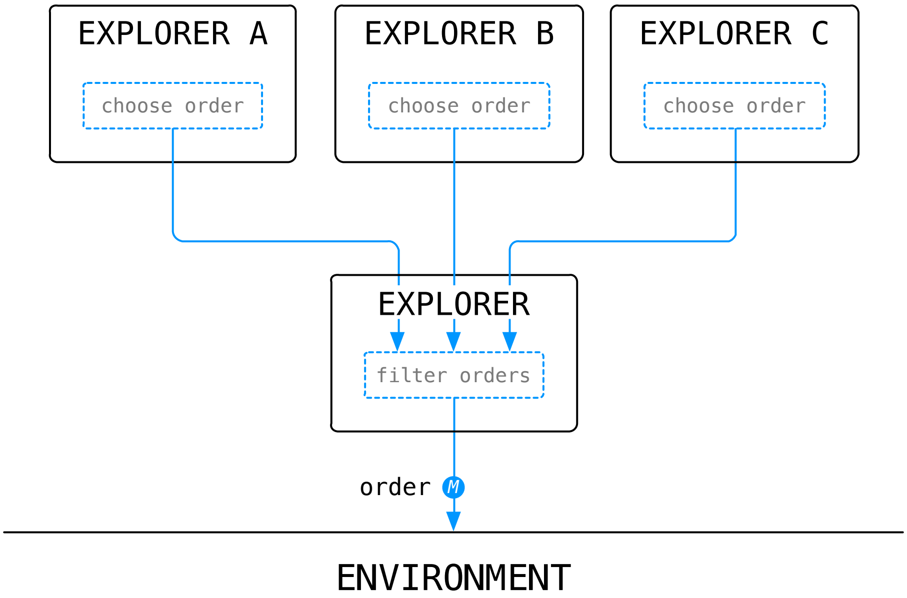

Figure 6.

5.4. Software Platforms

5.4.1. Meka robot plateform enhancement and maintenance

Participants: Antoine Hoarau, Freek Stulp, David Filliat.

Autonomous human-centered robots, for instance robots that assist people with disabilities, must be able to physically manipulate their environment. There is therefore a strong interest within the FLOWERS team to apply the developmental approach to robotics in particular to the acquisition of sophisticated skills for manipulation and perception. ENSTA-ParisTech has recently acquired a Meka (cf. 7) humanoid robot dedicated to human-robot interaction, and which is perfectly fitted to this research. The goal of this project is to install state-of-the-art software architecture and libraries for perception and control on the Meka robot, so that this robot can be jointly used by FLOWERS and ENSTA. In particular, we want to provide the robot with an initial set of manipulation skills.
The goal is to develop a set of demos, which demonstrate the capabilities of the Meka, and provide a basis on which researchers can start their experiments.

The platform is evolving as the sofware (Ubuntu, ROS, our code) is constantly updated and requires some maintenance so less is needed for later. A few demos were added, as the hand shaking demo, in which the robot detects people via kinect and initiates a hand shake with facial expressions. This demo has been used to setup a bigger human robot interaction experiment, currently tested on subjects at Ensta (cf. 8). Finally, we've seen that the robot itself also needs some maintenance; some components broke (a finger tendon), a welding got cold (in the arm) and a few cables experienced fatigue (led matrix and cameras) (cf. 9).

5.4.2. Teaching concepts to the Meka robot

Participants: Fabio Pardo [Correspondant], Olivier Mangin, Anna-Lisa Vollmer, Yuxin Chen, David Filliat.

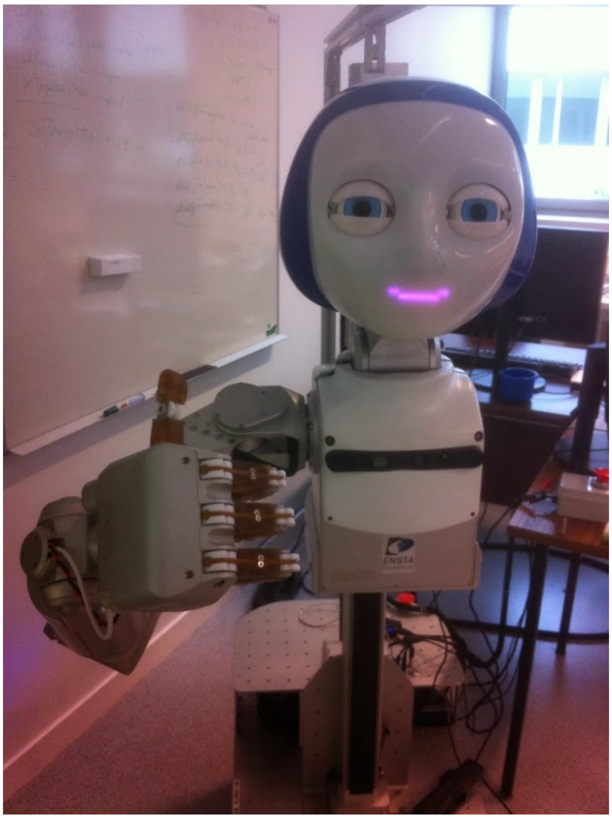

Figure 7. The Meka robot plateform acquired by ENSTA ParisTech

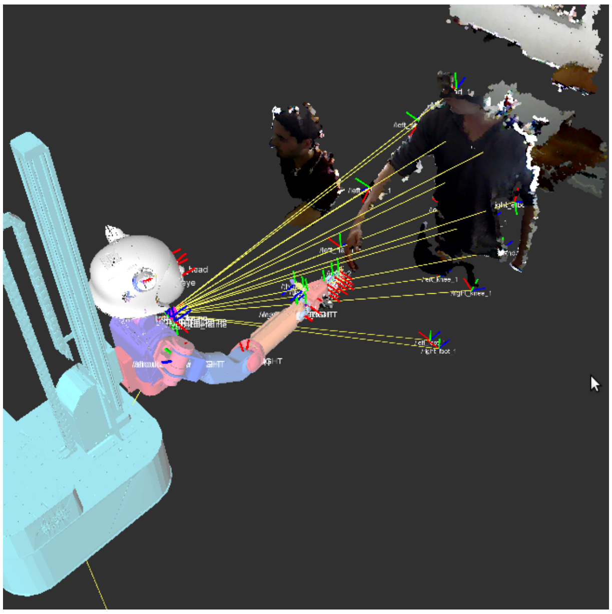

Figure 8. Hand shake demo visualized on Rviz (ROS)

This plateform was developped during Fabio Pardo's internship, in the dual context of the study of Anna-Lisa Vollmer's research on human robot interaction protocole during a learning task, and Olivier Mangin's research on mechanism for word learning and multimodal concept acquisition. The plateform is centered around an interaction zone where objects are presented to a Meka robot augmented with a kinect camera placed on top of the interaction zone. Several colorful objects are available to be presented and described to the robot. Several object may be present at the same time on the table. Typical object are easily caracterized by their colors and shapes, such as the *red ball*, the *yellow cup*, or the *blue wagon with red wheels*.

The robot software is capable of abstracting the visual and acoustic perception in the following way. The camera image is segmented into objects; from each object, a set of descriptors is extracted, typically SIFT or shape descriptors and color histograms. An incremental clustering algorithm transforms the continuous descriptors into a histogram of descrete visual descriptors that is provided to the learning algorithm. The acoustic stream is segmented into sentences by a silence detection process and each sentence is fed to Google's text to speach API. Finally each sentence is represented as a histogram of the words recognized in the sentence.

The robot is capable of learning multimodal concepts, spanning words and visual concepts, through the nonnegative matrix factorization framework introduced by Olivier Mangin (see). In addition several behaviors are programmed in the robot such as gaze following objects or understanding a few interaction questions.

The framework is illustrated on the following video https://www.youtube.com/watch?v=Ym5aYfzoQX8. It enables to modify the interaction as well as the learning mechanisms in order to study the interaction between the teacher and the learning robot.

5.4.3. Experiment platform for multiparameters simulations

Participants: Fabien Benureau, Paul Fudal.

Simulations in robotics have many shortcommings. At the same time, they offer high customizability, rapidity of deployment, abscence of failure, consistency across time and scalability. In the context of the PhD work of Fabien Benureau, it was decided to investigate hypothesis first in simulation before moving to real hardware.

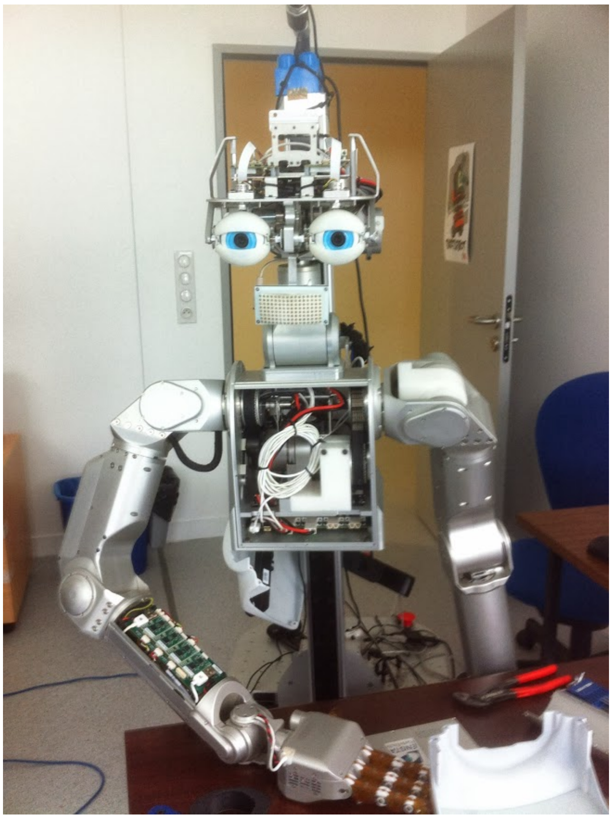

Figure 9. Maintenance is required on the robot

In order to be able to test a high number of different hypothesis, we developped a software platform that would scale to the computing ressource available.

We designed simple continuous simulations around a of-the-shelf 2D physic engine and wrote a highly modular platform that would automatically deploy experiments on cluster environments, with proper handling of dependencies; our work investigate transfer learning, and some experiments's input data is dependent of the results of another.

So far, this platform and the university cluster has allowed to conduct thousands of simulations in parallel, totaling more than 10 years of simulation time. It has led us to present many diverse experiments in our published work [34], each repeated numerous times. It has allowed us to conduct a multi-parameter analysis on the setup, which led to new insights, which are being presented in a journal article to be submitted in the beginning of this year.

Because of its high modularity, this platform is proving to be highly flexible. We are currently adaptating it to a modified, cluster-ready, version of the V-REP simulator. Those simulations will serve to back ones on similar real-world hardware that are currently setup.

5.4.4. pypot

Participants: Pierre Rouanet [correspondant], Steve N'Guyen, Matthieu Lapeyre.

Pypot is a framework developed to make it easy and fast to control custom robots based on dynamixel motors. This framework provides different levels of abstraction corresponding to different types of use. More precisely, you can use pypot to:

1. directly control robotis motors through a USB2serial device,
2. define the structure of your particular robot and control it through high-level commands,
3. define primitives and easily combine them to create complex behavior.

