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Activity Report 2015

Project-Team FLOWERS

Flowing Epigenetic Robots and Systems

RESEARCH CENTER
Bordeaux - Sud-Ouest

THEME
Robotics and Smart environments

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1. Members

Research Scientists

Pierre-Yves Oudeyer [Team leader, Inria, Senior Researcher, HdR]
Manuel Lopes [Inria, Senior Researcher, HdR]
Anna-Lisa Vollmer [Inria, Starting Research position]

Faculty Members

David Filliat [ENSTA, Professor, HdR]
Alexander Gepperth [ENSTA, Associate Professor]
Freek Stulp [ENSTA, Associate Professor]

Engineers

Loic Dauphin [Inria, from Oct 2015]
Matthieu Lapeyre [Inria, granted by FP7 ERC/09-EXPLORERS project]
Yoan Mollard [Inria, granted by FP7 /13-3RDHAND project]
Stephanie Noirpoudre [Inria, from Oct 2015, granted by Feder/CRA/Inria project Poppy Education]
Nicolas Rabault [Inria, granted by Feder/CRA/Inria project Poppy Education]
Pierre Rouanet [Inria, granted by OSEO Innovation]
Didier Roy [Inriagranted by Feder/CRA/Inria project Poppy Education]
Theo Segonds [Inria, from Apr 2015, granted by Feder/CRA/Inria project Poppy Education]

PhD Students

Yasmin Ansari [UNIV étrangère, from Nov 2015]
Baptiste Busch [Inria]
Louis-Charles Caron [ENSTA]
Yuxin Chen [ENSTA]
Guillaume Duceux [ENSTA]
Benjamin Clement [Inria, granted by CRA KidLearn project]
Céline Craye [Thales, granted by CIFRE]
Alexandra Delmas [AUT ENTREPRISE PRIV, granted by CIFRE]
Sebastien Forestier [Univ. Bordeaux]
Florian Golemo [Inria, from Dec 2015 by EU Project IGLU]
Clement Masson [ENSTA, from Jul 2015]
Adrien Matricon [Univ. Bordeaux]
Thibaut Munzer [Inria, granted by FP7 /13-3RDHAND project]
Gennaro Raiola [ENSTA]
William Schueller [Univ. Bordeaux]

Post-Doctoral Fellows

Cem Karaoguz [ENSTA, from Jun 2015]
Panagiotis Papadakis [ENSTA]
Mathieu Lefort [Inria]

Administrative Assistant

Nicolas Jahier [Inria]

Others

Fabien Benureau [Univ. Bordeaux]
Jonathan Grizou [Inria]

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 [83].

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" [139]. 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 [95], 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 [106] [142]. The approach of developmental robotics consists in importing and implementing concepts and mechanisms from developmental psychology [111], cognitive linguistics [82], and developmental cognitive neuroscience [99] 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] [123], grounding [93], situatedness [69], self-organization [137] [126], enaction [141], and incremental learning [80].

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 [16]. 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 [111], 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" [72] [87]. 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] [83] [86]. 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 [85] [96] [134]. Based on this, a number of researchers have began in the past few years to build computational implementation of intrinsic motivation [16] [121] [132] [75] [97] [108] [133]. 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 [121][16] [122] [131]. 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 [81] [94] 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 [111]. 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 [71]. 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 [138], [77], motivated by the various mechanisms that allow humans to socially guide a robot [128]. 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 [138], [101] [109].

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 [116], [117]. We also work on developing perceptual capabilities by gradually segmenting the perceptual space and identifying objects and their characteristics through interaction with the user [107] and robots experiments [98]. 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 [104].

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. Application Domains

Cognitive Sciences The computational modelling of life-long learning and development mechanisms achieved in the team centrally targets to contribute to our understanding of the processes of sensorimotor, cognitive and social development in humans. In particular, it provides a methodological basis to analyze the dynamics of the interaction across learning and inference processes, embodiment and the social environment, allowing to formalize precise hypotheses and later on test them in experimental paradigms with animals and humans. A paradigmatic example of this activity is the Neurocuriosity project achieved in collaboration with the cognitive neuroscience lab of Jacqueline Gottlieb, where theoretical models of the mechanisms of information seeking, active learning and spontaneous exploration have been developped in coordination with experimental evidence and investigation, see https://flowers.inria.fr/curiosity-information-seeking-and-attention-in-human-adults-models-and-experiments/.

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. Highlights of the Year

5.1. Highlights of the Year

Scientific Awards

Jonathan Grizou obtained the "Prix Le Monde de la recherche universitaire" for his thesis ([91]) and work on "Learning from unlabeled interaction" [30] [92]. This work allowed in particular to develop new algorithms for Brain-Computer Interfaces that remove the need for a phase of calibration and allow users to achieve sequential tasks. This work was achieved in collaboration with I. Iturrate and L. Montesano (Univ. Zaragoza, Spain), and the PhD was co-supervised by M. Lopes and PY. Oudeyer.

Matthieu Lapeyre obtained the "Second prix de thèse du GDR Robotique" for his thesis on the development of the open-source 3D printed Poppy Humanoid platform [102], now in use in various scientific, educational and artistic projects worldwide http://www.poppy-project.org. This work was achieved in collaboration with P. Rouanet and the PhD was supervised by PY Oudeyer.

Dissemination and transfer

In the context of the Poppy project, a contract was signed between Inria and the company Generation Robots agreeing on the worldwide reselling and distribution of the Poppy robotic kits, and in particular the Poppy Humanoid and Poppy Torso kits: http://www.generationrobots.com/.

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 in 2015 saw a large national dissemination, as it has been used by 8000 school children in 35 towns. 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. Also, in 2015 the team began a large scale transfer project called Poppy Education (Féder/Region Aquitaine/Inria co-finding) targeting to develop, evaluate and disseminate robotic pedagogical kits for teaching ICT in high-schools and university level courses.

6. New Software and Platforms

6.1. Poppy project

6.1.1. Introduction

- Participants: Matthieu Lapeyre, Pierre Rouanet, Nicolas Rabault, Theo Segonds, Jonathan Grizou and Pierre-Yves Oudeyer
- Contact: Pierre-Yves Oudeyer
- URL: https://www.poppy-project.org/

The Poppy Project develops open-sources 3D printed robots platforms 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.

6.1.2. Poppy Ergo Jr (hardware)

Poppy Ergo Jr is a new open hardware robot developped by the Poppy Project to explore the use of robots in classroom for learning robotic and computer science. It is a 6-Dofs arm designed to be both expressiv and low-cost. This is achieved by the use of FDM 3D printing, low cost Robotis XL-320 actuators. In addition we have added a Pi camera so the robot can detect object, faces or QR codes.

The Ergo Jr is controlled by the pypot software running on a Raspberry pi 2. The communication between the Raspberry pi and the actuators is made possible by the Pixl board we have designed.

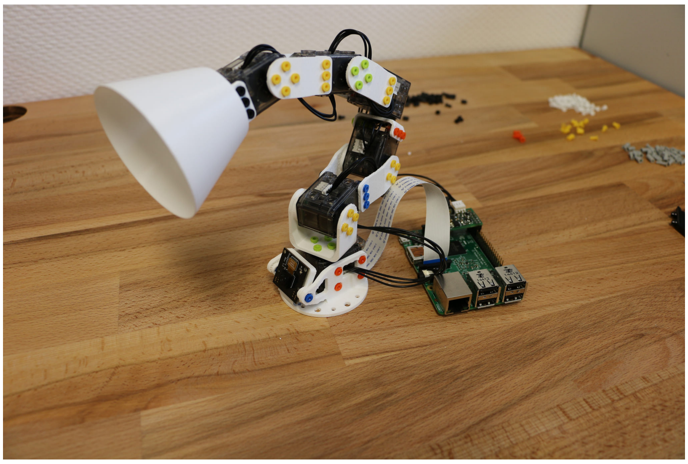

Figure 1. The new open hardware Poppy Ergo Jr, 6-DoFs arm robot for education

The sources are availables on the following web platforms:

- Github repository: https://github.com/poppy-project/poppy-ergo-jr
- CAD files: https://cad.onshape.com/documents/10951c2120eb4209abfff972/w/2b2ed99178db4a72aa4ebcc9

The Poppy Ergo Jr has several 3D printed tools to extend its capabilities. There are currently the lampshade, the gripper and a pen holder.

6.1.3. Pixl (Electronics)

Pixl is a tiny board used to create low cost robots based on raspbery pi and XL320 motors. This board have bean created by the Poppy project team. Pixl have 2 main features, the power part, and the communication part :

- The power part allow the user to plug an 7V AC/DC converter directly into the Pixl. This power will be distributed to all XL320 motors and will be converted to 5V for the raspberry pi.
- The communication part convert full duplex to half duplex and vice versa. The half duplex part switch between RX and TX automatically. Another connector allow the user to connect his XL320 network.

6.1.4. Poppy Com

FUNCTIONAL DESCRIPTION

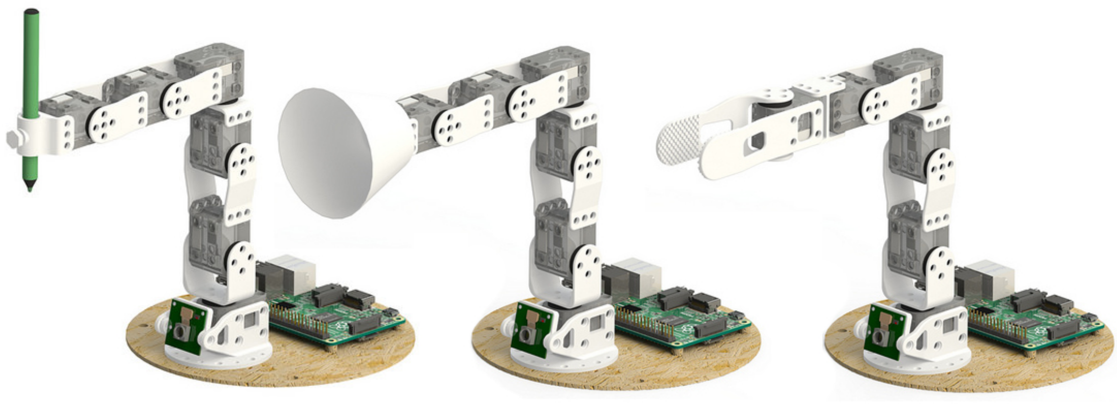

Figure 2. The Ergo Jr has 3 tools, a pen holder, a lampshade and a gripper

Poppy-com is a low level library who manage the new poppy system communication protocol. This work in progress library, writen in C/C++, is completely open-source and available on github. Atctually poppy-com work with Atmel ATMEGA series microcontroler and a test version can be run on X86 architectures. His main objectiv is to give access to the user at the lowest level of code. Each poppy system module run this code to be detected into the robt network and to comunicate with others modules. Users can write theire owns code and write it in any module. With this new level the user can create basic behavior directly into a poppy system module.

- Bootloader : The bootloader have to manage robot network discovery, auto-addressing, module specific firmware update validation, and user code update.
- User : The user side have a small part of code dedicated to the module management like motor management routines, sensors synchronizations, numerical treatment of signals... The empty memory of each modules can be used by the user and he can add his own code to manage his robot.

This library will be compatible with the Arduino univers, that allow non expert people to use it anyway. To simplify the robot functionality developpement and function execution localization we want to try to create a way to write a code for all a robot modules on only one code. Each function of this code could be redirected in a specific module, the execution can be completely distributed.