Pypot has been entirely written in Python to allow for fast development, easy deployment and quick scripting by non-necessary expert developers. It can also benefits from the scientific and machine learning libraries existing in Python. The serial communication is handled through the standard library and thus allows for rather high performance (10ms sensorimotor loop). It is crossed-platform and has been tested on Linux, Windows and Mac OS.

Pypot is also compatible with the V-REP simulator (http://www.coppeliarobotics.com). This allows the transparent switch from a real robot to its simulated equivalent without having to modify the code.

Pypot also defined a REST API permitting the development of web apps such as a web control interface faciliting the use of a robotic platform.

Pypot is part of the Poppy project (http://www.poppy-project.org) and has been released under an open source license GPL V3. More details are available on pypot website: https://github.com/poppy-project/pypot

5.5. Experimental Setups

5.5.1. Experimental Platform for User Study of Curiosity-driven Exploration

Participants: Pierre Rouanet [correspondant], Jonathan Grizou, Brice Miard, Julie Golliot.

This platform has been developed to investigate curiosity-driven behaviors and more precisely how humans explore new sensori-motor spaces. It consists in several simple games where users control a 2D/3D shape with the movements of their body. They have to discover the mapping between their movements and a shape displayed on the screen and learn how to make the controlled shape match the target one (fig 10).

The software is entirelly written in Python. It includes a Kinect wrapper allowing the access of 3D position of tracked skeleton joints. It provides a framework for creating new games based on the 2D drawing library (pygame). It also includes a web server used to display game instructions, cut-scene videos and questionnaire.

The presentation of the platform and the preliminary results of a user's study have been rapported in [58].

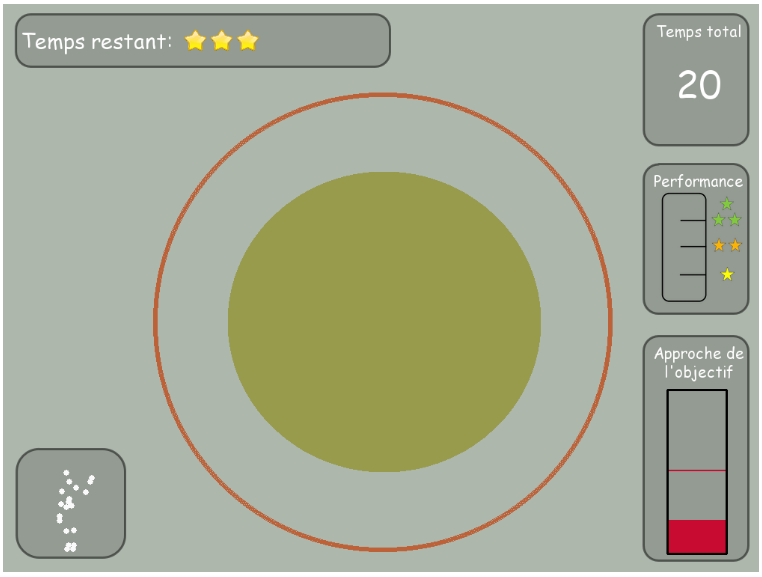

Figure 10. A screenshot representing the game interface as seen by the user.

5.5.2. Learning and representing object assembly tasks

Participants: Yoan Mollard [correspondant], Thibaut Munzer, Pierre Rouanet, Manuel Lopes.

In the context of the 3rd hand project 8.3.1.1 we created a framework for learning assembly tasks from demonstration. In this work we showed how a complex assembly task could be automatically decomposed in components allowing to learn constraints between different objects and their assembly plan. We created also a Graphical User Interface (GUI) allowing to present the learned data in a intuitive way, so that the user can be aware of what the computer has learned. This awareness is crucial for Human-Robot cooperation since the robot will base its decisions on the learned data. Making them clear to the user also allow to rely on him to find potential errors and correct the noise. Thus, the user can program the robot by combining demonstrations and manual corrections minimizing the overall programming phase. Our experimental setup consists in several sequencial phases:

1. **Demonstrations**: User provides several demonstrations of an assembly. All parts of the objects are individually tracked by an Optitrack tracking system
2. **Constraint extraction**: Trajectories are analysed to extract rigid constraints
3. **Segmentation**: Constraints on all demonstrations are segmented to find one constraint per object
4. **Plan computation**: We deduce relational MDP trajectories from raw data, creating one assembly step per constraint
5. **Presentation and correction**: The raw constraints and assembly plan are presented to the user in a friendly way through a 3D GUI so that he is able to visualize and correct them 12
6. **Execution**: The corrected informations are then sent to the robot for actual execution. The execution system only receives constraints and the plan, all motions are computed by a motion planner to reach the goals, but motions could also been extracted from the demonstrations using dynamic motor primitives (DMP). We used a simulated Baxter robot that we acquired during the year.

The framework is written in C++ (GUI) and Python (tracking system, data analysis and execution system), and is completely integrated into ROS. The main steps of the workflow are shown on figure 11.

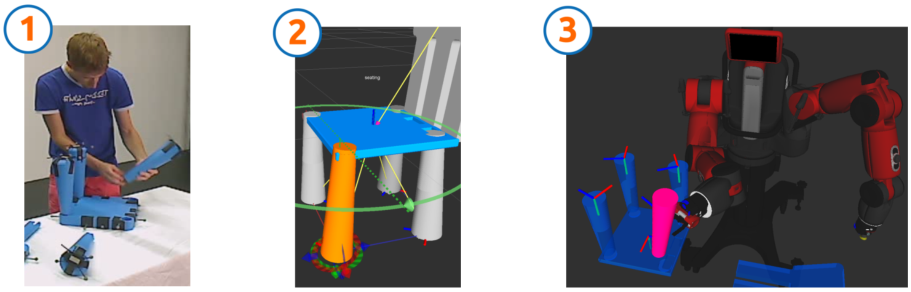

Figure 11. Demonstration, correction and execution of an assembly

The GUI itself 12 represents rigid constraints visually, and provides all the controls necessary to correct them using a graphical procedure. It shows the learned assembly plan as a list of sequential steps that the user can browse like any assembly manual. Also the GUI introduces degrees of freedom in the form of standard mechanical joints (rotational, prismatic, cylindrical joints ...) that the robot can use during execution to simplify the motions and decrease failures during motion planning. The GUI draw graphical cues to represent them and is also able to animate them to make them even clearer.

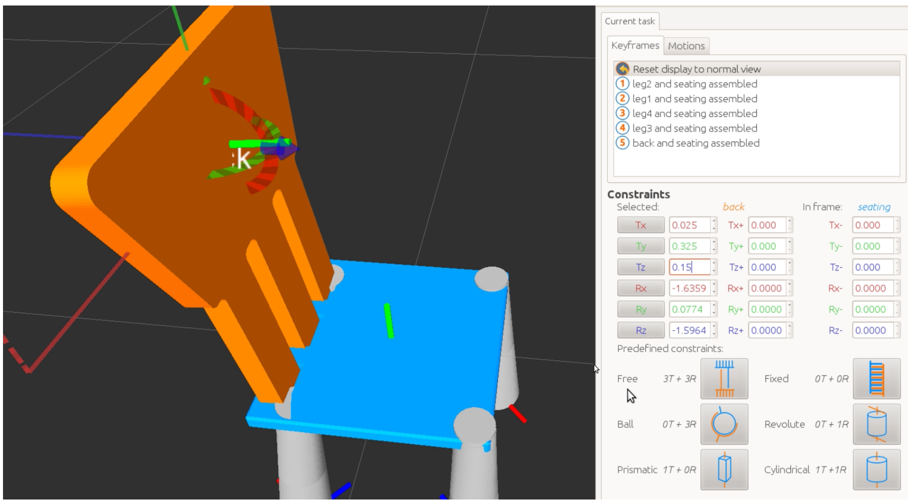

Figure 12. Detailed view of the GUI showing the learned constraints and assembly plan

5.6. Hardware

5.6.1. Poppy Platform

Participants: Matthieu Lapeyre [correspondant], Pierre Rouanet, Jonathan Grizou, Pierre-Yves Oudeyer [supervisor].

The Poppy Project [54], [53], [23] (see Figure 13, http://www.matthieu-lapeyre.com/thesis.pdf) develops an open-source 3D printed humanoid platform based on robust, flexible, easy-to-use and reproduce hardware and software. In particular, the use of 3D printing and rapid prototyping technologies is a central aspect of this project, and makes it easy and fast not only to reproduce the platform, but also to explore morphological variants. Poppy targets three domains of use: science, education and art (see http://www.poppy-project.org).

Poppy was initially designed with a scientific objective, aiming to be a new experimental platform opening the possibility to systematically study the role of morphology in sensorimotor control, in human-robot interaction and in cognitive development. Indeed, a suitable design of a robot morphology can greatly simplify control problems, increase robustness, and open new modes of interaction with the physical and social world. Thus, being able to study the body as an experimental variable, something which can be systematically changed and experimented, is of paramount importance. Yet, until recently it was complicated because building a robot relied on heavy and costly manufacturing techniques. 3D printing has changed the landscape of what is possible: Poppy Project transposed it to humanoid robotics, and it is now possible to explore new body shapes in just a few days. It enables and simplifies the experimentation, the reproduction and the modification of the morphology in research laboratories. It also allows collaborative working, sharing and replication of the results on these issues between laboratories. The ambition is to become a reference platform for benchmarking and dissemination of scientific results.

Thanks to the fact that it integrates advanced and yet easily accessible techniques in an embodiment that motivates students and the wider public, this platform also meets a growing societal need: education and training in technologies combining computer science, electronics and mechanics, as well as a training tool to the emergent revolutionary 3D printing process. With its openness, its design and its rather low-cost, Poppy provides a unique context for experimentation and learning of these technologies in a Do-It-Yourself (DIY) approach. Several experiences with Poppy in secondary, high schools, science museums and Fablabs in France and abroad are underway and will be discussed in the incoming sections. Finally, the possibility to easily modify both the hardware and the software also makes Poppy a useful tool for artistic projects working with interactive computerized installations.

5.6.1.1. Open-Source Robotic Platform

Poppy is the first complete 3D printed open-source and open-hardware humanoid robot. Its 3D printed skeleton and its Arduino-based electronics are open-hardware (Creative Commons). Its software is open-source (GPL V3), and allows programming beginners as well as advanced roboticists to control the robot in Python thanks to the PyPot library (https://github.com/poppy-project/pypot). Its motors are common off-the-shell Robotis actuators (http://www.robotis.com/xe/dynamixel_en), and allow for compliant control and soft physical human-robot interaction. Poppy presents an original mechanical structure which permits to obtain a light structure with 3.5kg for 84cm height. Before the arrival of 3D printing techniques, this kind of complex structure was either impossible to produce or extremely expensive. Now, anyone can produce and modify such robot in their home using affordable personal 3D printers.