- Participants: Pierre Rouanet, Matthieu Lapeyre, Nicolas Rabault and Pierre-Yves Oudeyer
- Contact: Pierre-Yves Oudeyer
- URL: https://www.poppy-project.org/
- Contact: Nicolas Rabault
- URL: https://github.com/poppy-project/poppy-com

6.1.5. Poppy System

FUNCTIONAL DESCRIPTION

In the Poppy project we are working on the Poppy System which is a new modular and open-source robotic architecture. It is designed to help people create and build custom robots. It permits, in a similar approach as Lego, building robots or smart objects using standardized elements.

Poppy System is an unified system where each essential robotic components (actuators, sensors, ...) is an independant module, connected with other through standardized interfaces:

- Unified mechanical interfaces which simplifies the assembly process and the design of 3D printable parts.
- Unified communication between elements using the same connector and bus for each module.
- Unified software makes it easy to program each module independantly.

The current Poppy robots (Humanoid, Torso, Ergo) will be updated using this novel architecture.

Our ambition is to create an ecosystem around this system so communities can develop custom modules, following the Poppy System standards, which can be compatible with all other Poppy robots.

6.1.6. Pypot

SCIENTIFIC DESCRIPTION

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:

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

Pypot is part of the Poppy project. It is the core library used by the different Poppy robots. This abstraction layer allows to seamlessly switch from one of the Poppy robot to another. It also provides a common set of tools, such as forward and inverse kinematics, simple computer vision, recording and replaying moves, or easy access to the autonomous exploration library Explauto.

To extend pypot application domains and connection to outside world, it also provides an HTTP REST API. On top of providing an easy way to connect to smart sensors or connected devices, it is notably used to connect to Snap! a variant of the well-known Scratch visual programming language.

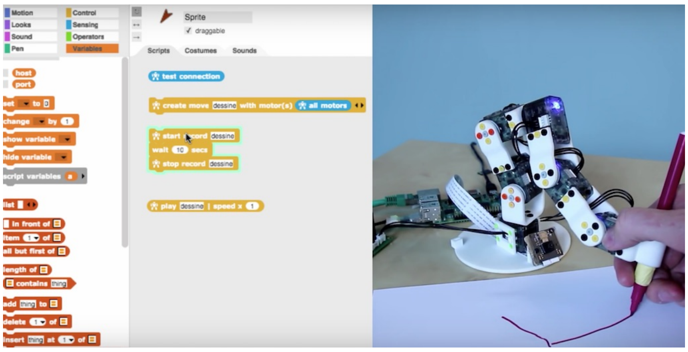

Figure 3. Example of using pypot to program a robot to reproduce a drawn shape

FUNCTIONAL DESCRIPTION

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. This allows the transparent switch from a real robot to its simulated equivalent without having to modify the code.

Finally, it has been developed to permit an easy and fast extension to other types of motors and sensors.

It works with Python 2.7 or Python 3.3 or later. It has also been adapted to the Raspberry-Pi board.

CONNECTION WITH THE VISUAL PROGRAMMING LANGUAGE SNAP!

Pypot has been connected to Snap!, a variant of the famous Scratch visual language, developed for teaching computer science to children. It is based on blocks that can be dragged-and-drop, and assembled to write scripts.

Thanks to the Snap! HTTP block, a connection can be made to pypot allowing users to directly control robots through their visual interfaces. A set of dedicated Snap! blocks have been designed, such as *set motor position* or *get motor temperature*.

Figure 4. Using Snap! to program a robot by demonstration and create complex choreographies

Snap! is also used as a tool for programming the robot by demonstration. Thanks to *record* and *play* blocks, users can easily trigger kinesthetic recording of the robots (or only subpart such as one arm). They can then be played or "mixed" - either played in sequence or in parallel - with other recordings to compose complex choreographies. The moves are encoded as a model of mixture of gaussians (GMM) which allows the definition of clean mathematical operators for combining them.

This tool has been developed and used in collaboration with artists who investigate the concept of robotic moves.

DISSEMINATION AND CONTRIBUTION

The pypot source file are released under the GPLv3 license and can be accessed on Github. They have been downloaded about 50k times (source Python Package Index) and forked about 50 times (source Github).

18 contributors have participated to its development.

Pypot are also largely based on jupyter notebooks to provide examples, tutorials or scientific experiments.

- Participants: Pierre Rouanet, Theo Segonds, Matthieu Lapeyre
- Contact: Pierre Rouanet
- URL: https://github.com/poppy-project/pypot

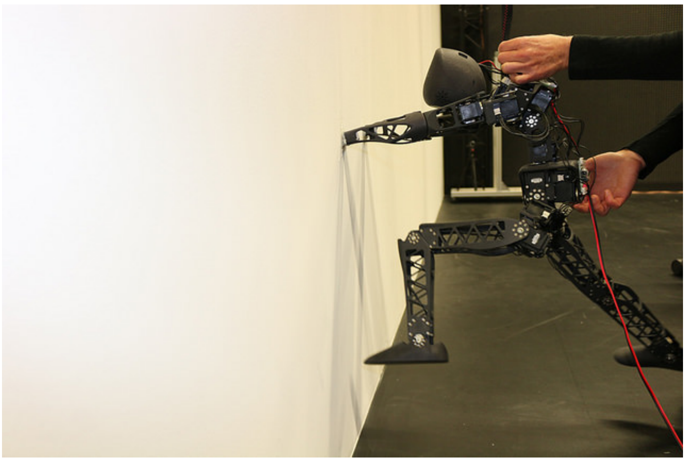

Figure 5. Artistic project exploring the concept of robotic move.

6.1.7. Inverse kinematics library

FUNCTIONAL DESCRIPTION

IKPy is a Python Inverse Kinematics library, designed to be simple to use and extend. It provides Forward and Inverse kinematics functionalities, bundled with helper tools such as 3D plotting of the kinematics chains. Being written entirely in Python, IKPy is lightweight and is based on numpy and scipy for fast optimization. IKPy is compatible with many robots, by automatically parsing URDF files. It also supports other (such as DH-parameters) and custom representations. Moreover, it provides a framework to easily implement new Inverse Kinematics strategies. Originally developed for the Poppy project, it can also be used as a standalone library. IKPy is open-source, and can be found at: https://github.com/Phylliade/ikpy

- Participants: Pierre Manceron, Pierre Rouanet, Pierre-Yves Oudeyer
- Contact: Pierre Rouanet
- URL: https://github.com/Phylliade/ikpy

6.2. Tools for robot learning, control and perception

6.2.1. CARROMAN

FUNCTIONAL DESCRIPTION

This software implements a control architecture for the Meka humanoid robot. It integrates the Stanford Whole Body Control in the M3 architecture provided with the Meka robot, and provides clear and easy to use interfaces through the URBI scripting language. This software provides a modular library of control modes and basic skills for manipulating objects, detecting objects and humans which other research projects can reuse, extend and enhance. An example would be to locate a cylindrical object on a table using stereo vision, and grasping it using position and force control.

- Contact: David Filliat

6.2.2. DMP-BBO

Black-Box Optimization for Dynamic Movement Primitives
FUNCTIONAL DESCRIPTION

The DMP-BBO 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 PIBB algorithm for direct policy search. The `dmp_bbo` C++ library (https://github.com/stulp/dmpbbo) has been extended to include the "unified model for regression", see Section 7.2.3. The implementation of several of the function approximators have been made real-time compatible.

- Participant: Freek Stulp
- Contact: Freek Stulp
- URL: https://github.com/stulp/dmpbbo

6.2.3. DyNAMoS

FUNCTIONAL DESCRIPTION

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.

- Participants: Alexander Gepperth and Mathieu Lefort
- Contact: Mathieu Lefort

6.2.4. Multimodal Concept Learning with Non-negative Matrix Factorization

FUNCTIONAL DESCRIPTION

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 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.

- Participant: Olivier Mangin
- Contact: Olivier Mangin
- URL: https://github.com/omangin/multimodal

6.2.5. Explorers

FUNCTIONAL DESCRIPTION

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.

- Participants: Pierre-Yves Oudeyer and Fabien Benureau
- Contact: Pierre-Yves Oudeyer
- URL: https://github.com/humm/explorers

6.2.6. Of 3-D point cloud

FUNCTIONAL DESCRIPTION

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.

- Participants: David Filliat, Alexander Gepperth and Louis-Charles Caron
- Contact: Alexander Gepperth

6.2.7. OptiTrack

FUNCTIONAL DESCRIPTION

This python library allows you to connect to an OptiTrack from NaturalPoint. 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.

- Participant: Pierre Rouanet
- Contact: Pierre Rouanet

6.2.8. PEDDETECT

FUNCTIONAL DESCRIPTION

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.

- Participant: Alexander Gepperth
- Contact: Alexander Gepperth

6.2.9. pyStreamPlayer

FUNCTIONAL DESCRIPTION

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.

- Participant: Alexander Gepperth
- Contact: Alexander Gepperth

6.2.10. Aversive++

FUNCTIONAL DESCRIPTION

Aversive++ is a C++ library that eases microcontroller programming. Its aim is to provide an interface simple enough to be able to create complex applications, and optimized enough to enable small microcontrollers to execute these applications. The other aspect of this library is to be multiplatform. Indeed, it is designed to provide the same API for a simulator (named SASIAE) and for AVR-based and ARM-based microcontrollers.

- Participants: Loïc Dauphin
- Contact: Loïc Dauphin
- Website: http://aversiveplusplus.com/

6.3. Explauto: Autonomous Exploration and Learning Benchmarking

An autonomous exploration library

SCIENTIFIC DESCRIPTION

An important challenge in Developmental Robotics is how robots can efficiently learn sensorimotor mappings by experience, i.e. the mappings between the motor actions they make and the sensory effects they produce. This can be a robot learning how arm movements make physical objects move, or how movements of a virtual vocal tract modulates vocalization sounds. The way the robot will collects its own sensorimotor experience have a strong impact on learning efficiency because for most robotic systems the involved spaces are high dimensional, the mapping between them is non-linear and redundant, and there is limited time allowed for learning. If robots explore the world in an unorganized manner, e.g. randomly, learning algorithms will be often ineffective because very sparse data points will be collected. Data are precious due to the high dimensionality and the limited time, whereas data are not equally useful due to non-linearity and redundancy. This is why learning has to be guided using efficient exploration strategies, allowing the robot to actively drive its own interaction with the environment in order to gather maximally informative data to feed the sensorimotor model.

In the recent year, work in developmental learning has explored various families of algorithmic principles which allow the efficient guiding of learning and exploration.

Explauto is a framework developed to study, model and simulate curiosity-driven learning and exploration in virtual and robotic agents. Explauto's scientific roots trace back from Intelligent Adaptive Curiosity algorithmic architecture [120], which has been extended to a more general family of autonomous exploration architecture by [73] and recently expressed as a compact and unified formalism [114]. The library is detailed in [115].

In Explauto, the strategies to explore sensorimotor models are called interest models. They implements the active exploration process, where sensorimotor experiments are chosen to improve the forward or inverse prediction of the sensorimotor model. The simplest strategy is to randomly draw goals tin the motor or sensory space. More efficient strategies are based on the active choice of learning experiments that maximize learning progress, for e.g. improvement of predictions or of competences to reach goals [120]. This automatically drives the system to explore and learn first easy skills, and then explore skills of progressively increasing complexity. Both random and learning progress models can act either on the motor or on the sensory space, resulting in motor babbling or goal babbling strategies.

- Motor babbling consists in sampling commands in the motor space according to a given strategy (random or learning progress), predicting the expected sensory consequence, executing the command through the environment and observing the actual sensory effect. Both sensorimotor and interest models are finally updated according to this experience.
- Goal babbling consists in sampling goals in the sensory effect space and to use the current state of the sensorimotor model to infer a motor action supposed to reach the goals (inverse prediction). The robot/agent then executes the command through the environment and observes the actual sensory effect. Both sensorimotor and interest models are finally updated according to this experience.