Several web tools support collaboration and sharing among members of the Poppy community: a portal web site (www.poppy-project.org), GitHub repositories for the hardware and software with associated wikis for documentation (www.github.com/poppy-project/), and a forum based on Discourse [1] technology (forum.poppy-project.org).

6. New Results

6.1. Highlights of the Year

PY. Oudeyer and M. Lopes, together with J. Gottlieb (Univ. Columbia, NY) organized the first International Symposium on Neurocuriosity symposium on Information Seeking, Curiosity and Attention, pioneering a

[1] www.discourse.org

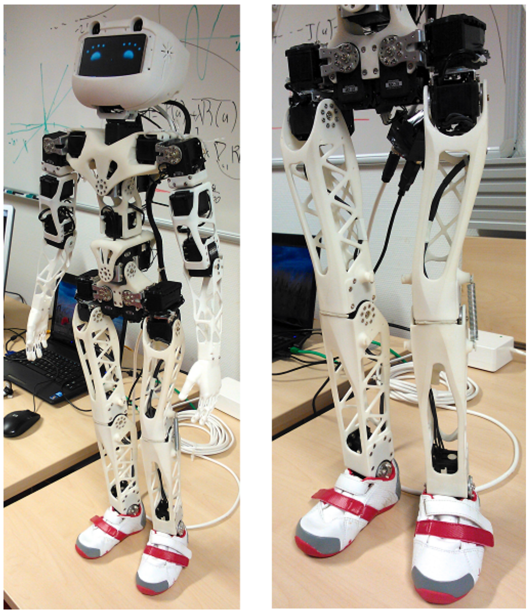

Figure 13. a. Global view of the Poppy platform. b. Zoom on legs design

gathering of world experts on curiosity from developmental psychology, neuroscience, ethology and computational modelling (see https://openlab-flowers.inria.fr/t/first-interdisciplinary-symposium-on-information-seeking-curiosity-and-attention/21). This was achieved in the context of associated team Neurocuriosity with the cognitive neuroscience lab of J. Gottlieb at Univ. Columbia, NY, US. The first results investigating predictions of theoretical formal models of curiosity on human exploration were also published [25].

O. Mangin obtained the Best thesis poster from Bordeaux doctoral school of mathematics and computer science, for his PhD thesis "The Emergence of Multimodal Concepts: From Perceptual Motion Primitives to Grounded Acoustic Words" [24].

The team, in collaboration with Inaki Iturrate and Luis Montesano, published major results on calibration-free brain-computer interface methods, where incremental machine learning algorithms are used to remove the phase of calibration for an important family of use contexts [44] [45].

In october 2014, the team announced the release of a new version of the Poppy Project platform, dedicated in particular to the use of tools for creating and programming interactive robots in Education and Art. This platform, which is a result of research on the role of morphology in skill acquisition within ERC project Explorers, was selected as finalist for the Global Fab Awards 2014 (https://www.fab10.org/en/awards) which select the best worldwide projects in the Makers ecosystem. It was also presented in major international press and media (https://www.poppy-project.org/in-the-press/), in multiple hackatons and demos, in particular at the major international conference LeWeb (https://www.poppy-project.org/social-life/, and its video on the web was seen 125k times. Poppy Project was presented at Elysée, during a French Tech event, to François Hollande (http://www.inria.fr/centre/bordeaux/actualites/poppy-le-robot-humanoide-a-l-elysee), and in Bordeaux to Axelle Lemaire. Web site: http://www.poppy-project.org

The Flowers team made major achievements in diffusing science and technology towards the general public. The team developped the IniRobot pedagogical kit, for the discovery of computer science and robotics in primary schools. The kit was first developped and evaluated in schools, in collaboration with a group of teachers, and then began to be largely disseminated and used in september 2014 to schools in Talence, Bordeaux, Lormont, and Lille. A dedicated web site has been created, allowing all users and contributors to share their experiences with the kit: https://dm1r.inria.fr/c/kits-pedagogiques/inirobot. PY. Oudeyer was invited to give a TedX talk (https://www.youtube.com/watch?v=AP8i435ztwE, video viewed by more than 9000 people), and was interviewed and invited to talk about our research on major media channels (e.g. Le Monde, Les Echos, France Inter, see http://www.pyoudeyer.com/press/).

6.2. Robotic And Computational Models Of Human Development

6.2.1. Computational Models Of Information-Seeking, Curiosity And Attention

Participants: Manuel Lopes, Pierre-Yves Oudeyer [correspondant], Jacqueline Gottlieb, Adrien Baranes, Pierre Rouanet, Brice Miard, Jonathan Grizou.

6.2.1.1. The effects of task difficulty, novelty and the size of the search space on intrinsically motivated exploration

Devising efficient strategies for exploration in large open-ended spaces is one of the most difficult computational problems of intelligent organisms. Because the available rewards are ambiguous or unknown during the exploratory phase, subjects must act in intrinsically motivated fashion. However, a vast majority of behavioral and neural studies to date have focused on decision making in reward-based tasks, and the rules guiding intrinsically motivated exploration remain largely unknown. To examine this question we developed a paradigm for systematically testing the choices of human observers in a free play context. Adult subjects played a series of short computer games of variable difficulty, and freely choose which game they wished to sample without external guidance or physical rewards. Subjects performed the task in three distinct conditions where they sampled from a small or a large choice set (7 vs. 64 possible levels of difficulty), and where they did or did not have the possibility to sample new games at a constant level of difficulty. We show that despite the absence of external constraints, the subjects spontaneously adopted a structured exploration strategy whereby they (1) started with easier games and progressed to more difficult games, (2) sampled the entire choice set including extremely difficult games that could not be learnt, (3) repeated moderately and high difficulty games much more frequently than was predicted by chance, and (4) had higher repetition rates and chose higher speeds if they could generate new sequences at a constant level of difficulty. The results suggest that intrinsically motivated exploration is shaped by several factors including task difficulty, novelty and the size of the choice set, and these come into play to serve two internal goals—maximize the subjects' knowledge of the available tasks (exploring the limits of the task set), and maximize their competence (performance and skills) across the task set. This was published in [25].

6.2.1.2. A new experimental setup to study the structure of curiosity-driven exploration in humans

We started evaluating several games that test how humans explore a space of motor tasks of different complexities. Our objective is to observe what exploratory behaviors do people use when learning a new skill. The main hypothesis we are testing is that skills that provide a larger learning progress will be favored and so we will see a progression from the simpler to the more complex skills. Surely there are individual differences and the causes and impact of those differents is a very important research topic. The Abstract Games we created allows us to create several dimensions of complexity for the games. In this task, there are several abstract forms that appear in the screen and the user is able to control them using its own body (tracked using a Kinect sensor), see Fig. 2. The relation between the degrees of freedom and the forms/colors/sizes of the shapes is arbitrary and the user must explore its body to be able to control its behavior. This was published in [58].

6.3. Life-Long Robot Learning And Development Of Motor And Social Skills

6.3.1. Exploration and learning of sensorimotor policies

6.3.1.1. Non-linear regression algorithms for motor skill acquisition: a comparison

Participants: Thibaut Munzer [correspondant], Freek Stulp, Olivier Sigaud.

Endowing robots with the capability to learn is an important goal for the robotics research community. One part of this research is focused on learning skills, where usually two learning paradigms are used sequentially. First, a robot learns a motor primitive by demonstration (or imitation). Then, it improves this motor primitive with respect to some externally defined criterion. We realized a study on how the representation used in the demonstration learning step can influence the performance of the policy improvement step. We provide a conceptual survey of different demonstration learning algorithms and perform an empirical comparison of their performance when combined with a subsequent policy improvement step. These study have been published at the JFPDA conference [61].

During this work, we have discovered that many (batch) regression algorithms (amongst others, locally weighted (projection) regression, Gaussian mixture regression, radial basis function networks, and Gaussian process regression) use only one of two underlying model representations to represent a function: a weighted sum of basis function, or a mixture of linear models. Furthermore, we show that the former is a special case of the latter. This insights provides a deep understanding of the relationship between these algorithms, that, despite being derived from very different principles, use a function representation that can be captured within one unified model. A review article on this topic has been submitted to Neural Networks.

6.3.1.2. Simultaneous On-line Discovery and Improvement of Robotic Skill Options

Participants: Freek Stulp [correspondant], Laura Herlant, Antoine Hoarau, Gennaro Raiola.

The regularity of everyday tasks enables us to reuse existing solutions for task variations. For instance, most door-handles require the same basic skill (reach, grasp, turn, pull), but small adaptations of the basic skill are required to adapt to the variations that exist (e.g. levers vs. knobs). In a joint project with Laura Herlant of Carnegie Mellon University, we developed the algorithm “Simultaneous On-line Discovery and Improvement of Robotic Skills” (SODIRS) that is able to autonomously discover and optimize skill options for such task variations. We formalize the problem in a reinforcement learning context, and use the PI^{BB} algorithm to continually optimize skills with respect to a cost function. SODIRS discovers new subskills, or “skill options”, by clustering the costs of trials, and determining whether perceptual features are able to predict which cluster a trial will belong to. This enables SODIRS to build a decision tree, in which the leaves contain skill options for task variations. We demonstrate SODIRS’ performance in simulation, as well as on a Meka humanoid robot performing the ball-in-cup task. This work has led to a publication at IROS [64].

6.3.1.3. Simultaneous On-line Discovery and Improvement of Robotic Skill Options

Participants: Freek Stulp [correspondant], Nicolas Alberto Torres, Michael Mistry.

Freek Stulp supervised the Master’s thesis project of Nicolas Torres Alberto from the Telecom Physique Strasbourg, which led to a publication at Humanoids’14 [65]. The project focused on improving autonomy in learning inverse dynamics models for computed torque control. In computed torque control, robot dynamics are predicted by dynamic models. This enables more compliant control, as the gains of the feedback term can be lowered, because the task of compensating for robot dynamics is delegated from the feedback to the feedforward term. Previous work has shown that Gaussian process regression is an effective method for learning computed torque control, by setting the feedforward torques to the mean of the Gaussian process. We extend this work by also exploiting the variance predicted by the Gaussian process, by lowering the gains if the variance is low. This enables an automatic adaptation of the gains to the uncertainty in the computed torque model, and leads to more compliant low-gain control as the robot learns more accurate models over time. On a simulated 7-DOF robot manipulator, we demonstrate how accurate tracking is achieved, despite the gains being lowered over time. This is a first step towards life-long learning robots, that continuously and autonomously adapt their control parameters (feedforward *and* feedback) over extended periods of time.

6.3.1.4. Learning manipulation of flexible tools

Participants: Clément Moulin-Frier [correspondant], Marie-Morgane Paumard, Pierre Rouanet.

Clément Moulin-Frier and Pierre Rouanet supervised the internship of Marie-Morgane Paumard from the *Ecole Normale Supérieure de Cachan*, at the Bachelor level. The internship has been realized from May to August 2014. Her report is entitled *Learning the manipulation of flexible tools in developmental robotics: a fishing robot* and is available at this address: https://flowers.inria.fr/clement_mf/files/Paumard_RapportDeStage.pdf.