It has been shown that this second strategy allows a progressive covering of the reachable sensory space much more uniformly than in a motor babbling strategy, where the agent samples directly in the motor space [73].

FUNCTIONAL DESCRIPTION

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).

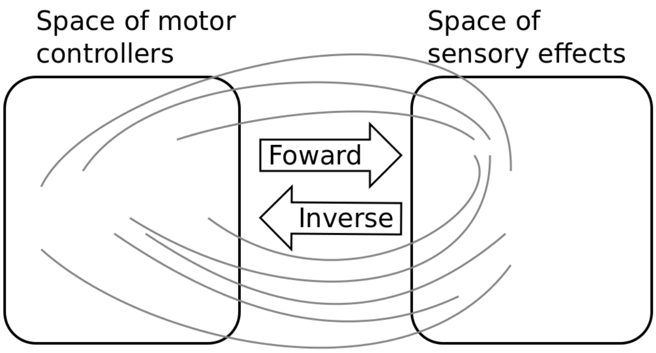

Figure 6. Complex sensorimotor mappings involve a high dimensional sensorimotor spaces. For the sake of visualization, the motor M and sensory S spaces are only 2D each in this example. The relationship between M and S is non-linear, dividing the sensorimotor space into regions of unequal stability: small regions of S can be reached very precisely by large regions of M, or large regions in S can be very sensitive to variations in M.: s as well as a non-linear and redundant relationship. This non-linearity can imply redundancy, where the same sensory effect can be attained using distinct regions in M.

The library comes with several built-in environments. Two of them corresponds to simulated environments: a multi-DoF arm acting on a 2D plan, and an under-actuated torque-controlled pendulum. The third one allows to control real robots based on Dynamixel actuators using the Pypot library.

Learning sensorimotor mappings involves machine learning algorithms, which are typically regression algorithms to learn forward models, from motor controllers to sensory effects, and optimization algorithms to learn inverse models, from sensory effects, or goals, to the motor programs allowing to reach them. We call these sensorimotor learning algorithms sensorimotor models. The library comes with several built-in sensorimotor models: simple nearest-neighbor look-up, non-parametric models combining classical regressions and optimization algorithms, online mixtures of Gaussians, and discrete Lidstone distributions. Explauto sensorimotor models are online learning algorithms, i.e. they are trained iteratively during the interaction of the robot in the environment in which it evolves.

Explauto provides also a unified interface to define exploration strategies using the InterestModel class. The library comes with two built-in interest models: random sampling as well as sampling maximizing the learning progress in forward or inverse predictions.

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.

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

- Participants: Pierre Rouanet, Clément Moulin-Frier, Sébastien Forestier, Pierre-Yves Oudeyer
- Contact: Pierre Rouanet
- URL: https://github.com/flowersteam/explauto

6.4. KidLearn: active teaching in Intelligent Tutoring Systems

KEYWORD: Automatic Learning
FUNCTIONAL DESCRIPTION

KidLearn is a software which adaptively personalize sequences of learning activities to the particularities of each individual student. It aims at proposing to the student the right activity at the right time, maximizing concurrently his learning progress and its motivation.

- Participants: Benjamin Clement, Pierre Yves Oudeyer, Didier Roy and Manuel Lopes
- Contact: Manuel Lopes
- URL: https://flowers.inria.fr/research/kidlearn/

6.5. Self-calibration BCI

KEYWORDS: Neurosciences - Health - Brain-Computer Interface
FUNCTIONAL DESCRIPTION

Self-calibration BCI is a Matlab library which 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).

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, showing that the users were able to guide from scratch an agent to a desired position.

- Participants: Manuel Lopes, Jonathan Grizou and Pierre-Yves Oudeyer
- Contact: Jonathan Grizou
- URL: https://github.com/flowersteam/self_calibration_BCI_plosOne_2015/

6.6. Platforms

6.6.1. Platform: Collaborative assemblies with Baxter

- Participant: Yoan Mollard, Baptiste Busch, Thibaut Munzer
- Contact: Yoan Mollard

FUNCTIONAL DESCRIPTION This platform is a set of software components and hardware robotic components designed as an experimental setup for performing scientific experiments with the Baxter robot illustrating human-robot collaboration. It comes with a set of capabilities (pick objects, handover, hold objects in place, ...) and physical objects (screwdriver, landmarks, camera mounts, ...) created on purpose or hacked to serve these capabilities. The initial capabilities focus on industrial activities and allow the robot to provide assistance to workers in manufacturing factories for their daily tasks (pieces fetching, screwing, assembly, ...). We simulated an industrial environment with a trolley acting as a feeder where all spare parts are initially located, a workspace for the worker and 7 spare parts composing a wooden toolbox that users and robot will handle for their collaborative tasks. This industrial environment is the one of the 3rd hand project, but the platform and its capabilities will progessively be improved and enriched to be used for other projects. The picture 7 illustrates the experimental setup.

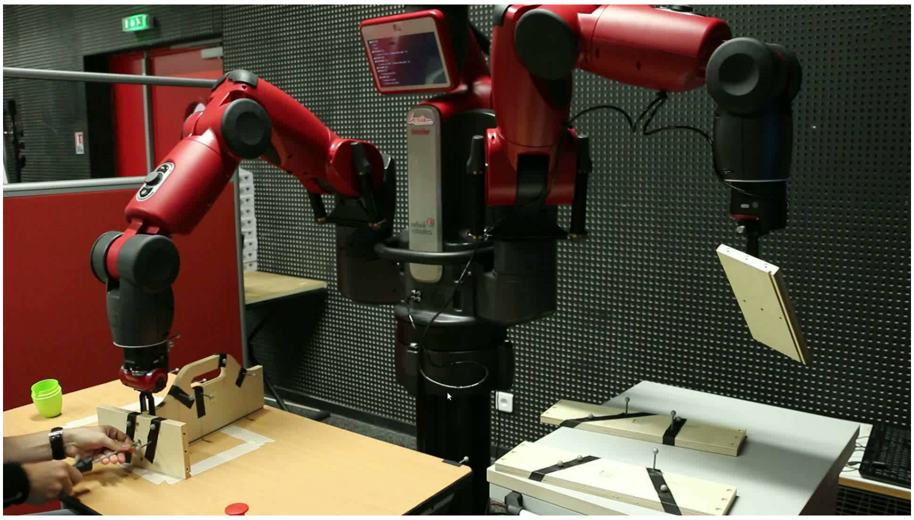

Figure 7. Experimental setup for human-robot collaborative assemblies of a wooden toolbox

7. New Results

7.1. Robotic And Computational Models Of Human Development and Cognition

7.1.1. Computational Models Of Information-Seeking, Curiosity And Attention in Humans and Animals

Participants: Manuel Lopes, Pierre-Yves Oudeyer [correspondant], Jacqueline Gottlieb, Adrien Baranes, William Schueller, Sebastien Forestier, Nabil Daddaouda, Nicholas Foley.

This project involves a collaboration between the Flowers team and the Cognitive Neuroscience Lab of J. Gottlieb at Columbia Univ. (NY, US) on the understanding and modeling of mechanisms of curiosity and attention that until now have been little explored in neuroscience, computer science and cognitive robotics. It is organized around the study of the hypothesis that information gain could generate intrinsic reward in the brain (living or artificial), controlling attention and exploration independently from material rewards. The project combines expertise about attention and exploration in the brain and a strong methodological framework for conducting experimentations with monkeys and humans (Gottlieb's lab) together with cognitive modeling of curiosity and learning in the Flowers team.

Such a collaboration paves the way towards a central objective, which is now a central strategic objective of the Flowers team: designing and conducting experiments in animals and humans informed by computational/mathematical theories of information seeking, and allowing to test the predictions of these computational theories.

7.1.1.1. Context

Curiosity can be understood as a family of mechanisms that evolved to allow agents to maximize their knowledge of the useful properties of the world - i.e., the regularities that exist in the world - using active, targeted investigations. In other words, we view curiosity as a decision process that maximizes learning (rather than minimizing uncertainty) and assigns value ("interest") to competing tasks based on their epistemic qualities - i.e., their estimated potential allow discovery and learning about the structure of the world.

Because a curiosity-based system acts in conditions of extreme uncertainty (when the distributions of events may be entirely unknown) there is in general no optimal solution to the question of which exploratory action to take [105], [122], [130]. Therefore we hypothesize that, rather than using a single optimization process as it has been the case in most previous theoretical work [90], curiosity is comprised of a family of mechanisms that include simple heuristics related to novelty/surprise and measures of learning progress over longer time scales[16] [74], [112]. These different components are related to the subject's epistemic state (knowledge and beliefs) and may be integrated with fluctuating weights that vary according to the task context. We will quantitatively characterize this dynamic, multi-dimensional system in the framework of Bayesian Reinforcement Learning, as described below.

Because of its reliance on epistemic currencies, curiosity is also very likely to be sensitive to individual differences in personality and cognitive functions. Humans show well-documented individual differences in curiosity and exploratory drives [103], [129], and rats show individual variation in learning styles and novelty seeking behaviors [88], but the basis of these differences is not understood. We postulate that an important component of this variation is related to differences in working memory capacity and executive control which, by affecting the encoding and retention of information, will impact the individual's assessment of learning, novelty and surprise and ultimately, the value they place on these factors [127], [136], [70], [140]. To start understanding these relationships, about which nothing is known, we will search for correlations between curiosity and measures of working memory and executive control in the population of children we test in our tasks, analyzed from the point of view of a computational model based on Bayesian reinforcement learning.

A final premise guiding our research is that essential elements of curiosity are shared by humans and non-human primates. Human beings have a superior capacity for abstract reasoning and building causal models, which is a prerequisite for sophisticated forms of curiosity such as scientific research. However, if the task is adequately simplified, essential elements of curiosity are also found in monkeys [103], [100] and, with adequate characterization, this species can become a useful model system for understanding the neurophysiological mechanisms.

7.1.1.2. Objectives

Our studies have several highly innovative aspects, both with respect to curiosity and to the traditional research field of each member team.

- Linking curiosity with quantitative theories of learning and decision making: While existing investigations examined curiosity in qualitative, descriptive terms, here we propose a novel approach that integrates quantitative behavioral and neuronal measures with computationally defined theories of Bayesian Reinforcement Learning and decision making.
- Linking curiosity in children and monkeys: While existing investigations examined curiosity in humans, here we propose a novel line of research that coordinates its study in humans and non-human primates. This will address key open questions about differences in curiosity between species, and allow access to its cellular mechanisms.
- Neurophysiology of intrinsic motivation: Whereas virtually all the animal studies of learning and decision making focus on operant tasks (where behavior is shaped by experimenter-determined primary rewards) our studies are among the very first to examine behaviors that are intrinsically motivated by the animals' own learning, beliefs or expectations.
- Neurophysiology of learning and attention: While multiple experiments have explored the single-neuron basis of visual attention in monkeys, all of these studies focused on vision and eye movement control. Our studies are the first to examine the links between attention and learning, which are recognized in psychophysical studies but have been neglected in physiological investigations.
- Computer science: biological basis for artificial exploration: While computer science has proposed and tested many algorithms that can guide intrinsically motivated exploration, our studies are the first to test the biological plausibility of these algorithms.
- Developmental psychology: linking curiosity with development: While it has long been appreciated that children learn selectively from some sources but not others, there has been no systematic investigation of the factors that engender curiosity, or how they depend on cognitive traits.

7.1.1.3. Current results

During the first period of the associated team (2013-2015), we layed the operational foundations of the collaboration resulting in several milestone joint journal articles [110], [90], [84][27], new experimental paradigms for the study of curiosity, and organized a major scientific event: the first international interdisciplinary symposium on information seeking, curiosity and attention (web: https://openlab-flowers.inria.fr/t/first-interdisciplinary-symposium-on-information-seeking-curiosity-and-attention/21).

In particular, new results in 2015 include:

7.1.1.4. Eye movements reveal epistemic curiosity in human observers

Saccadic (rapid) eye movements are primary means by which humans and non-human primates sample visual information. However, while saccadic decisions are intensively investigated in instrumental contexts where saccades guide subsequent actions, it is largely unknown how they may be influenced by curiosity – the intrinsic desire to learn. While saccades are sensitive to visual novelty and visual surprise, no study has examined their relation to epistemic curiosity – interest in symbolic, semantic information. To investigate this question, we tracked the eye movements of human observers while they read trivia questions and, after a brief delay, were visually given the answer. We showed that higher curiosity was associated with earlier anticipatory orienting of gaze toward the answer location without changes in other metrics of saccades or fixations, and that these influences were distinct from those produced by variations in confidence and surprise. Across subjects, the enhancement of anticipatory gaze was correlated with measures of trait curiosity from personality questionnaires. Finally, a machine learning algorithm could predict curiosity in a cross-subject manner, relying primarily on statistical features of the gaze position before the answer onset and independently of covariations in confidence or surprise, suggesting potential practical applications for educational technologies, recommender systems and research in cognitive sciences. We published these results in [27], providing full access to the annotated database allowing readers to reproduce the results. Epistemic curiosity produces specific effects on oculomotor anticipation that can be used to read out curiosity states.

7.1.1.5. Intrinsically motivated oculomotor exploration guided by uncertainty reduction and conditioned reinforcement in non-human primates

Intelligent animals have a high degree of curiosity – the intrinsic desire to know – but the mechanisms of curiosity are poorly understood. A key open question pertains to the internal valuation systems that drive curiosity. What are the cognitive and emotional factors that motivate animals to seek information when this is not reinforced by instrumental rewards? Using a novel oculomotor paradigm, combined with reinforcement learning (RL) simulations, we show that monkeys are intrinsically motivated to search for and look at reward-predictive cues, and that their intrinsic motivation is shaped by a desire to reduce uncertainty, a desire to obtain conditioned reinforcement from positive cues, and individual variations in decision strategy and the cognitive costs of acquiring information. The results suggest that free-viewing oculomotor behavior reveals cognitive and emotional factors underlying the curiosity driven sampling of information. [84]

7.1.2. Computational Models Of Speech Development: the Roles of Active Learning, Curiosity and Self-Organization

Participants: Pierre-Yves Oudeyer [correspondant], Clement Moulin-Frier, Sébastien Forestier.

7.1.2.1. Special issue on the cognitive nature of speech sounds

Together with Jean-Luc Schwartz and Kenneth de Jong, Flowers members Clément Moulin-Frier and Pierre-Yves Oudeyer guest-edited a milestone special issue of the Journal of Phonetics focusing on theories of the cognitive nature of speech sounds, and with a special emphasis on presenting and analyzing a rich series of computational models of speech evolution and acquisition developped in the past years internationally, including models developped by the guest-editors. The editorial of this special issue was published in [35] and the special issue is accessible at: http://www.sciencedirect.com/science/journal/00954470/53.

7.1.2.2. The COSMO model: A Bayesian modeling framework for studying speech communication and the emergence of phonological systems

(Note: this model was developped while C. Moulin-Frier was at GIPSA Lab, and writing was partly achieved while he was at Inria). While the origin of language remains a somewhat mysterious process, understanding how human language takes specific forms appears to be accessible by the experimental method. Languages, despite their wide variety, display obvious regularities. In this paper, we attempt to derive some properties of phonological systems (the sound systems for human languages) from speech communication principles. The article [33] introduces a model of the cognitive architecture of a communicating agent, called COSMO (for “Communicating about Objects using Sensory–Motor Operations’) that allows a probabilistic expression of the main theoretical trends found in the speech production and perception literature. This enables a computational comparison of these theoretical trends, which helps us to identify the conditions that favor the emergence of linguistic codes. It presents realistic simulations of phonological system emergence showing that COSMO is able to predict the main regularities in vowel, stop consonant and syllable systems in human languages.

7.1.2.3. The role of self-organization, motivation and curiosity in speech development and evolution

In the article [34], Oudeyer discusses open scientific challenges for understanding development and evolution of speech forms. Based on the analysis of mathematical models of the origins of speech forms, with a focus on their assumptions, the article studies the fundamental question of how speech can be formed out of non-speech, at both developmental and evolutionary scales. In particular, it emphasizes the importance of embodied self-organization, as well as the role of mechanisms of motivation and active curiosity-driven exploration in speech formation. Finally, it discusses an evolutionary-developmental perspective of the origins of speech.

7.1.2.4. Robotic models of the joint development of speech and tool use

A scientific challenge in developmental and social robotics is to model how autonomous organisms can develop and learn open repertoires of skills in high-dimensional sensorimotor spaces, given limited resources of time and energy. This challenge is important both from the fundamental and application perspectives. First, recent work in robotic modeling of development has shown that it could make decisive contributions to improve our understanding of development in human children, within cognitive sciences [90]. Second, these models are key for enabling future robots to learn new skills through lifelong natural interaction with human users, for example in assistive robotics [124].

In recent years, two strands of work have shown significant advances in the scientific community. On the one hand, algorithmic models of active learning and imitation learning combined with adequately designed properties of robotic bodies have allowed robots to learn how to control an initially unknown high-dimensional body (for example locomotion with a soft material body [73]). On the other hand, other algorithmic models have shown how several social learning mechanisms could allow robots to acquire elements of speech and language [79], allowing them to interact with humans. Yet, these two strands of models have so far mostly remained disconnected, where models of sensorimotor learning were too “low-level” to reach capabilities for language, and models of language acquisition assumed strong language specific machinery limiting their flexibility. Preliminary work has been showing that strong connections are underlying mechanisms of hierarchical sensorimotor learning, artificial curiosity, and language acquisition [125].

Recent robotic modeling work in this direction has shown how mechanisms of active curiosity-driven learning could progressively self-organize developmental stages of increasing complexity in vocal skills sharing many properties with the vocal development of infants [113]. Interestingly, these mechanisms were shown to be exactly the same as those that can allow a robot to discover other parts of its body, and how to interact with external physical objects [120].

In such current models, the vocal agents do not associate sounds to meaning, and do not link vocal production to other forms of action. In other models of language acquisition, one assumes that vocal production is mastered, and hand code the meta-knowledge that sounds should be associated to referents or actions [79]. But understanding what kind of algorithmic mechanisms can explain the smooth transition between the learning of vocal sound production and their use as tools to affect the world is still largely an open question.

The goal of this work is to elaborate and study computational models of curiosity-driven learning that allow flexible learning of skill hierarchies, in particular for learning how to use tools and how to engage in social interaction, following those presented in [120], [73], [118], [113]. The aim is to make steps towards addressing the fundamental question of how speech communication is acquired through embodied interaction, and how it is linked to tool discovery and learning.

A first question that we study in this work is the type of mechanisms that could be used for hierarchical skill learning allowing to manage new task spaces and new action spaces, where the action and task spaces initially given to the robot are continuous and high-dimensional and can be encapsulated as primitive actions to affect newly learnt task spaces.

We presented preliminary results on that question in a poster session [89] of the ICDL/Epirob conference in Providence, RI, USA in August 2015. In this work, we rely more specifically on the R-IAC and SAGG-RIAC series of architectures developed in the Flowers team and we develop different ways to extend those architectures to the learning of several task spaces that can be explored in a hierarchical manner. We describe an interactive task to evaluate different hierarchical learning mechanisms, where a robot has to explore its motor space in order to push an object to different locations. The task can be decomposed into two subtasks where the robot can first explore how to make movements with its hand and then integrate this skill to explore the task of pushing an object.

In the Simplest First strategy, the agent explores successively but with a fixed curriculum the different tasks to learn in the good order: from the simplest one (learning hand movements given motor parameters) to the more complex one (pushing a block with hand movements) that need knowledge about the simpler task to be learned.

In the Top-Down Guidance strategy, the module learning the more complex task (pushing a block with hand movements) gives goals (hand movements) to be reached by the lower-level module (learning hand movements given motor parameters) that will explore for a while to reach that goal before switching to a new given goal.

We also compare our architectures to the control ones where the robot learns directly the not decomposed task, with a competence-based intrinsic motivation (goal babbling) or a fully random motor babbling.

The results show a better exploration for the Top-Down Guidance than the Simplest First hierarchical exploration strategy, and that learning intermediate representations is beneficial in this setup.

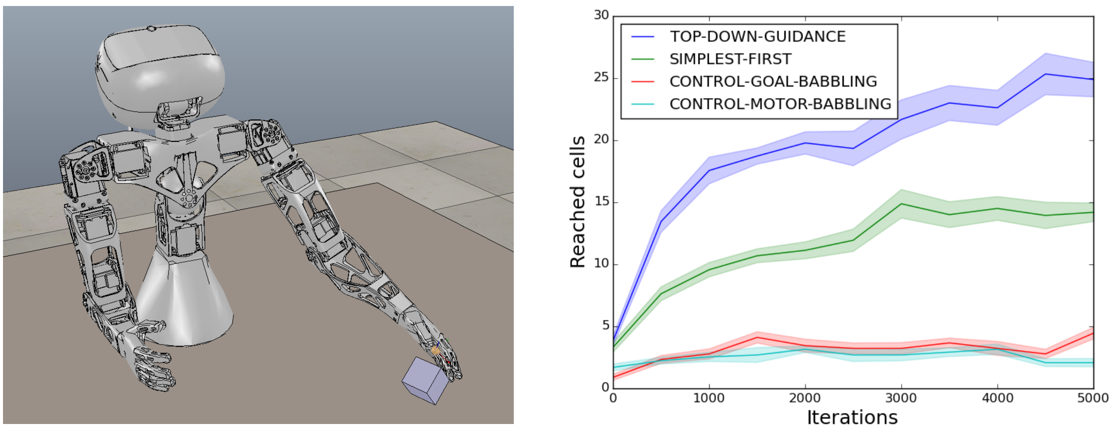

Figure 8. Left: Poppy Torso in the V-REP simulator pushing a block. Right: Exploration results of the different strategies.

7.1.3. Learning in Adult-Child and Human-Robot Interaction

Participants: Anna-Lisa Vollmer [correspondant], Pierre-Yves Oudeyer.

Learning in Adult-Child and Human-Robot Interaction

7.1.3.1. The Change of 'Motionese' Parameters Depending on Children's Age.

Two adult-child interaction studies were analyzed with the focus on the parental teaching behavior, in particular on *motionese* parameters (modifications of child-directed movement). In the first cross-sectional study, parental action demonstrations to three groups of 8–11, 12– 23 and 24–30 month-olds ($N = 84$ parents) were investigated. The youngest group of participants was investigated longitudinally in the second study ($N = 18$ parents). Together the results suggest that some motionese parameters (motion pauses, velocity, acceleration) persist over different ages while other parameters (action length, roundness and pace) occur predominantly in the younger group and seem to be primarily used to attract infants' attention on the basis of movement. In contrast, parameters appearing to be more in charge of structuring the action by organizing it in motion pauses seem to persist. We discuss the results in terms of facilitative vs. pedagogical learning in a paper currently under review for the Journal of Experimental Child Psychology.