Learning how to manipulate flexible tools is an harsh issue in robotics, since there is generally no analytical model of the system dynamics available. Learning algorithms are therefore a pivotal tool to control such systems. Marie-Morgane conceived an experiment on the manipulation of a fishing rod by a 2-arm robot equipped with a movement generation and perceptual systems. She studied how an optimization algorithm allows the robot to reach particular position of the hook on the floor. Then, she analyzed the distribution of effects (i.e. final fishhook position) in different contexts as well as optimization performances for particular goals.

6.3.1.5. Learning how to reach various goals by autonomous interaction with the environment: unification and comparison of exploration strategies

Participants: Clément Moulin-Frier [correspondant], Pierre-Yves Oudeyer.

In the field of developmental robotics, we are particularly interested in the exploration strategies which can drive an agent to learn how to reach a wide variety of goals. We unified and compared such strategies, recently shown to be efficient to learn complex non-linear redundant sensorimotor mappings. They combine two main principles. The first one concerns the space in which the learning agent chooses points to explore (motor space vs. goal space). Previous works (Rolf et al., 2010; Baranes and Oudeyer, 2012) have shown that learning redundant inverse models could be achieved more efficiently if exploration was driven by goal babbling, triggering reaching, rather than direct motor babbling. Goal babbling is especially efficient to learn highly redundant mappings (e.g the inverse kinematics of a arm). At each time step, the agent chooses a goal in a goal space (e.g uniformly), uses the current knowledge of an inverse model to infer a motor command to reach that goal, observes the corresponding consequence and updates its inverse model according to this new experience. This exploration strategy allows the agent to cover the goal space more efficiently, avoiding to waste time in redundant parts of the sensorimotor space (e.g executing many motor commands that actually reach the same goal). The second principle comes from the field of active learning, where exploration strategies are conceived as an optimization process. Samples in the input space (i.e motor space) are collected in order to minimize a given property of the learning process, e.g the uncertainty (Cohn et al., 1996) or the prediction error (Thrun, 1995) of the model. This allows the agent to focus on parts of the sensorimotor space in which exploration is supposed to improve the quality of the model. In [59], we have shown how an integrating probabilistic framework allows to model several recent algorithmic architectures for exploration based on these two principles, and compare the efficiency of various exploration strategies to learn how to uniformly cover a goal space. This was published in [59].

6.3.1.6. Reusing Motor Commands to Learn Object Interaction

Participants: Fabien Benureau [correspondant], Pierre-Yves Oudeyer.

We have proposed the Reuse algorithm, that exploit data produced during the exploration of an first environment to efficiently bootstrap the exploration of second, different but related environment. The effect of the Reuse algorithm is to produce a high diversity of effects early during exploration. The algorithm only constrains the environments to share the same motor space, and makes no assumptions about learning algorithms or sensory modalities. We have illustrated our algorithm on a 6-joints robotic arm interacting with a virtual object, and showed that our algorithm is robust to dissimilar environments, and significantly improves the early exploration of similar ones. This was published in [34].

6.3.1.7. Socially Guided Intrinsic Motivation for Robot Learning of Motor Skills

Participants: Mai Nguyen [correspondant], Pierre-Yves Oudeyer.

We have presented a technical approach to robot learning of motor skills which combines active intrinsically motivated learning with imitation learning. Our architecture, called SGIM-D, allows efficient learning of high-dimensional continuous sensorimotor inverse models in robots, and in particular learns distributions of parameterised motor policies that solve a corresponding distribution of parameterised goals/tasks. This is made possible by the technical integration of imitation learning techniques within an algorithm for learning inverse models that relies on active goal babbling. In an experiment where a robot arm has to learn to use a flexible fishing line , we have illustrated that SGIM-D efficiently combines the advantages of social learning and intrinsic motivation and benefits from human demonstration properties to learn how to produce varied outcomes in the environment, while developing more precise control policies in large spaces. This was published in [28].

6.3.1.8. A social learning formalism for learners trying to figure out what a teacher wants them to do

Participants: Thomas Cederborg [correspondant], Pierre-Yves Oudeyer.

We have elaborated a theoretical foundation for approaching the problem of how a learner can infer what a teacher wants it to do through strongly ambiguous interaction or observation. This groups the interpretation of a broad range of information sources under the same theoretical framework. A teacher's motion demonstration, eye gaze during a reproduction attempt, pushes of good/bad buttons and speech comment are all treated as specific instances of the same general class of information sources. These sources all provide (partially and ambiguously) information about what the teacher wants the learner to do, and all need to be interpreted concurrently. We introduce a formalism to address this challenge, which allows us to consider various strands of previous research as different related facets of a single generalized problem. In turn, this allows us to identify important new avenues for research. To sketch these new directions, several learning setups were introduced, and algorithmic structures are introduced to illustrate some of the practical problems that must be overcome. This was published in [26].

6.3.2. Task learning from social guidance

6.3.2.1. Inverse Reinforcement Learning in Relational Domains

Participants: Thibaut Munzer [correspondant], Bilal Piot, Mathieu Geist, Olivier Pietquin, Manuel Lopes.

We introduced a first approach to the Inverse Reinforcement Learning (IRL) problem in relational domains. IRL has been used to recover a more compact representation of the expert policy leading to better generalize among different contexts. Relational learning allows one to represent problems with a varying number of objects (potentially infinite), thus providing more generalizable representations of problems and skills. We show how these different formalisms can be combined by modifying an IRL algorithm (Cascaded Supervised IRL) such that it handles relational domains. Our results indicate that we can recover rewards from expert data using only partial knowledge about the dynamics of the environment. We evaluate our algorithm in several tasks and study the impact of several experimental conditions such as: the number of demonstrations, knowledge about the dynamics, transfer among varying dimensions of a problem, and changing dynamics.

6.4. Autonomous And Social Perceptual Learning

6.4.1. Unsupervised and online non-stationary obstacle discovery and modelling using a laser range finder

Participants: Guillaume Duceux, David Filliat [correspondant].

Recognizing objects is an important capability for assistance robots, but most methods rely on vision and a heavy training procedures to be able to recognize some objects. Using laser range finders has shown its efficiency to perform mapping and navigation for mobile robots. However, most of existing methods assume a mostly static world and filter away dynamic aspects while those dynamic aspects are often caused by non-stationary objects which may be important for the robot task. We propose an approach that makes it possible to detect, learn and recognize these objects through a multi-view model, using only a planar laser range finder. We show using a supervised approach that despite the limited information provided by the sensor, it is possible to recognize efficiently up to 22 different object, with a low computing cost while taking advantage of the large field of view of the sensor. We also propose an online, incremental and unsupervised approach that make it possible to continuously discover and learn all kind of dynamic elements encountered by the robot including people and objects. These results have been published at the IROS conference [40].

6.4.2. Task oriented representations by discriminative modulation of a generative learning method

Participants: Mathieu Lefort, Alexander Gepperth [correspondant].

PROPRE (which stands for PROjection - PREdiction) is a generic and modular unsupervised neural learning paradigm that extracts meaningful concepts of multiple data flows based on predictability across stimuli. It consists on the combination of three modules. First, a topological projection of each data flow on a self-organizing map. Second, a decentralized prediction of each projection activity from each other map activities. Third, a predictability measure that quantifies the prediction error. This measure is used to modulate the projection learning so that to favor the mapping of predictable stimuli across data flows. This model was applied to the visual supervised classification of the pedestrian orientation. The modulation of the visual representation learning by the predictability measure (quantifying the ability to detect the orientation of the pedestrian) improves significantly classification performances of the system independently of the predictability measure used [55]. Moreover, PROPRE provides a combination of interesting functional properties, such as online and incremental learning [56].

6.4.3. Learning of multimodal representations based on the self-evaluation of their predictability power

Participants: Mathieu Lefort, Thomas Kopinski, Alexander Gepperth [correspondant].

PROPRE paradigm (see section 6.4.2) was also applied to the classification of gestures caught from two time-of-flight (ToF) cameras. In this context, the predictability measure acts as a self-evaluation module that biases the learned representations towards stimuli correlated across modalities, i.e. related to the ability of one camera to predict the other one. We show in [57] that this unsupervised multimodal representations learning improves the gesture recognition performance, compared to isolated camera representations learning, even not as much as supervised one.

6.4.4. Resource-efficient online learning of classification and regression tasks

Participants: Mathieu Lefort, Thomas Kopinski, Thomas Hecht, Alexander Gepperth [correspondant].

This activity investigates the coupling of generative and discriminative learning (SOM and regression) to achieve incremental learning that stays resource-efficient when the number of input and output dimensions is high. On the one hand, we apply this technique to sensory classification problems where input dimensionalities can exceed 10000 in the presence of multiple categories. On the other hand, we target the learning of forward and inverse regression models for robotics, possibly combining proproceptive with sensory information which again leads to high data dimensionality. A special kind of regression task we consider in this context is optimal integration of sensory information, where the most likely underlying value must be inferred from several noisy sensor readings. In contrast to popular approaches like XCF or LWPR, our approach achieves efficiency by avoiding a precise partitioning of the input space, relying on a dimensionality-reduced topological projection of the input space instead. While this achives slightly inferior results on standard benchmarks, we can treat high-dimensional incremental learning problems that are inaccessible to other algorithms, and especially to LWPR. This activity has resulted in two submissions to ESANN 2015 and one to IEEE Transactions on Autonomous Mental Development.

6.4.5. Indoor semantic mapping on a mobile robot

Participants: Louis-Charles Caron [correspondant], Alexander Gepperth, David Filliat.

Semantic mapping is the act of storing high-level information in a persistent map of the environment. The semantic information considered here is the identity of objects encountered by a mobile robot in an indoor environment [35]. The robot runs a SLAM algorithm and builds a map using a laser range finder. The semantic information is collected by analysing the point cloud provided by an RGB-D camera mounted on the robot. The choice of features used to describe the objects, the type of fusion and the recognition algorithm influence the overall capacity of the algorithm. Shape features perform very well, but are blind to changes in color. The fusion of different types of features can reduce the recognition rates on some objects but increases the overall figure. This increase is more significant as the number of objects to recognitze gets larger [36]. After running the object recognition algorithm, the identity of the objects is stored alongside the map. The stored information influences future recognition attempts on objects that were already seen by the robot to improve the recognition process. A 3-d map along with a snapshot and the identity of each object seen is displayed to a user.

6.5. Robot Design And Morphological Computation

6.5.1. Rapid morphological exploration with the Poppy humanoid platform.

Participants: Matthieu Lapeyre [correspondant], Steve N'Guyen, Alexandre Le Falher, Pierre-Yves Oudeyer.

In the paper [53], we discuss the motivation and challenges raised by the desire to consider the morphology as an experimental variable on real robotic platforms as well as allowing reproducibility and diffusion of research results in the scientific community. In this context, we present an alternative design and production methodology that we have applied to the conception of Poppy humanoid, the first complete 3D printed open-source and open-hardware humanoid robot. Robust and accessible, it allows exploring quickly and easily the fabrication, the programming and the experimentation of various robotic morphologies. Both hardware and software are open-source, and a web platform allows interdisciplinary contributions, sharing and collaborations. Finally we conduct an experiment to explore the impact of four different foot morphologies on the robot's dynamic when it makes a footstep. We show that such experimentation can easily be achieved and shared in couple of days at almost no cost.