7.1.3.2. An Alternative to Mapping a Word onto a Concept in Language Acquisition: Pragmatic Frames

According to the mapping metaphor, for a child to learn a word, s/he has to map a word onto a concept of an object/event. We are not convinced that associations can explain word learning, because even though children's attention is on the objects, they do not necessarily remember the connection of the word with the referent. In this theoretical paper, we propose an alternative to the mapping process that is classically assumed as a mechanism for word learning. Our main point holds that word learning is a task, in which children accomplish a goal in cooperation with a partner. In our approach, we follow Bruner's (1983) idea and further specify pragmatic frames as learning units that drive language acquisition and cognitive development. These units consist of a sequence of language and actions that are co-constructed with a partner to achieve a joint goal. We elaborate on this alternative, offer some initial parametrizations of the concept and embed it in the current language learning approaches in a paper currently under review for Frontiers in Psychology, section Cognitive Science.

7.1.3.3. Meta-Analysis of Pragmatic Frames in Human-Robot Interaction for Learning and Teaching: State-of-the-Art and Perspectives

One of the big challenges in robotics today is to learn from inexperienced human users. Despite tremendous research efforts and advances in human-robot interaction (HRI) and robot learning in the past decades, learning interactions with robots remain brittle and rigidly organized, and often are limited to learning only one single task. In this work, we applied the concept of pragmatic frames known from developmental research in humans in a meta-analysis of current approaches on robot learning. This concept offers a new research perspective in HRI as multiple flexible interaction protocols can be used and learned to teach/learn multiple kinds of skills in long-term recurring social interaction. This perspective, thus, emphasizes teaching as a collaborative achievement of teacher and learner. Our meta-analysis focuses on robot learning from a human teacher with respect to the pragmatic frames they (implicitly) use. We show that while the current approaches offer a variety of different learning and teaching behavior, they all employ highly pre-structured, hard-coded pragmatic frames. Compared to natural human-human interaction, interactions are lacking flexibility and expressiveness, and mostly are hardly viable for being realized with truly naive and uninstructed users. We elaborated an outlook on the future research direction with its relevant key challenges that need to be solved for leveraging pragmatic frames for robot learning. These results have been submitted to the Frontiers in Neurorobotics Journal.

7.1.3.4. Alignment to the Actions of a Robot

Alignment is a phenomenon observed in human conversation: Dialog partners' behavior converges in many respects. Such alignment has been proposed to be automatic and the basis for communicating successfully. Recent research on human-computer dialog promotes a mediated communicative design account of alignment according to which the extent of alignment is influenced by interlocutors' beliefs about each other. Our work aims at adding to these findings in two ways. a) Our work investigates alignment of manual actions, instead of lexical choice. b) Participants interact with the iCub humanoid robot, instead of an artificial computer dialog system. Our results confirm that alignment also takes place in the domain of actions. We were not able to replicate the results of the original study in general in this setting, but in accordance with its findings, participants with a high questionnaire score for emotional stability and participants who are familiar with robots align their actions more to a robot they believe to be basic than to one they believe to be advanced. Regarding alignment over the course of an interaction, the extent of alignment seems to remain constant, when participants believe the robot to be advanced, but it increases over time, when participants believe the robot to be a basic version. These results were published in [38].

7.1.4. Models of Multimodal Concept Acquisition with Non-Negative Matrix Factorization

Participants: Pierre-Yves Oudeyer, Olivier Mangin [correspondant], David Filliat, Louis Ten Bosch.

In the article [32] we introduced MCA-NMF, a computational model of the acquisition of multi-modal concepts by an agent grounded in its environment. More precisely our model finds patterns in multimodal sensor input that characterize associations across modalities (speech utterances, images and motion). We propose this computational model as an answer to the question of how some class of concepts can be learnt. In addition, the model provides a way of defining such a class of plausibly learnable concepts. We detail why the multimodal nature of perception is essential to reduce the ambiguity of learnt concepts as well as to communicate about them through speech. We then present a set of experiments that demonstrate the learning of such concepts from real non-symbolic data consisting of speech sounds, images, and motions. Finally we consider structure in perceptual signals and demonstrate that a detailed knowledge of this structure, named compositional understanding can emerge from, instead of being a prerequisite of, global understanding. An open-source implementation of the MCA-NMF learner as well as scripts and associated experimental data to reproduce the experiments are publicly available.

The python code and datasets allowing to reproduce these experiments and results are available at: https://github.com/omangin/multimodal.

7.1.5. Models of Self-organization of lexical conventions: the role of Active Learning in Naming Games

Participants: William Schueller [correspondant], Pierre-Yves Oudeyer.

Our work focuses on the Naming Games framework [135], meant to simulate lexicon evolution in a population from interactions at the individual level. A quite diverse subset of the possible scenarios and algorithms has already been studied, and those do lead to the self-organization of a shared lexicon (understood as associations between meanings and words). However, high values for some parameters (population size, number of possible words and/or meanings that can be refered to) can lead to really slow dynamics. Following the introductory work done in [119], we introduced a new measure of vocabulary evolution based on information theory, as well as various active learning mechanisms in the Naming Games framework allowing the agents to choose what they talk about according to their past. We showed that it improves convergence dynamics in the studied scenarios and parameter ranges. Active learning mechanisms use the confidence an agent has on its own vocabulary (is it already widely used in the population or not?) to choose between exploring new associations (growing vocabulary) or strengthening already existing ones (spreading its own associations to other agents). This was presented at the ICDL/Epirob conference in Providence, RI, USA in August 2015 [59].

A follow-up to this work consisted of changing slightly the base algorithms, allowing agents to select what they want the others to talk about instead of selecting what they would talk about (hearer's choice scenario, the original one being speaker's choice scenario). In the class of algorithms used, with active learning, it leads to faster convergence, with increased robustness to change in parameter values.

All the simulations can be easily rerun using the provided code and explanatory notebooks on https://github.com/flowersteam/naminggamesal.

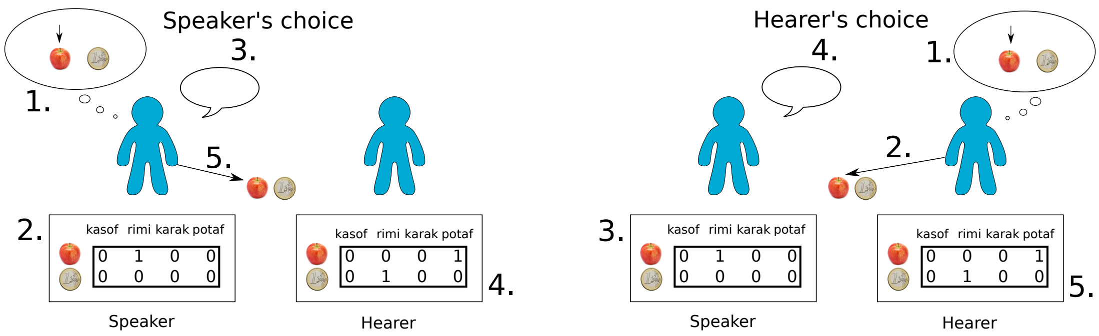

Figure 9. Interaction processes in both active scenarios considered in our work. Beforehand, two individuals have been randomly selected among a population, designated as speaker (S) and hearer (H). Speaker's choice: 1. S chooses a topic, 2. S checks its vocabulary to find or invent an associated word, 3. S utters the word, 4. H guesses the intended meaning, 5. S indicates the intended meaning. Hearer's choice: 1. H chooses a topic, 2. H indicates the intended meaning, 3. S checks its vocabulary to find or invent an associated word, 4. S utters the word, 5. H checks its vocabulary for a meaning associated to the uttered word. In both cases, if all meanings match, the interaction is considered a success, otherwise a failure. After the process, both agents can update their vocabularies to take the interaction into account.

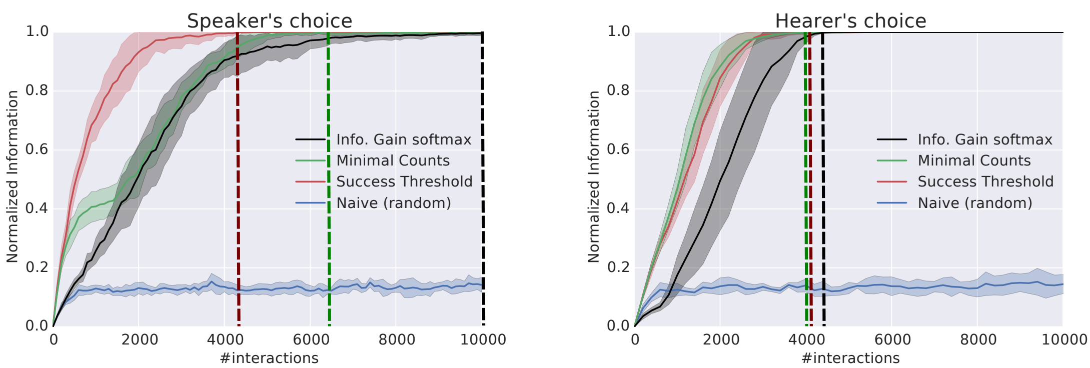

Figure 10. Strategy comparisons in both active scenarios. The measure indicates level of convergence towards a population-wide shared vocabulary (a value of 1 means every agent has the exact same vocabulary). Naive (random, no active learning) strategy converges slowly. Hearer's choice policy is more efficient for all active learning strategies. Last 5% of information are acquired slower when the speaker is choosing. Vertical lines show full convergence time for each strategy. (number of meanings = number of words = population size =20, averaged over 8 trials)

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

7.2.1. Uncalibrated BCI

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

We developed an new approach for self-calibration BCI for reaching tasks using error-related potentials. The proposed method exploits task constraints to simultaneously calibrate the decoder and control the device, by using a robust likelihood function and an ad-hoc planner to cope with the large uncertainty resulting from the unknown task and decoder. The method has been evaluated in closed-loop online experiments with 8 users using a previously proposed BCI protocol for reaching tasks over a grid. The results show that it is possible to have a usable BCI control from the beginning of the experiment without any prior calibration. Furthermore, comparisons with simulations and previous results obtained using standard calibration hint that both the quality of recorded signals and the performance of the system were comparable to those obtained with a standard calibration approach. [30]

7.2.2. Learning from Demonstration

Participants: Manuel Lopes, Thibaut Munzer [correspondant], Marc Toussaint, Li Wang Wu, Yoan Mollard, Andrea Baisero, Bilal Piot, Matthieu Geist, Olivier Pietquin.

Learning from Demonstration

7.2.2.1. Relational Activity Processes for Modeling Concurrent Cooperation

In multi-agent domains, human-robot collaboration domains, or single-robot manipulation with multiple end-effectors, the activities of the involved parties are naturally concurrent. Such domains are also naturally relational as they involve multiple objects, multiple agents, and models should generalize over objects and agents. We propose a novel formalization of relational concurrent activity processes that allows us to transfer methods from standard (relational) MDPs, such as Monte-Carlo planning and learning from demonstration, to concurrent cooperation domains. We formally compare the formulation to previous propositional models of concurrent decision making and demonstrate the planning and learning from demonstration methods on a real-world human-robot assembly task.

7.2.2.2. Interactive Learning

In paper [56] we consider that robot programming can be made more efficient, precise and intuitive if we leverage the advantages of complementary approaches such as learning from demonstration, learning from feedback and knowledge transfer. We designed a system that, starting from low-level demonstrations of assembly tasks, is able to extract a high-level relational plan of the task. A graphical user interface (GUI) allows then the user to iteratively correct the acquired knowledge by refining high-level plans, and low-level geometrical knowledge of the task. A final process allows to reuse high-level task knowledge for similar tasks in a transfer learning fashion. We conducted a user study with 14 participants asked to program assembly tasks of small furniture (chair and bench) to validate this approach. The results showed that this combination of approaches leads to a faster programming phase, more precise than just demonstrations, and more intuitive than just through a GUI.