6.6. Educational Technologies

6.6.1. KidLearn

Participants: Manuel Lopes [correspondant], Pierre-Yves Oudeyer, Didier Roy, Benjamin Clement.

Kidlearn is a research project studying how machine learning can be applied to intelligent tutoring systems. It aims at developing methodologies and software which adaptively personalize sequences of learning activities to the particularities of each individual student. Our systems aim at proposing to the student the right activity at the right time, maximizing concurrently his learning progress and its motivation. In addition to contributing to the efficiency of learning and motivation, the approach is also made to reduce the time needed to design ITS systems.

Intelligent Tutoring System (ITS) are computer environments designed to guide students in their learning. Through the proposal of different activities, it provides teaching experience, guidance and feedback to improve learning. The FLOWERS team has developed several computational models of artificial curiosity and intrinsic motivation based on research on psychology that might have a great impact for ITS. Results showed that activities with intermediate levels of complexity, neither too easy nor too difficult but just a little more difficult that the current level, provide better teaching experiences. The system is based on the combination of three approaches. First, it leverages Flowers team's recent models of computational models of artificial curiosity and intrinsic motivation based on research in psychology and neuroscience. Second, it uses state-of-the-art Multi-Arm Bandit (MAB) techniques to efficiently manage the exploration/exploitation challenge of this optimization process. Third, it leverages expert knowledge to constrain and bootstrap initial exploration of the MAB, while requiring only coarse guidance information of the expert and allowing the system to deal with didactic gaps in its knowledge. In 2014, we have run a second pilot experiment in elementary schools of Région Aquitaine, where 7-8 year old kids could learn elements of mathematics thanks to an educational software that presented the right exercises at the right time to maximize learning progress. [69], [37], [38], [39]

6.6.2. Education and the Poppy project

Participants: Matthieu Lapeyre [correspondant], Pierre-Yves Oudeyer, Didier Roy.

The Poppy platform was initially designed for research purposes and even more specifically for studying biped locomotion and human-robot interaction. However, it has been designed with open science goals in mind, both to share our research and create tools for researchers. As we are convinced of the need for multidisciplinary contributions in order to improve the state of the art in the robotics field, we decided right from the beginning to use and create modern and easy-to-use tools. This choice has strongly affected the way we designed our platform. Indeed, being simple to use, easily reproducible and hackable, modular, 3D printable and as plug 'n play as possible lead to the development of hardware (Poppy) and software (pypot) tools that can be also used by non-expert people.

Thus Poppy meets a growing societal need: education and training in technologies combining computer science, electronics and mechanics, as well as a training tool for the emergent revolutionary 3D printing process. Since October 2013 (open source release), we have been contacted by several Fablabs, universities, engineering schools and even high schools. We have had the opportunity to meet with educational teams and it appears they are looking for new motivational tools for group projects.

In this context, the Poppy platform appears well suited. Indeed, it integrates advanced and yet easily accessible techniques (3D printing, Arduino, Python) in an embodiment that motivates students and the wider public. With its openness, design and rather low-cost, Poppy is highly hackable and provides a unique context for learning and experimenting with these technologies in a Do-It-Yourself (DIY) way.

The paper [54] describes the use of the Poppy platform as a tool for scientific researches as well as educationnal and artistic applications.

Several experiments with Poppy in middle and high schools, science museums and Fablabs in France and abroad are already underway and will be discussed in the upcoming **Partnerships and Cooperations** sections.

6.6.3. Expression of emotions with Poppy Humanoid

Participants: Fabien Benureau [correspondant], Matthieu Lapeyre.

Two students in 3rd year of the Cognitive Science major at the University of Bordeaux led a TER project this year using Poppy under the supervision of Fabien Benureau, exploring how the attitude towards robots influences how humans recognise the emotion they try to express. Poppy having no facial expression — or face — yet, the students expressed the five expressions they selected (anger, surprise, joy, sadness, disgust) with body movements alone. They videotaped the sequences of movements (videos are available here http://python.sm.u-bordeaux2.fr/ter/2014/sc/desprez-zerdoumi/?page_id=289) and created an experiment asking volunteers to guess which emotion was displayed. The form also included the Negative Attitude towards Robots Scale (NARS), to investigate the possible correlation between fear of robot and the ability to identify their emotional attitude. The results showed no correlation between the two, although it was admitted that the experiment would have to be improved and ran again before any conclusion could be made.

6.7. Interactive Learning and user adaptation

6.7.1. Interactive learning from unlabeled instructions

Participants: Grizou Jonathan [correspondant], Itturate Inaki, Montesano Luis, Pierre-Yves Oudeyer, Manuel Lopes.

Interactive learning deals with the problem of learning and solving tasks using human instructions. It is common in human-robot interaction, tutoring systems, and in human-computer interfaces such as brain-computer ones. In most cases, learning these tasks is possible because the signals are predefined or an ad-hoc calibration procedure allows to map signals to specific meanings. In this work, we addressed the problem of simultaneously solving a task under human feedback and learning the associated meanings of the feedback signals. This has important practical application since the user can start controlling a device from scratch, without the need of an expert to define the meaning of signals or carrying out a calibration phase. We proposed an algorithm that simultaneously assign meanings to signals while solving a sequential task under the assumption that both, human and machine, share the same a priori on the possible instruction meanings and the possible tasks. This work was published in a conference paper [45] and a journal paper will be submitted in January 2015.

We communicated about this work to the human-robot interaction (HRI) community. A robot equiped with our algortihm would be able to interact with a human without knowing in advance the specific communicative signals used by the human. This work was published in the HRI Pionneer workshop [46].

This work was presented during the thesis defense of Jonathan Grizou entitled: Learning from Unlabeled Interaction Frames, on October 24, 2014. The video, slides, and thesis manuscript can be found at: http://jgrizou.com/projects/thesis-defense/

6.7.2. Calibration-Free BCI Based Control

Participants: Grizou Jonathan [correspondant], Itturate Inaki, Montesano Luis, Pierre-Yves Oudeyer, Manuel Lopes.

We applied previous work on interactive learning from unlabeled instructions [45] to Brain-Machine Interaction problem, leading to a Calibration-Free brain computer interfaces. So far in such brain-computer interfaces (BCI), an explicit calibration phase was required to build a decoder that translates raw electroencephalography signals from the brain of each user into meaningful instructions. Our method removes the calibration phase, and allows a user to control a device to solve a sequential task. We performed experiments where four users use BCI to control an agent on a virtual world to reach a target without any previous calibration process. Our approach is promising for the deployments of BCI applications out of the labs. This work was published in a conference paper [44] and a journal paper will be submitted in January 2015.

This work was presented during the thesis defense of Jonathan Grizou entitled: Learning from Unlabeled Interaction Frames, on October 24, 2014. The video, slides, and thesis manuscript can be found at: http://jgrizou.com/projects/thesis-defense/

6.8. Studying the Co-Construction of Interaction Protocols in Collaborative Tasks with Humans

6.8.1. Experimental Setups for User Study of Alignment in Asymmetric Interactions

Participants: Anna-Lisa Vollmer [correspondant], Jonathan Grizou, Manuel Lopes, Katharina Rohlfing, Pierre-Yves Oudeyer.

In interaction, humans align and effortlessly create common ground in communication, allowing efficient collaboration in widely diverse contexts. Robots are still far away from being able to adapt in such a flexible manner with non-expert humans to complete collaborative tasks. Challenges include the capability to understand unknown feedback or guidance signals, to make sense of what they refer to depending on their timing and context, and to agree on how to organize the interaction into roles and turns.

As a first step in approaching this issue, we investigated the processes used by humans to negotiate a protocol of interaction when they do not already share one. We developed a new experimental setup, where two humans have to collaborate to solve a task. The channels of communication they can use are constrained and force them to invent and agree on a shared interaction protocol in order to solve the task. These constraints allow us to analyze how a communication protocol is progressively established through the interplay and history of individual actions.

We consider a remote construction task, where one user (user A) knows what to build but do not have access to the construction site while its partner (user B) is at the site but do not know what to do. By constraining the communicative channel between the two partners, we study how, and if, they will agree on a similar set of signals to convey information and what type of information they tend to produce. The experimental setup consist of box with button, a video recording system and two screens. User A can send signals to user B by pressing buttons (fig. 14). Signals are displayed on a screen (fig. 14) at user B side. User A is not aware of what is displayed on user B screen, neither user B is aware of the relation between button presses and screen events. The video of user B construction scene is streamed to a screen at user B side. The task consist of bulding arbitrary construction (fig. 14) using colored toy bricks (fig. 14).

The various data recolted during these interaction sequences (fig. 15) allow us to study the Co-Construction of Interaction Protocols. This work was published in a conference paper [66].

6.9. Other

6.9.1. A Framework for Proactive Assistance

Participants: Alexandre Armand, David Filliat [correspondant].

Figure 14. Three examples of sign displayed on the learner screen; The box and the button use as an interface for the teacher to communicate with the learner; Examples of construction presented to the teacher.

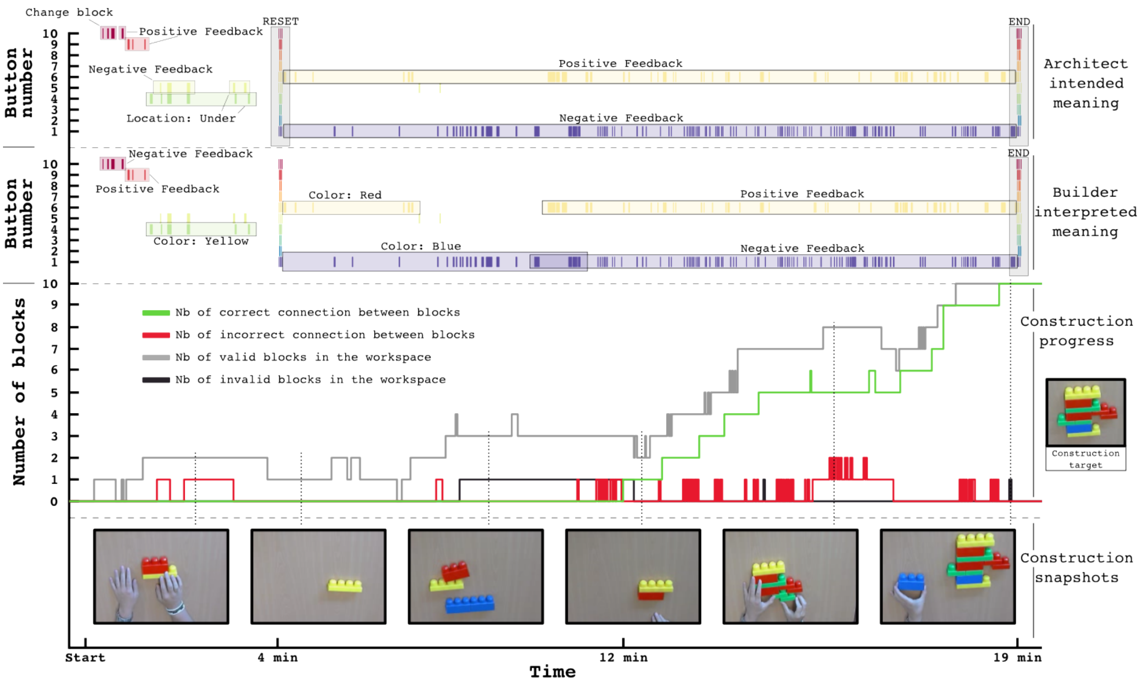

Figure 15. Timeline for one experiment of an architect and a builder collaborating towards building the construction target (right hand side). The top and middle part show the timeline of button presses associated with the intended meaning from the architect (top) and the understood meaning from the builder (middle).

We worked in collaboration with Renault on the problems of adapting driving assitance systems by learning individual drivers behaviours and of integrating more advanced perception in these systems. Advanced Driving Assistance Systems usually provide assistance to drivers only once a high risk situation has been detected. Indeed, it is difficult for an embedded system to understand driving situations, and to predict early enough that it is to become uncomfortable or dangerous. Most of ADAS work assume that interactions between road entities do not exist (or are limited), and that all drivers react in the same manner in similar conditions. We propose a framework that enables to fill these gaps. On one hand, an ontology which is a conceptual description of entities present in driving spaces is used to understand how all the perceived entities interact together with the subject vehicle, and govern its behavior. On the other hand, a dynamic Bayesian Network enables to estimate the driver situation awareness with regard to the perceived objects, based on the ontology inferences, map information, driver actuation and learned driving style. This work was published in a workshop [33] and a conference paper [32].

7. Bilateral Contracts and Grants with Industry

7.1. Bilateral Contracts with Industry

7.1.1. Advanced platform for Urban Mobility (PAMU)

Participants: David Filliat [correspondant], Emmanuel Battesti.

Development of extension of a planning algorithm on a autonomous electric car for Renault SAS. We improved a planning module in order to produce global plans to reach a goal specified in a digital map and to perform local reactive planning to avoid dynamic obstacles. This module is integrated in the PAMU autonomous vallet parking developed by Renault with several academic partners. The final demonstration of the system was made in october 2014.

7.2. Bilateral Grants with Industry

7.2.1. Development of an Contextual electronic copilot for driving assistance

Participants: David Filliat [correspondant], Alexandre Armand.

Financing of the CIFRE PhD grant of Alexandre Armand by Renault SAS with the goal of developping an Contextual electronic copilot for driving assistance based on the learning of the behavior of the driver.

7.2.2. Curiosity and visual attention

Participants: David Filliat [correspondant], Celine Craye.

Financing of the CIFRE PhD grant of Celine Craye by Thales S.A. with the goal of developing a mechanism of visual attention guiding the exploration of a robot.

7.2.3. Auto-Apprentissage Auto-Adaptable pour la compliance au traitement

Participants: Manuel Lopes [correspondant], Alexandra Delmas, Pierre-Yves Oudeyer, Benjamin Clement.

Financing of the CIFRE PhD grant of Alexandra Delmas by Itwell with the goal of developing a tool for self-learning for patients to improve their compliance to treatment.

8. Partnerships and Cooperations

8.1. Regional Initiatives

8.1.1. Comacina Capsule Creative

The artist community is a rich source of inspiration and can provide new perspectives to scientific and technological questions. This complementarity is a great opportunity that we want to enforce in the Poppy project by making the robot accessible to non-robotic-expert users. The first experimentation of the use of Poppy in an art project was an artist residency entitled "Étres et Numérique". Led by the artists [2] Amandine Braconnier (mixed media artist) and Marie-Aline Villard (dancer-researcher), supported by the Fabrik Pola and the Aquitaine Region, this contemporary art project focused on the way to express emotions through robotic body movement in physical interaction with a human dancer. This work took the form of a seven day art-science residency involving members of the Poppy project and the artists. During the residency, the ease of programming through the pypot library permitted to design a simple interface allowing the dancer to physically sculpt novel movements, which softness could be dynamically controlled. This residency took part in a French high school (Lycée Saintonge, Bordeaux) and was also an educational experiment where young students participated to workshops where they explored Poppy movements and physical interaction with the robot. The residency restitution was a contemporary art dance performance involving poetic choreography, alternating phases of autonomous robot movements and passive robot movements provoked by the dancer. A description of this experiment is available at: https://forum.poppy-project.org/t/artist-residency-etres-et-numerique/72.

8.1.2. Poppy at Saintonge Sainte-Famille highschool (Bordeaux)

After the artistic residency that took place in the chapel at the Saintonge Sainte Famille high school, some teachers have become interested in the educational potential of the Poppy project and would like to integrate it as a common thread into the school year.

Poppy was initially designed for research purposes and seems to be also adapted for higher education. Yet using Poppy in secondary education seems excessive as it is expensive and the use of high quality servo-actuators is not really justified. However, the experience with high-school students is still interesting and we accepted this opportunity to do a pilot experiment.

For the teachers, the main goal was to gain experience of using such tools in a project context and evaluate the potential and limitations for educational purposes. For us, we were interested in the reaction of young students to Poppy and in getting an opinion on the relevance of Poppy for education at this level. Also, it was a real crash test of our design (hardware and software) in non-experienced hands and outside the laboratory.

The experiment took place in the Saintonge Sainte Famille high school on May 26th & 27th, and involved near 40 *première STI2D* students (equivalent to UK Year 12) preparing a professional baccalaureate and three teachers (*"Energy and environment"*, *"Architecture and construction"*, and *"Digital information systems"*). It was organized as a workshop in three 4-hour sessions. The last two hours were dedicated to oral presentations in the lecture hall allowing students to share their experiences and work.

For this first pilot experiment, we decided to reduce the cost by using only a sub-part of the whole Poppy. For us the most relevant part for high-school students was the upper body (thorax, head and the two arms), because it avoids to work on complex sensory-motor behaviours such as balancing and walking while keeping the expressive potential of Poppy. The total cost of Robotis Dynamixel motors, electronics and 3D printing service was about €2500 (20 % tax included).

The student team managed to assemble a fully functional Poppy. Groups working on control were able to make a live demo of Poppy moving at the end of the workshop.

This experience was very instructive on several aspects relative to the usage of Poppy for education purpose. In particular, it raises some problems we would have never thought about without a "real world" experimentation in a school environement.

[2] Comacina Capsule Creative, http://www.comacina.org/

8.1.3. ENSAM

The orientation of a (high school) student, choosing a career, is often based on an imagined representation of a discipline, sector of activity or training. Moreover, higher education is sometimes for a college student or a student a self centered universe, with inaccessible teaching methodologies and level of competence.

The Arts and Métiers campus at Bordeaux-Talence in partnership with Inria wishes to contribute with its educational and scientific expertise to the development of new teaching methods and tools. The objective is to develop teaching sequences based on a project approach relying on an attractive multidisciplinary technological system: the humanoid Inria Poppy robot. These teaching sequences will be built and tailored to different levels of training, from high schools to Engineer schools.

The new formation "Bachelor of Technology", started in September 2014 at Ensam Bordeaux, is resolutely turned towards a project based pedagogy, outlining concepts from concrete situations. The humanoid Inria Poppy robot offers an open platform capable of providing an unifying thread for the different subjects covered during the 3-years of the Bachelor formation: mechanics, manufacturing (3D printing), electrical, mechatronics, computer sciences, design…

For the 1st and 2nd year of the ENSAM Engineer cursus, the Poppy robot can again be an interesting thread to support the teaching and to conduct further investigation.

8.1.4. DIGITEO

Alexander Gepperth is participating in two projects (PhD and PostDoc) financed by the local "Digiteo" initiative of the Plateau de Saclay.

8.2. National Initiatives

8.2.1. Hackathon at Universcience

On march 22th & 23th 2014, UniverSciences [3] organized a hackathon for the general public around the assembly of a Poppy robot. It involved 15 robotic enthusiasts, from children to adults. Participants were dispatched around several workshops during the two days. While a group was dedicated to the actual assembly of the different Poppy parts, others were exploring how to program the robot with the Python software or working on designing and 3D printing hardware improvements. Aside the workshops around Poppy, several presentations and conferences about robotics were set-up. In this context, participants are not only spectators of a scientific mediation act but also actors.

In two days, this group of new users, self-trained using online documentation have been able to build from scratch the whole robot and make it move using the Pypot library. They even designed a new original semi-passive solution for the ankle joint, as well as a robot helmet which was 3D printed and assembled within the time of the workshop. This experiment did not only show that the platform was easily usable in an educational context with users of all ages, and was rebuildable in two days by a little group, but it also showed high educational value as testified by users and educators (see https://forum.poppy-project.org/t/poppy-project-at-la-cite-des-sciences-et-de-lindustrie/)

8.3. European Initiatives

8.3.1. FP7 & H2020 Projects

8.3.1.1. 3rd HAND

Type: FP7

Defi: Cognitive Systems and Robotics

Instrument: Specific Targeted Research Project

Objectif: Robotics, Cognitive Systems and Smart Spaces, Symbiotic Interaction

[3] Paris museum of sciences and technologies

Duration: October 2013 - September 2016

Coordinator: Manuel Lopes

Partner: Universitaet Darmstadt, Germany

Partner: Stuttgart University, Germany

Partner: University of Innsbruck, Austria

Inria contact: Manuel Lopes

Abstract: Robots have been essential for keeping industrial manufacturing in Europe. Most factories have large numbers of robots in a fixed setup and few programs that produce the exact same product hundreds of thousands times. The only common interaction between the robot and the human worker has become the so-called "emergency stop button". As a result, re-programming robots for new or personalized products has become a key bottleneck for keeping manufacturing jobs in Europe. The core requirement to date has been the production in large numbers or at a high price. Robot-based small series production requires a major breakthrough in robotics: the development of a new class of semi-autonomous robots that can decrease this cost substantially. Such robots need to be aware of the human worker, alleviating him from the monotonous repetitive tasks while keeping him in the loop where his intelligence makes a substantial difference.

In this project, we pursue this breakthrough by developing a semi-autonomous robot assistant that acts as a third hand of a human worker. It will be straightforward to instruct even by an untrained layman worker, allow for efficient knowledge transfer between tasks and enable a effective collaboration between a human worker with a robot third hand. The main contributions of this project will be the scientific principles of semi-autonomous human-robot collaboration, a new semi-autonomous robotic system that is able to: i) learn cooperative tasks from demonstration; ii) learn from instruction; and iii) transfer knowledge between tasks and environments.

8.3.1.2. EXPLORERS

Type: FP7

Defi: NC

Instrument: ERC Starting Grant

Objectif: NC

Duration: December 2009 - November 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.