7.2.2.3. Inverse Reinforcement Learning in Relational Domains

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. This was published in [49]

7.2.3. A Unified Model for Regression

Regression is the process of learning relationships between inputs and continuous outputs from example data, which enables predictions for novel inputs. Regression lies at the heart of imitation learning, and value function approximation for reinforcement learning. In [37], we provide a novel perspective on regression, by distinguishing rigoroulsy between the models and representations assumed in regression, and the algorithms used to train the parameters of these models. A rather surprising insight is that many regression algorithms [1] use very similar models; in fact, we show that the algorithm-specific models are *all* special cases of a "unified model". This perspective clearly seperates between representations and algorithms, and allows for a modular exchange between them, for instance in the context of evolutionary optimization.

7.2.4. Multiple Virtual Guides

In co-manipulation, humans and robots solve manipulation tasks together. Virtual guides are important tools for co-manipulation, as they constrain the movement of the robot to avoid undesirable effects, such as collisions with the environment. Defining virtual guides is often a laborious task requiring expert knowledge. This restricts the usefulness of virtual guides in environments where new tasks may need to be solved, or where multiple tasks need to be solved sequentially, but in an unknown order.

To this end, we have proposed a framework for *multiple probabilistic virtual guides*, and demonstrated a concrete implementation of such guides using kinesthetic teaching and Gaussian mixture models [57], [58]. Our approach enables non-expert users to design virtual guides through demonstration. Also, they may demonstrate novel guides, even if already known guides are active. Finally, users are able to intuitively select the appropriate guide from a set of guides through physical interaction with the robot.

7.2.5. Legible Motion

Participants: Manuel Lopes, Baptiste Busch [correspondant], Jonathan Grizou, Freek Stulp.

In a human-robot collaboration context, understanding and anticipating the robot intentions ease the completion of a joint-task. Whereas previous work has sought to explicitly optimize the legibility of behavior, we investigate legibility as a property that arises automatically from general requirements on the efficiency and robustness of joint human-robot task completion. We propose an optimization algorithm, based on policy improvement, that brings out the most legible robot's trajectories during the interaction (cf. Figure 11). The conducted user study highlights that humans become better at predicting sooner the robot's intentions. This leads to faster and more robust overall task completion. This work have been published to IROS 2015[60] and was submitted to the International Journal of Social Robotics under the special issue: Towards a framework for Joint Action.

7.2.6. Demonstrator of human-robot interface for teaching a collaborative task in the context of assistive robotics

Participants: Pierre Rouanet [correspondant], Yoan Mollard, Thibaut Munzer, Baptiste Busch, Manuel Lopes, Pierre-Yves Oudeyer.

In the context of the Roméo 2 project, we have developed a demonstrator of a human-robot interface designed for non-expert users. It allows them to teach a new collaborative task to a robot through simple and intuitive interactions. It is based on the approach of inverse reinforcement learning in relational domains described above.

The context of the demonstrator is assistive robotics where typically an elderly person wants to teach a robot (we use Baxter in this case) how it can help him to prepare a meal. For instance, the user will show the robot that first he wants the robot to hold its bowl and that he stirs it. Then, the robot should put the bowl on a plate. Then, the user will teach the robot that he wants the robot to grab a glass and put it on the right of the bowl...

[1] Locally Weighted Regression, Receptive Field Weighted Regression, Locally Weighted Projection Regression, Gaussian Mixture Regression, Model Trees, Radial Basis Function Networks, Kernel Ridge Regression, Gaussian Process Regression , Support Vector Regression Incr. Random Features Regularized Least Squares, Incr. Sparse Spectrum Gaussian Process Regr., Regression Trees, Extreme Learning Machines.

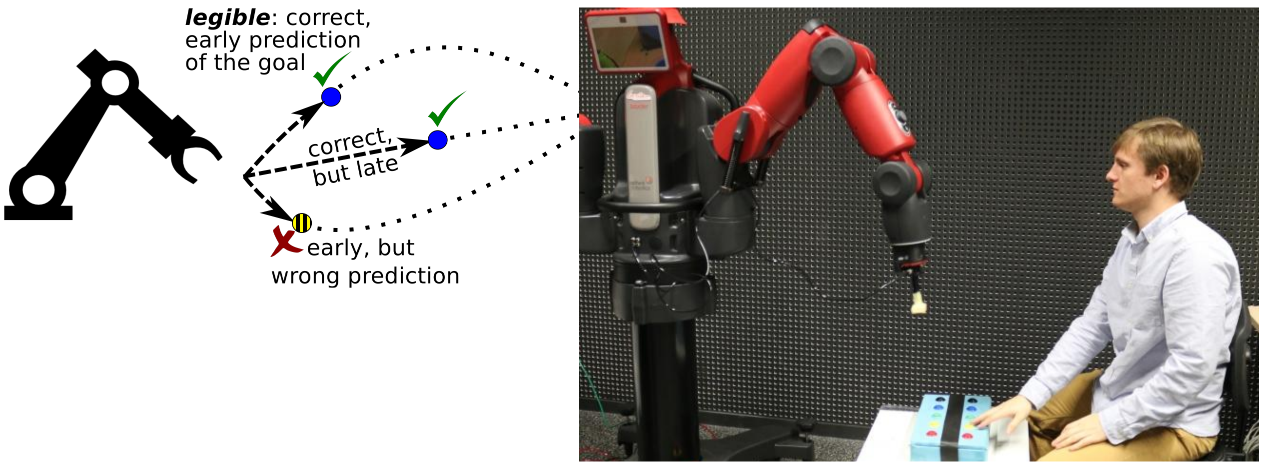

Figure 11. Illustration of the experimental setup. The robots aims for a button and press it. The human predict the target and is instructed to quickly press the button of the same color when sufficiently confident about this prediction.

7.2.7. Diversity-driven curiosity-driven learning and transfer learning

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

7.2.7.1. Diversity-driven selection of exploration strategies in multi-armed bandits

In [40], we considered a scenario where an agent has multiple available strategies to explore an unknown environment. For each new interaction with the environment, the agent must select which exploration strategy to use. We provide a new strategy-agnostic method that treat the situation as a Multi- Armed Bandits problem where the reward signal is the diversity of effects that each strategy produces. We test the method empirically on a simulated planar robotic arm, and establish that the method is both able discriminate between strategies of dissimilar quality, even when the differences are tenuous, and that the resulting performance is competitive with the best fixed mixture of strategies.

7.2.7.2. Behavioral Diversity Generation in Autonomous Exploration Through Reuse of Past Experience

The production of behavioral diversity—producing a diversity of effects—is an essential strategy for robots exploring the world when facing situations where interaction possibilities are unknwon or non-obvious. It allows to discover new aspects of the environment that cannot be inferred or deduced from available knowledge. However, creating behavioral diversity in situations where it is the most crucial, i.e. new and unknown ones, is far from trivial. In particular in large and redundant sensorimotor spaces, some effects can typically only be produced by a few number of specific motor commands. We introduced a method to create behavioral diversity by re-enacting past experiences, along with a measure that quantifies this diversity. We showed that our method is robust to morphological and representation changes, that it can learn how to interact with an object by reusing experience from another and how scaffolding behaviors can emerge by simply switching the attention of the robot to different parts of the environment. Finally, we showed that the method can robustly use simulated experiences and crude cognitive models to provide behavioural diversity in the real world. This result are under review.

7.3. Autonomous And Social Perceptual Learning

Participants: David Filliat [correspondant], Freek Stulp, Celine Craye, Yuxin Chen, Clement Masson, Adrien Matricon.

7.3.1. Incremental Learning of Object-Based Visual Saliency

Searching for objects in an indoor environment can be drastically improved if a task-specific visual saliency is available. We describe a method to learn such an object-based visual saliency in an intrinsically motivated way using an environment exploration mechanism. We first define saliency in a geometrical manner and use this definition to discover salient elements given an attentive but costly observation of the environment. These elements are used to train a fast classifier that predicts salient objects given large-scale visual features. In order to get a better and faster learning, we use intrinsic motivation to drive our observation selection, based on uncertainty and novelty detection. Our approach has been tested on RGB-D images, is real-time, and outperforms several state-of-the-art methods in the case of indoor object detection. We published these results in two conferences [43], [42]

7.3.2. Cross-situational noun and adjective learning in an interactive scenario

Learning word meanings during natural interaction with a human faces noise and ambiguity that can be solved by analysing regularities across different situations. We propose a model of this cross-situational learning capacity and apply it to learning nouns and adjectives from noisy and ambiguous speeches and continuous visual input. This model uses two different strategy: a statistical filtering to remove noise in the speech part and the Non Negative Matrix Factorization algorithm to discover word-meaning in the visual domain. We present experiments on learning object names and color names showing the performance of the model in real interactions with humans, dealing in particular with strong noise in the speech recognition. We published these results in a conference paper [41]

7.3.3. Learning representation with gated auto-encoders

We investigated algorithms that would be able to learn relevant visual or multi-modal features from data recorded while the robot performed some task. Representation learning is a currently very active research field, mainly focusing on deep-learning, which investigates how to compute more meaningful features from the raw high dimensional input data, providing a more abstract representation from which it should be easier to make decision or deduction (e.g classification, prediction, control, reinforcement learning). In the context of robotics, it is notably interesting to apply representation learning in a temporal and multi-modal approach exploiting vision and proprioception so as to be able to find feature that are relevant for building models of the robot itself and of its actions and their effect on the environment. Among the many existing approaches, we decided to explore the use of gated auto-encoders, a particular kind of neural networks including multiplicative connections, as they seem well adapted to this problem. Preliminary experimentations have been carried out with gated auto-encoders to learn transformations between two images. We observed that Gated Auto-Encoders (GAE) can successfully find compact representations of simple transformations such as translations, rotation or scaling between two small images. This is however not directly scalable to realistic images such as ones acquired by a robot's camera because of the number of parameters, memory size and compational power it would require (unless drastically downsampling the image which induces sensible loss of information). In addition, the transformation taking an image to the next one can be the combination of transformations due to the movement of several object in the field of view, composed with the global movement of the camera. This induces the existence of an exponential number of possible transformations to model, for which the basic GAE architecture is not suited. To tackle both issue, we are developing a convolutional architectures inspired form Convolutional Neural Networks (CNNs) that provide different modelisations for different parts of the image, which might be usefull to model combinations of transformations. Our Convolutional Gated Auto-Encoder is designed to perform generic feature learning in an unsupervised way (while most CNNs are trained in a supervised fasion) and we are currently testing it on realistic image sequences. We plan to extend this architecture to find relations between modalities as, for instance, proproceptive information and its evolution could be used to predict the next visual features. Similarly, proprioceptive information could be used as a supervising signal to learn visual features.

7.3.4. Learning models by minimizing complexity

In machine learning, it is commonly assumed that simpler models have better chances at generalizing to new, unseen data. Following this principle, we developped an algorithm relying on minimization of a given complexity measure to build a collection of models which jointly explain the observation of the training datapoints. The resulting collection is composed of as few models as possible, each using as few dimensions as possible and each as regular as possible. As of now, each model is a multivariate polynomial, with the complexity of a polynomial of degree N in d variables being N*d+1. The complexity of the collection is the sum of the complexity of all its models. The algorithm starts by associating each datapoint to a local model of complexity 1 (degree 0, no variables), then models are iteratively merged into models of higher complexity, as long as those merges don't increase the complexity of the collection and as long as the resulting models stay within a certain distance of their associated datapoints. We applied this algorithm to the problem of inverse dynamics, which we studied in simulation. For a given robot, torques needed to compensate gravity at equilibrium are entirely determined by the values of its joint angles. As it is common that robots actually perform only low-dimensional tasks, and do not explore their full state space during normal operation, we would like the complexity of our models to mirror the structure of the task. When the task was expressed in the joint space, we got satisfying results on that point, and got good predictions for unseen datapoints. When the task was expressend in end-effector position, it turned out to be impossible to learn the underlying manifolds because a given end-effector position can correspond to various joint configurations, and thus to various torques, making it impossible to predict those torques from the end-effector position alone. We are currently working on applying this model to data generated by an exploration algorithm on a robot arm manipulating objects.