8.4. International Initiatives

8.4.1. Inria Associate Teams

8.4.1.1. NEUROCURIOSITY

Title: NeuroCuriosity

International Partner (Institution - Laboratory - Researcher):

Columbia Neuroscience (ÉTATS-UNIS)

Duration: 2013 - 2015

One of the most striking aspects of human behavior is our enormous curiosity, drive for exploration. From a child feverishly examining a new toy with its hands and its eyes, to a tourist exploring a new city, to a scientist studying the brain, humans incessantly want to know. This exuberant curiosity shapes our private and social lives, and is arguably a key cognitive feature that allows our species to understand, control and alter our world. We aim to develop a novel unified biological and computational theory, which explains curiosity in the domain of visual exploration and attention as a deliberate decision motivated by learning progress. This theory will build and improve upon pioneer computational models of intrinsic motivation elaborated in developmental robotics, and be empirically evaluated in the context of visual exploration in monkeys through behavioral and brain imaging techniques. This will be the first attempt at a biological-computational framework of intrinsic motivation and perceptual exploration and their underlying cognitive mechanisms.

8.4.2. Inria International Partners

8.4.2.1. Informal International Partners

Jonathan Grizou, Manuel Lopes, and Pierre-Yves Oudeyer collaborated with Inaki Itturate (EPFL) and Luis Montesano (Zaragoza University) on Calibration-Free Brain-Computer Interaction. This collaboration leaded to the following publications [45], [44] . Since then, more experiments have been performed and a journal paper will be submitted in January 2015.

Jonathan Grizou and Manuel Lopes collaborated with Sammuel Barret and Peter Stone (LARG groupd, University of Texas at Austin) on extending our work on adaptive interaction to the multi-agent domain in the adhoc team framework. Their collaboration is still active and a joint paper is in preparation for beginning of 2015.

Anna-Lisa Vollmer, Jonathan Grizou, Manuel Lopes, and Pierre-Yves Oudeyer collaborated with Katharina Rohlfing (Bielefeld University) for studying the co-construction of interaction protocol in collaborative tasks with humans. We develloped a new experimental setup to investigate the processes used by humans to negotiate a protocol of interaction when they do not already share one. This collaboration leaded to the following publication [66].

Pierre-Yves Oudeyer worked with Linda Smith (Psychological and brain sciences department, Indiana Univ., Bloomington, US) on computational modeling of cognitive development, in particular on the role of curiosity driven processes on the evolution of language (see http://www.pyoudeyer.com/OudeyerSmithTopicsCogSci14.pdf).

Thibaut Munzer and Manuel Lopes worked with Bilal Piot (Supelec), Mathieu Geist (Supelec) and Olivier Pietquin (Lille University) to develop an Inverse Reinforcement Learning algorithm for Relational Domains.

Thibaut Munzer and Freek Stulp worked with Olivier Sigaud (ISIR, UPMC) to study regression algorithm for DMP and their impact on DMP optimization. From this collaboration resulted the publication [61].

Freek Stulp has started a cooperation with Michael Mistry at the University of Birmingham on learning inverse dynamics models. This has lead to a joint publication at the 2014 IEEE International Conference on Humanoid Robotics, where Freek Stulp and Michael Mistry presented a poster.

A cooperation with Laura Herlant of Carnegie Mellon University on discovering skill options lead to a joint publication at the 2014 IEEE/RSJ International Conference on Intelligent Robots and Systems, where Laura Herlant gave a presentation.

Gennaro Raiola and Freek Stulp presented a poster titled “Libraries of Motion Primitives as Active Virtual Fixtures for Co-manipulation” at the Forum STIC Paris-Saclay http://www.digiteo.fr/forum-stic-paris-saclay.

Egor Sattarov and Alexander Gepperth presented a poster entitled "MODALSENSE-multimodal perception architecture for intelligent vehicles" at the Forum STIC Paris-Saclay http://www.digiteo.fr/forum-stic-paris-saclay.

Alexander Gepperth and Mathieu Lefort are collaborating with the university of applied sciences of Bottrop (Germany) on the subject of multimodal hand gesture recognition. In the context of this collaboration, Alexander Gepperth supervises a PhD student, Thomas Kopinski.

Gennaro Raiola has started partially working at CEA LIST to integrate his work on virtual mechanism on the Alfred robot at CEA. This is done under the joint supervision of Freek Stulp and Xavier Lamy (CEA LIST), in the context of the DIGITEO-funded project “PrActIx”

8.5. International Research Visitors

8.5.1. Visits of International Scientists

- Luis Montesano, University of Zaragoza, Spain
- Jacqueline Gottlieb, Columbia University, USA
- Thomas Kopinski, University of Applied Sciences Bottrop, Germany
- Thomas Schultz, McGill University, Canada
- Gary Cottrell, Univ. California San Diego
- Minoru Asada, Osaka University, Japan.
- Anne Warlaumont, Univ. California at Merced, US.

8.5.2. Visits to International Teams

- Manuel Lopes visited Jan Peters at Technical University of Darmstadt
- Manuel Lopes visited Zachary Pardos at University of Berkeley
- Pierre-Yves Oudeyer visited the Center for Brain and Cognitive Development, Birbeck College, London

8.5.2.1. Explorer programme

Jonathan Grizou

Date: Aug 2014 - Sep 2014

Institution: University of Texas at Austin (USA)

Jonathan Grizou received a Inria explorer fellowship to visit the LARG groupd headed by Peter Stone at the university of Texas at Austin. He visited their lab for a month in September 2014 and worked on adhoc team problems with Sammuel Barret and Peter Stone.

9. Dissemination

9.1. Promoting Scientific Activities

9.1.1. Invited Talks

- Manuel Lopes made a plenary talk at the conference Technologies de l'Information et de la Communication pour l'Enseignement (TICE), 18-20Novembre, Beziers, France
- Manuel Lopes made an invited talk at the Robotics: Science and Systems : Workshop on Learning Plans with Context From Human Signals, USA.
- Manuel Lopes made an invited talk ICRA Workshop on Active Visual Learning and Hierarchical Visual Representations for General-Purpose Robot Vision, Hong-Kong
- Manuel Lopes made an invited talk ICRA Workshop on Autonomous Grasping and Manipulation: An Open Challenge, Hong-Kong
- Alexander Gepperth gave an invited lecture at the FP7-sponsored Summer School "Neuronal dynamics approaches to cognitive robotics", Bochum, Germany
- Matthieu Lapeyre gave a talk at Journéees Scientifiques Inria 2014 (06/26/2014) about the Poppy project and especially on the open source aspects of the project.
- Matthieu Lapeyre participated to Open experience at WAVE 2014 conference (09/11/2014) about new models of distribution and presented the particularity of Poppy as an open science project.
- Matthieu Lapeyre made a talk at Digital Intelligence 2014 conference held in Nantes (France) about the use of Poppy for educational and artistic applications.
- Olivier Mangin made an invited talk at Language and Body symposium, International Association for the Study of Child Language Conference (IASCL), 14-18 July 2014, Amsterdam, Netherlands.
- Steve N'Guyen gave a talk at the ISIR lab (Institut des Systèmes Intelligents de et Robotique, Paris) about the Poppy project (06/10/2014).
- Clément Moulin-Frier gave two invited talks. The first one was at the Humanoids 2014 conference in Madrid, Spain, during the workshop entitled *Active Learning in Robotics: Exploration Strategies in Complex Environments*: http://www.ausy.tu-darmstadt.de/Workshops/Humanoids2014ActiveLearning. The second one was at the *PyconFr*, a French software developer conference: http://www.pycon.fr/2014/schedule/presentation/37/
- Pierre-Yves Oudeyer gave the following talks:
  - (Keynote) (march 2014) Developmental Robotics: : Lifelong Learning and the Morphogenesis of Developmental Structures, AAAI Spring Symposium on Implementing Selves with Safe Motivational Systems and Self-Improvement, Stanford Univ., US. https://www.youtube.com/watch?v=bkv83GKYpkI&list=PL8W4iBcZa2ElG_Q38ihjPdINjgkVXt0Uu
  - (Keynote) (june 2014) Curiosity-driven learning and development: How robots can help us understand humans, WACAI 2014, http://wacai14.litislab.fr/?page_id=140
  - (jan. 2014) Emergence du langage et robotique développementale, Séminaire de l'association X-SHS, https://www.youtube.com/watch?v=LQ5evY4aCkI
  - (feb. 2014) Developmental Robotics: Lifelong Learning and the Morphogenesis of Developmental Structures, Dagstuhl Seminar 14081 on "Robots learning from experiences", http://www.dagstuhl.de/program/calendar/partlist/?semnr=14081&SUOG
  - (march 2014) La robotique comme outil pour comprendre les origines du langage, Rencontres Mollat, Bordeaux.
  - (march 2014) Comment les robots nous aident a comprendre l'homme, Forum des Sciences Cognitives, Paris. https://www.youtube.com/watch?v=enQYBR3zFpo

- (april 2014) Fabricating Open-Source Baby Robots, Tedx Cannes, https://www.youtube.com/watch?v=AP8i435ztwE
- (april 2014) Poppy: Open Source Robotics Platform for Science, Art and Education, La Cantine, Rennes.
- (may 2014) Open Source Developmental Robotics, Bodywara workshop Inria/FING, Bordeaux.
- (june 2014) KidLearn: Machine learning for personalizing educational contents, Digital Intelligence conference, Nantes.
- (july 2014) The roles of active learning in sensorimotor and language development, International Conference of of the International Society of Infant Studies (ISIS 2014), Symposium on Integrative models of language acquisition, slides: https://www.dropbox.com/s/qcpad2lvbe3fs93/ISIS2014.pptx?dl=0
- (sept. 2014) Curiosity-driven learning and development in robots, IX Advanced Multimodal Information Retrieval int'l summer school.
- (oct. 2014) Open source developmental robotics, Séminaire du Centre de Recherche Interdisciplinaire, Univ. Paris VII.
- (nov. 2014) The impact of curiosity-driven learning on self-organization of developmental process: robotic models, First International Symposium on Information Seeking, Curiosity and Attention, Bordeaux, France, vidéo: https://www.youtube.com/watch?v=9ATEhHB99wQ&list=PL9T8000j7sJDZL1NrTL-zyFmeJlvXYXzm
- (nov. 2014) Modeling cognitive development with robots, Seminar of the Center for Brain and Cognitive Development, Birbeck college.

9.1.2. Scientific events organisation

9.1.2.1. General chairs

9.1.2.1.1. First interdisciplinary symposium on Information-seeking, curiosity and attention

General chairs Pierre-Yves Oudeyer, Jacqueline Gottlieb, Manuel Lopes
6-7 Nov. 2014, Inria Bordeaux Sud-Ouest, France
Summary:
The past few years have seen a surge of interest in the mechanisms of active learning, curiosity and information seeking, and this body work has highlighted a number of highly significant questions regarding higher cognition and its development (for a recent review, see Tics13). One question is how subjects explore to build explanatory models of their environment, and how these models further constrain the sampling of additional information. A related question is how the brain generates the intrinsic motivation to seek information when physical rewards are absent or unknown, and how this impacts cognitive development in the long term. Our goal is to stimulate discussion on these and related topics and foster further research in this nascent and complex field. https://openlab-flowers.inria.fr/t/first-interdisciplinary-symposium-on-information-seeking-curiosity-and-attention/21

9.1.2.2. responsable of the conference program committee

Clément Moulin-Frier will be program chair at the ICDL/Epirob conference to be held in AUgust 2015 in Brown University, Providence, Rhode Island, USA: http://www.icdl-epirob.org/

9.1.2.3. member of the conference program committee

David Filliat was Associate Editor for IROS. Freek Stulp was on the Program Committee of RSS, and an Associate Editor for IROS and ICRA. Alexander Gepperth was on the programme committee of ESANN and IJCNN.