7.4. Applications for Robotic myoelectric prostheses: co-adaptation algorithms and design of a 3D printed robotic arm prosthesis

Participants: Pierre-Yves Oudeyer [correspondant], Manuel Lopes, Joel Ortiz, Mathilde Couraud, Aymar de Rugy, Daniel Cattaert, Florent Paclet.

Together with the Hybrid team at INCIA, CNRS, the Flowers team continued to work on establishing the foundations of a long-term project related to the design and study of myoelectric robotic prosthesis. The ultimate goal of this project is to enable an amputee to produce natural movements with a robotic prosthetic arm (open-source, cheap, easily reconfigurable, and that can learn the particularities/preferences of each user). This will be achieved by 1) using the natural mapping between neural (muscle) activity and limb movements in healthy users, 2) developing a low-cost, modular robotic prosthetic arm and 3) enabling the user and the prosthesis to co-adapt to each other, using machine learning and error signals from the brain, with incremental learning algorithms inspired from the field of developmental and human-robot interaction. In particular, in 2015 two lines of work were achieved, concerning two important scientific challenges, and in the context of a PEPS CNRS project:

First, an experimental setup was designed to allow fast prototyping of 3D printed robotic prostheses (internship of Joel Ortiz). This work was based on the use of the Poppy open-source modular platform, and resulted in a functional prototype. Several video demonstrations are available at: https://forum.poppy-project.org/t/real-time-control-of-a-prosthetic-robotic-arm-poppy-with-muscle-activities/1656.

Second, first versions of co-adaptation algorithms were designed, implemented and tested with human subjects, based on the combination of advanced models of the arm biomechanics and incremental learning algorithms (internship of Mathilde Couraud). An article is under preparation.

7.5. Applications for Educational Technologies

7.5.1. 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. [29]

7.5.2. Poppy System

Participants: Matthieu Lapeyre [correspondant], Nicolas Rabault, Pierre Rouanet, Pierre-Yves Oudeyer.

In the Poppy project we are working on the Poppy System which is a new modular and open-source robotic architecture. It is design to help people create and build custom robots. It permits, in a similar approach as Lego, building robots or smart objects using standardized elements.

Poppy System is an unified system where each essential robotic components (actuators, sensors, ...) is an independant module, connected with other through standardized interfaces.

- Unified mechanical interfaces which simplifies the assembly process and the design of 3D printable parts.
- Unified communication between elements using the same connector and bus for each module.
- Unified software makes it easy to program each module independantly.

The current Poppy robots (Humanoid, Torso, Ergo) will be updated using this novel architecture.

Our ambition is to create an ecosystem around this system so communities can develop custom modules, following the Poppy System standards, which can be compatible with all other Poppy robots.

7.5.3. Poppy Education

Participants: Pierre-Yves Oudeyer [correspondant], Didier Roy, Théo Segonds, Stéphanie Noirpoudre, Marie Demangeat, Thibault Desprez, Matthieu Lapeyre, Pierre Rouanet, Nicolas Rabault.

Poppy Education aims to create, evaluate and disseminate pedagogical kits "turnkey solutions" complete, open-source and low cost, for teaching computer science and robotics. It is designed to help young people to take ownership with concepts and technologies of the digital world, and provide the tools they need to allow them to become actors of this world, with a considerable socio-economic potential. It is carried out in collaboration with teachers and several official french structures (French National Education, Highschools, engineers schools, ...). For secondary education and higher education, scientific literacy centers, Fablabs.

The Poppy robotic platform used in the project is free hardware and software, printed in 3D, and is intended primarily for:

- learning of computer science and robotics,
- introduction to digital manufacturing (3D printing ...)
- initiation to the integration of IT in physical objects in humanoid robotics, mechatronics.
- artistic activities.

Educational sectors covered by the project are mainly: Enseignement d'exploration ICN en seconde, enseignement ISN en terminale S et bientôt en 1ère , filière STI2D, MPS seconde.

Users and their needs are placed at the center of this project. The pedagogical tools of the project are being created directly with them and evaluated in real life by experiments. Poppy Education is based on the robotic platform poppy, from which it is possible to construct different robots, including:

- Poppy Humanoid is a robust and complete robotics platform designed for genuine experiments in the real world and can be adapted to specific user needs.
- Poppy Torso is a variant of Poppy Humanoid. It is a torso humanoid robot that can be easily installed on a table.
- Poppy Ergo Jr is a robotic arm. Solid and inexpensive, it is perfect to be used in class. Poppy robots are easy to program. Different options are possible based on students level and teaching objectives :
- Pixl is a board who manage power and communication between a raspberry pi and robotis XL320 low cost motors. We use this bord for all our low cost robots.
- Python. Directly from a web browser, using Ipython notebooks (an interactive terminal, in a web interface for the Python Programming Language).
- Snap. The visual programming system Snap, which is a variant of Scratch. Its features allow a thorough introduction of IT.
- C ++, Java, Matlab, Ruby, Javascript, etc. thanks to a REST API that allows you to send commands and receive information from the robot with simple HTTP requests.

Poppy Humanoid, Torso and Ergo robots can be simulated with the free simulator V-REP. It is possible in the classroom to work on the simulated model and then allow students to run their program on the physical robot.

Experimentations have began to be setup in 10 high-schools of Region Aquitaine, and 3 university level institutions: Lycée Camille Jullian (Bordeaux), Lycée Victor Louis (Talence), Lycée Saint Genès (Talence), Lycée François Mauriac (Bordeaux), Lycée Jean Moulin (Langon), Lycée des Graves (Gradignan), Lycée Sud Medoc (Le Taillan Medoc), Lycée Alfred Kastler (Talence), Lycée Raoul Follereau (Nevers), Aérocampus Auqitaine, ENSEIRB/IPB, ENSAM Talence.

7.5.4. IniRobot : Education and Thymio II Project (partnership with EPFL)

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

IniRobot Project consists to produce and diffuse a pedagogical kit for teachers and animators, to help to train them directly or by the way of external structures. The aim of the kit is to initiate children to computer science and robotics. The kit provides a micro-world for learning, and takes an enquiry-based educational approach, where kids are led to construct their understanding through practicing an active investigation methodology within teams. It is based on the use of the Thymio II robotic platform. More details about this projects were published in RIE 2015 [50], which presents the detailed pedagogical objectives and a first measure of results showing that children acquired several robotics-related concepts. See also https://dm1r.inria.fr/inirobot or http://www.inirobot.fr. The project is carried out in main collaboration with the LSRO Laboratory from EPFL (Lausanne) and others collaborations with French National Education/Rectorat d'Aquitaine.

Deployment: After 16 months of activity, IniRobot is used by about 900 adults and 8000 children in 35 cities of France. Example of action in university: MEEF teacher training for the hope of Aquitaine. Example of action in school: training of all Gironde Pedagogical ICT Advisors, covering nearly 1000 schools. Example of action in the extracurricular time: training 82 facilitators TAP cities of Talence, Pessac, Lille, ..., CDC Gates of inter-seas. Example of national action: Training of the digital mediators of the 8 Inria centers.

8. Bilateral Contracts and Grants with Industry

8.1. Bilateral Contracts with Industry

8.1.1. Advanced platform for Urban Mobility (PAMU)

Participants: David Filliat [correspondant], Emmanuel Battesti.

We further developed a planning algorithm for 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. A milestone demonstration of the system was made at the 22nd ITS World Congress, in Bordeaux, on the 5-9 October 2015.

8.2. Bilateral Grants with Industry

8.2.1. 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.

8.2.2. 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.

8.2.3. 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.

9. Partnerships and Cooperations

9.1. Regional Initiatives

9.1.1. Poppy Education

Poppy Education

Program: Feder - Région Aquitaine

Duration: January 2014 - December 2017

Coordinator: PY Oudeyer, Inria Flowers

Partners: Inria Flowers

Funding: 1 million euros (co-funded by Feder/EU Commission, Region Aquitaine and Inria)

Poppy Education aims to create, evaluate and disseminate pedagogical kits “turnkey solutions” complete, open-source and low cost, for teaching computer science and robotics. It is designed to help young people to take ownership with concepts and technologies of the digital world, and provide the tools they need to allow them to become actors of this world, with a considerable socio-economic potential. It is carried out in collaboration with teachers and several official french structures (French National Education/Rectorat, Highschools, engineering schools, ...). It targets secondary education and higher education, scientific literacy centers, Fablabs.

Poppy robotic platform used in the project is free hardware and software, printed in 3D, and is intended primarily for:

- learning of computer science and robotics,
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- initiation to the integration of IT in physical objects in humanoid robotics, mechatronics.
- artistic activities.

Educational sectors covered by the project are mainly: Enseignement d'exploration ICN en seconde, enseignement ISN en terminale S et bientôt en 1ère , filière STI2D, MPS seconde. Web: http://www.poppy-project.org/education.

9.1.2. 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 contributes 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 is now used to support the teaching and to conduct further investigation.

9.1.3. KidLearn and Region Aquitaine

A Conseil Régional d'Aquitaine Project (KidLearn, 2015-) began, coordinated by Manuel Lopes entitled KidLearn. Will fund 50% of a 3 years PhD student.

We propose here a research project that aims at elaborating algorithms and software systems to help humans learn efficiently, at school, at home or at work, by adapting and personalizing sequences of learning activities to the particularities of each individual student. This project leverages recent innovative algorithmic models of human learning (curiosity in particular, developed as a result of ERC European project of the Flowers team), and combines it with state-of-the-art optimization algorithms and an original integration with existing expert knowledge (human teachers). Given a knowledge domain and a set of possible learning activities, it will be able to propose the right activity at the right time to maximize learning progress. It can be applied to many learning situations and potential users: children learning basic knowledge in schools and with the support of their teachers, older kids using educational software at home, of adults needing to acquire new skills through professional training ("formation professionnelle"). Because it combines innovations in computational sciences (machine learning and optimization) with theories of human cognition (theories of human learning and of education), this project is also implementing a strong cross-fertilization between technology and human sciences (SHS).

9.1.4. Comacina Capsule Creative Art/Science project and Idex/Univ. Bordeaux

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 Comacina project, in collaboration with the Flowers team and supported by funding from Idex/Univ. Bordeaux, explored the role of movements and light in expressing emotions: http://comacina.org. This project was implemented through several residencies during the year, and several performances at various cultural places in Aquitaine, including at Pole Evasion in Ambares-et-Lagrave. a report is available at https://flowers.inria.fr/RencontreAutourDuGeste.pdf. It benefitted from funding from the Art/Science Idex call for project.

9.2. National Initiatives

F. Stulp: Collaboration: with Olivier Sigaud of the Institut des Systèmes Intelligents (ISIR) et de Robotique of Université Pierre et Marie Curie (UPMC) [37].

F. Stulp: Collaboration: with Xavier Lamy of Laboratoire d'Intégration de Systèmes et des Technologies of the Commissariat à l'énergie atomique et aux énergies alternatives (CEA-LIST) and Pedro Rodriguez-Ayerbe and Sami Tliba of Supélec [57], [58]. Funded by Digiteo, project "PrActIx".

PY Oudeyer and M Lopes collaborated with Aymar de Rugy, Daniel Cattaert and Florent Paclet (INCIA, CNRS/Univ. Bordeaux) about the design of myoelectric robotic prostheses based on the Poppy platform, and on the design of algorithms for co-adaptation learning between the human user and the prosthesis. This was funded by a PEPS CNRS grant.