9.1.2.4. reviewer

David Filliat was reviewer for ICARCV, ICRA, IROS, RFIA. Freek Stulp was a reviewer for ICRA and IROS. Manuel Lopes was reviewer for Iros, Icra, HRI, Aamas. Jonathan Grizou was reviewer for ICDL and HRI. Alexander Gepperth was reviewer for IROS, IJCNN, ESANN and ITSC.

9.1.3. Journal

9.1.3.1. member of the editorial board

Pierre-Yves Oudeyer was editor of the IEEE CIS Newsletter on AMD and associate editor of IEEE Transactions on Autonomous Mental Development, Frontiers in Humanoid Robotics, Frontiers in Neurorobotics, Internationa Journal of Social Robotics, as well as member of the editorial board of Advances in Interaction Studies, John Benjamins Publishing Company.

Clément Moulin-Frier and Pierre-Yves Oudeyer are co-editors of a special issue in *Journal of Phonetics*, a major journal in speech science. This special issue, entitled *On the cognitive nature of speech sound systems* is focused on a target paper for which Clément Moulin-Frier is the first author. A dozen of international contributions are currently under review, the publication is expected during the spring of 2015. https://hal.archives-ouvertes.fr/hal-01073668

9.1.3.2. reviewer

David Filliat was reviewer for International Journal of Robotics Research, Robotics and Autonomous Systems, Neurocomputing Pierre Rouanet was reviewer for the journal IEEE Transactions on Human-Machine Systems. Freek Stulp was a reviewer for Autonomous Robots. Manuel Lopes was reviewer for IEEE Transactions on Robotics, IEEE Transactions on Autonomous Mental Development Jonathan Grizou was reviewer for IEEE Transactions on Autonomous Mental Development. Alexander Gepperth was reviewer IEEE Transactions on Intelligent Transportation Systems, Neurocomputing, Neural Networks, Neural Processing Letters and Cognitive Computation. PY Oudeyer reviewed projects for the European Commission and Inria, and was a reviewer for IEEE ICDL-Epirob, ICRA, IEEE TAMD.

9.2. Teaching - Supervision - Juries

9.2.1. Teaching

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

Master: Apprentissage, 5 heures. M2, Enseirb-Matmeca (Manuel Lopes).

Master: La robotique de compagnie: concepts et tecniques, 9 heures. M2, ENSTA - ParisTech (Manuel Lopes).

Master: Robotique Mobile, 21 heures. M2, ENSTA - ParisTech (David Filliat).

Master: Perception pour la robotique, 12 heures. M2 Systemes Avances et Robotique, University Pierre et Marie Curie (David Filliat)

Licence 2: Graphe, Langage, Cryptologie, 21 heures. Pôle universitaire français de Ho Chi Minh Ville

Pedagogical resources : Développement ans diffusion of IniRobot pedagogical kit (see highlights), Didier Roy, Thomas Guitard et Pierre-Yves Oudeyer.

9.2.2. Supervision

PhD in progress: Louis-Charles Caron, RGB-D object recognition on a mobile robot, started january 2012 (superv. Alexander Gepperth).

PhD in progress: Thomas Hecht, Bio-inspired sensor fusion, started November 2013 (superv. Alexander Gepperth).

PhD in progress: Egor Sattarov, Multimodal vehicle perception architecture, started November 2013 (co-superv. Alexander Gepperth).

PhD in progress: Thomas Kopinski, Machine Learning for human-machine interaction, started November 2012 (superv. Alexander Gepperth).

PhD in progress: Guillaume Duceux, Navigation and exploration based on RGB-D cameras, started october 2011 (superv. David Filliat).

PhD in progress: Alexandre Armand, Contextual electronic copilot for driving assistance, started feb. 2011 (superv. David Filliat)

PhD in progress: Yuxin Chen, Interactive learning of objects and names on a humanoid robot, started oct. 2013 (superv. David Filliat).

PhD in progress: Celine Craye, Curiosity and visual attention for the guidance of an exploration robot, started apr. 2014 (superv. David Filliat).

PhD in progress: Thibaut Munzer, Learning from Instruction (superv. Manuel Lopes).

PhD in progress: Baptiste Busch, Interactive Learning (superv. Manuel Lopes).

PhD in progress: Alexandra Delmas, Auto-Apprentissage Auto-Adaptable pour la compliance au traitement (superv. Manuel Lopes).

PhD in progress: Fabien Benureau, Exploration strategies in developmental robotics (superv. PY Oudeyer)

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

PhD finished: Matthieu Lapeyre, Poppy: Open source 3D printed and fully-modular robotic platform for Science, Art and Education, started sept. 2010 (superv. Pierre-Yves Oudeyer).

9.2.3. PhD Juries

Ryad Akrour (Pierre-Yves Oudeyer, Examinateur) : Robust Preference Learning-based Reinforcement Learning, Univ. Paris Sud.

Raphael Laurent (Pierre-Yves Oudeyer, Examinateur) : COSMO : un modèle bayésien des interactions sensori-motrices dans la perception de la parole, Univ. Grenoble.

Kirill Makikhin (Pierre-Yves Oudeyer, Rapporteur) : Towards a Biologically Plausible Computational Model of Developmental Learning with Robotic Applications, Univ. Queensland, Australia.

Hung Ngo (Pierre-Yves Oudeyer, Rapporteur) : Artificial Curiosity: Algorithms for Autonomous Acquisition of Robotic Skills, Univ. Svizera Italiana.

Olivier Mangin (19/03/14, David Filliat, Examinateur) : The Emergence of Multimodal Concepts: From Perceptual Motion Primitives to Grounded Acoustic Words. Univ Bordeaux, Pierre-Yves Oudeyer (dir.).

Fabien Hervouet (30/06/2014, David Filliat, Rapporteur) : Exploration et structuration intrinsèquement motivées d'espaces d'apprentissage sensorimoteur : contributions théoriques, plateforme et expérimentations

Adrien Jauffret (11/07/2014, David Filliat, Rapporteur) : De l'auto-évaluation aux émotions - approche neuromimétique et bayesienne de l'apprentissage de comportements complexes impliquant des informations multimodales

Kangni Kueviakoe (30/09/2014, David Filliat, Rapporteur) : Localisation multi-capteurs garantie : Résolution d'un problème de satisfaction de contraintes

Emilie Wirbel (7/10/14, David Filliat, Rapporteur) : Localisation et navigation topologiques de robots humanoïdes

Irene Ayllon Clemente (25/7/14, Alexander Gepperth, Rapporteur) : An on-line learning system for speech acquisition.

9.3. Popularization

IniRobot: Development, evaluation and dissemination of the IniRobot program for initiating young kids (primary schools) to computer science and robotics. This has been used and deployed in several major towns in France, including Lille, Talence and Lormont. Several days of formation for teachers have been organized to foster dissemination. The kit is Creative Commons, and available on the dedicated web site created: https://dm1r.inria.fr/c/kits-pedagogiques/inirobot

PY Oudeyer gave a TedX talk in Cannes, explaining open-source developmental robotics, https://www.youtube.com/watch?x-yt-ts=1421828030&x-yt-cl=84411374&v=AP8i435ztwE

PY Oudeyer gave several interviews in the general press (e.g. Le Monde, Les Echos, Sciences et Avenir) to explain societal issues of robotics, http://www.pyoudeyer.com/press/

PY Oudeyer wrote three popular science articles to explain societal issues of robotics:

- "What can we learn about development from baby robot" http://www.pyoudeyer.com/WhatDoWeLearnFromBabyRobotsOudeyer2015.pdf
- Oudeyer, P-Y. (2014) Robotique: les grands défis à venir, Futuribles, Mars 2014 http://www.pyoudeyer.com/PYOudeyerRobotFuturibles14.pdf.
- Oudeyer, P-Y. (2014) Des abeilles aux sources de la parole, in Breve de Maths, Mathématiques pour la planète terre, Nouveau monde editions, http://www.breves-de-maths.fr/des-abeilles-aux-sources-de-la-parole/.

06/02/2014 : "Developmental Robotics - Learning objects by interaction", David Filliat, Invited conference, Institut Bull, Réunion du groupe de réflexion CEM "Cerveaux et machines"

6-8/02/2014 : Aquitec, Yoan Mollard presented the Poppy platform to students and visitors

18-20/03/2014 : Innorobo 2014, Yoan Mollard and Steve N'guyen presentend the projects Poppy and 3rd hand

11/04/2014 : "Semantic Mapping", David Filliat, Invited Conference, Laboratoire Imagine, Ecole Nationale Supérieure des Ponts et Chaussées

20-22/06/2014: Poppy has been presented in the Paris Makerfair and obtained a "maker of merit" award.

2-8/07/2014: Demonstrations of Poppy took place at the FAB10 conference in Barcelona, the biggest conference about the maker revolution. Poppy was among the ten finalists for the Fablab award.

4-5/09/2014: Clement Moulin-Frier, Steve N'Guyen and Pierre Rouanet participated to a Hackathon in "cité des sciences" about programming the Poppy humanoid platform.

11/10/2014: Robotics animations for the "Fete de la science" at ENSTA ParisTech,

17/10/2014 : "Robots and Social Interaction Decisions - Developmental robotics", David Filliat, Invited presentation for the ITechLaw 2014 conference.

25-28/10/2014: Clement Moulin-Frier and Pierre Rouanet presented the Poppy platform and the associated libraries - pypot and explauto - to the PyConFR2014 conference and organised of a Hackathon.

19-21/11/2014: Clement Moulin-Frier, Nicolas Rabault, and Pierre Rouanet presented the Poppy platform to the fossa 2014 conference.

10/12/2014: Robotics demonstration for "Science Break" organised by Diagonale Paris Saclay : http://sciencebreak.ladiagonale-paris-saclay.fr

Clément Moulin-Frier contributed to a scientific diffusion paper in the French journal *Biofutur* about the use of robotics in the study of language evolution and acquisition: http://www.biofutur.com/anciens-numeros. https://hal.archives-ouvertes.fr/hal-01100048

Fabien Benureau supervised two students in 3rd year of the Cognitive Science major at the University of Bordeaux on their TER project. The project used Poppy, exploring how the attitude towards robots influences how humans recognise the emotion they try to express. Poppy having no facial expression — or face — yet, the students expressed the five expressions they selected (anger, surprise, joy, sadness, disgust) with body movements alone. They videotaped the sequences of movements (videos are available here http://python.sm.u-bordeaux2.fr/ter/2014/sc/desprez-zerdoumi/?page_id=289) and created an experiment asking volunteers to guess which emotion was displayed. The form also included the Negative Attitude towards Robots Scale (NARS), to investigate the possible correlation between fear of robot and the ability to identify their emotional attitude. The results showed no correlation between the two, although it was admitted that the experiment would have to be improved and ran again before any conclusion could be made.

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