A collaboration with the national InMediats project was organized around the Poppy project. InMediats is a national project gathering 6 science museums (Bordeaux, Rennes, Grenoble, Caen, Toulouse, Paris) that aims at setting large popular science actions allowing the general public to access the latest research and development http://inmediats.fr/le-programme/. In this context, the collaboration with the Flowers team consisted in setting up a network of educational activities around robotics and the use of the Poppy platform in the six towns, with the target to foster the discovery of robotics technologies and their societal dimensions: http://inmediats.fr/poppy-lhistoire-dune-collaboration-inter-centre/. In this context several successful workshops with the general public were organized.

9.3. European Initiatives

9.3.1. FP7 & H2020 Projects

9.3.1.1. 3rd HAND

Title: Semi-Autonomous 3rd Hand

Programm: FP7

Duration: October 2013 - September 2017

Coordinator: Inria

Partners:

Technische Universitaet Darmstadt (Germany)

Universitaet Innsbruck (Austria)

Universitaet Stuttgart (Germany)

Inria contact: Manuel Lopes

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. We will demonstrate its efficiency in the collaborative assembly of an IKEA-like shelf where the robot acts as a semiautonomous 3rd-Hand. http://www.3rdhandrobot.eu

9.3.1.2. DREAM

Title: Deferred Restructuring of Experience in Autonomous Machines

Programm: H2020

Duration: January 2015 - December 2018

Coordinator: UPMC

Partners:

Armines (ENSTA ParisTech)

Queen Mary University London (England)

University of A Coruna (Spain)

Vrije University Amsterdam (Holland)

Contact: David Filliat

Abstract: A holy grail in robotics and artificial intelligence is to design a machine that can accumulate adaptations on developmental time scales of months and years. From infancy through adult- hood, such a system must continually consolidate and bootstrap its knowledge, to ensure that the learned knowledge and skills are compositional, and organized into meaningful hierarchies. Consolidation of previous experience and knowledge appears to be one of the main purposes of sleep and dreams for humans, that serve to tidy the brain by removing excess information, to recombine concepts to improve information processing, and to consolidate memory. Our approach – Deferred Restructuring of Experience in Autonomous Machines (DREAM) – incorporates sleep and dream-like processes within a cognitive architecture. This enables an individual robot or groups of robots to consolidate their experience into more useful and generic formats, thus improving their future ability to learn and adapt. DREAM relies on Evo- lutionary Neurodynamic ensemble methods (Fernando et al, 2012 Frontiers in Comp Neuro; Bellas et al., IEEE-TAMD, 2010) as a unifying principle for discovery, optimization, re- structuring and consolidation of knowledge. This new paradigm will make the robot more autonomous in its acquisition, organization and use of knowledge and skills just as long as they comply with the satisfaction of pre-established basic motivations. DREAM will enable robots to cope with the complexity of being an information-processing entity in domains that are open-ended both in terms of space and time. It paves the way for a new generation of robots whose existence and purpose goes far beyond the mere execution of dull tasks. http://www.robotsthatdream.eu

9.3.2. Collaborations in European Programs, except FP7 & H2020

9.3.2.1. IGLU

Title: Interactive Grounded Language Understanding (IGLU)

Programm: CHIST-ERA

Duration: October 2015 - September 2018

Coordinator: University of Sherbrooke, Canada

Partners:

University of Sherbrooke, Canada

Inria Bordeaux, France

University of Mons, Belgium

KTH Royal Institute of Technology, Sweden

University of Zaragoza, Spain

University of Lille 1 , France

University of Montreal, Canada

Inria contact: Manuel Lopes

Language is an ability that develops in young children through joint interaction with their caretakers and their physical environment. At this level, human language understanding could be referred as interpreting and expressing semantic concepts (e.g. objects, actions and relations) through what can be perceived (or inferred) from current context in the environment. Previous work in the field of artificial intelligence has failed to address the acquisition of such perceptually-grounded knowledge in virtual agents (avatars), mainly because of the lack of physical embodiment (ability to interact physically) and dialogue, communication skills (ability to interact verbally). We believe that robotic agents are more appropriate for this task, and that interaction is a so important aspect of human language learning and understanding that pragmatic knowledge (identifying or conveying intention) must be present to complement semantic knowledge. Through a developmental approach where knowledge grows in complexity while driven by multimodal experience and language interaction with a human, we propose an agent that will incorporate models of dialogues, human emotions and intentions as part of its decision-making process. This will lead anticipation and reaction not only based on its internal state (own goal and intention, perception of the environment), but also on the perceived state and intention of the human interactant. This will be possible through the development of advanced machine learning methods (combining developmental, deep and reinforcement learning) to handle large-scale multimodal inputs, besides leveraging state-of-the-art technological components involved in a language-based dialog system available within the consortium. Evaluations of learned skills and knowledge will be performed using an integrated architecture in a culinary use-case, and novel databases enabling research in grounded human language understanding will be released. IGLU will gather an interdisciplinary consortium composed of committed and experienced researchers in machine learning, neurosciences and cognitive sciences, developmental robotics, speech and language technologies, and multimodal/multimedia signal processing. We expect to have key impacts in the development of more interactive and adaptable systems sharing our environment in everyday life. http://iglu-chistera.github.io/

9.4. International Initiatives

9.4.1. Inria Associate Teams not involved in an Inria International Labs

9.4.1.1. NEUROCURIOSITY

Title: NeuroCuriosity

International Partner (Institution - Laboratory - Researcher):

University of Columbia (United States) - Neuroscience - Jacqueline Gottlieb

Start year: 2013

See also: https://flowers.inria.fr/curiosity-information-seeking-and-attention-in-human-adults-models-and-experiments/

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.

9.4.2. Inria International Partners

9.4.2.1. Informal International Partners

AL Vollmer and PY Oudeyer continued a major collaboration with Katharina Rohlfing (**Univ. Paderborn, Germany**) and Britta Wrede (**CITEC/Univ. Bielefeld, Germany**) on the study of how interactional structures help learners to acquire sensorimotor and linguistic skills in interaction with teachers, and based on the development of a new framework for conceptualizing pragmatic frames.

In the context of the Neurocuriosity project, a collaboration was initiated with Celeste Kidd, **Rochester Baby Lab, Univ. Rochester, US**.

In the context of the SMART-E Marie Curie Project (http://smart-e-mariecurie.eu), Yasmin Ansari from **SSSA, Pisa, Italy**, is visiting the Flowers team for 3 months for a collaboration involving the study of how algorithms for active learning of inverse models can be applied to learn soft robot control.

In the context of our projects on educational robotics research and applications, Didier Roy and PY Oudeyer have collaborated with Francesco Mondada, Morgane Chevallier and Gordana Gerber (**EPFL, Lausanne**), and Stéphane Magnenat and Fanny Riedo (**Mobsya association, Switzerland**).

Collaboration with Vittorio Loreto, Physics Department, Sapienza University of Rome, on statistical aspects of the Language Games. (W. Schueller and P.-Y. Oudeyer)

9.4.3. Participation In other International Programs

F. Stulp: Collaboration with Andrej Gams and Rok Vuga of the Josef Stefan Institute, Ljubljana, Slovenia. Funded by the “Programme Proteus 2015” for cooperations between France and Slovenia. Project “LoCoRoS”.

9.5. International Research Visitors

9.5.1. Visits of International Scientists

- Marc Toussaint, University of Stuttgart, Sept 2015
- Michele Sebag, CNRS, Sept 2015
- Oliver Brock, Technical University of Berlin, Sept 2015
- Stephano Cerri, University of Montpellier, Sept 2015
- Pierre Bessière, Univ. Paris VI and CNRS, april 2015
- Verena Hafner, Univ. Berlin, Germany, april 2015
- Jean-Baptiste Mouret, Inria, april 2015
- Yasmin Ansari, SSSA, Italy, december 2015

9.5.2. Visits to International Teams

- Pierre-Yves Oudeyer visited the SPECS Lab, Univ. Pompeu Fabra, Barcelona
- Pierre-Yves Oudeyer visited ISIR, Univ. Paris VI
- Pierre-Yves Oudeyer visited LPNC/GIPSA Lab, Grenoble

9.5.2.1. Research stays abroad

- Manuel Lopes spent 2 weeks at the University of Columbia
- Anna-Lisa Vollmer is visiting Bielefeld University, Germany for a long-term research stay

10. Dissemination

10.1. Promoting Scientific Activities

10.1.1. Scientific events organisation

10.1.1.1. General chair

D Roy organized and was general chair of Colloque Robotique et Education (june 2015) : Research, users reports, talks and workshops about robotics for education. Program : http://dm1r.fr/wp-content/uploads/2015/05/colloque_robotique_education_2324062015.pdf. Videos: https://www.youtube.com/playlist?list=PL9T8000j7sJDcOoHA8r18561F3jDXZASN.

10.1.1.2. Member of the organizing committees

- PY Oudeyer was member of the steering committee of the fOSSa international conference on Free Open Source Software, Nantes: https://fossa.inria.fr.
- PY Oudeyer was workshop chair of the IJCNN 2015 International Joint Conference on Neural Networks, Killarney, Ireland: http://www.ijcnn.org
- PY Oudeyer has been member of the steering committee of the IEEE ICDL-Epirob International Conference on Development and Learning and Epigenetics Robotics.

10.1.2. Scientific events selection

10.1.2.1. Member of the conference program committees

- David Filliat was Associate Editor for IROS, and member of the conference committee for ECMR.
- Manuel Lopes was member of the conference committee for HRI, AAMAS.
- PY Oudeyer was member of the program committee of IEEE ICDL-Epirob

10.1.2.2. Reviewer

- Manuel Lopes was reviewer for IJCAI, IROS, ICRA.
- David Filliat was reviewer for ESANN, RFIA, ECMR.
- Pierre Rouanet was reviewer for IROS.
- Thibaut Munzer was reviewer for IROS.
- PY Oudeyer was reviewer for IEEE ICDL-Epirob, IROS, ICRA.

10.1.3. Journal

10.1.3.1. Member of the editorial boards

- PY Oudeyer has been Editor-in-Chief of the IEEE CIS Newsletter on Cognitive and Developmental Systems, http://icdl-epirob.org/cdsnl
- PY Oudeyer and Clément Moulin-Frier guest edited a special issue of the Journal of Phonetics, on the cognitive nature of speech sounds.
- PY Oudeyer has been associate editor of IEEE Transactions on Autonomous Mental Development, Frontiers in Humanoid Robotics, Frontiers in Neurorobotics, IEEE RAS Letters.
- Manuel Lopes is an associated editor for the, IEEE Transactions on Autonomous Mental Development

10.1.3.2. Reviewer - Reviewing activities

- Pierre Rouanet has reviewed papers for the IEEE Robotics and Automation Letters (RA-L).
- Anna-Lisa Vollmer was reviewer for Frontiers in Robotics and AI and Transactions on Autonomous Mental Development
- David Filliat was reviewer for International Journal of Robotics Research, IEEE Transaction on Robotics
- PY Oudeyer was reviewer for Infancy, Journal of Infant Behavioral Development, Journal of Phonetics, IEEE TAMD.

10.1.4. Invited talks

- PY Oudeyer gave a keynote talk at the Evostar 2015 international conference on bio-inspired computation: http://www.evostar.org/2015/, entitled “Open-source baby robots for science, education and art, april 2015.
- PY Oudeyer gave a keynote talk at the Devoxx 2015 international conference, entitled “Building open-source robots capable of autonomous learning” http://www.devoxx.fr, april 2015.

- PY Oudeyer gave a keynote talk at the BICA 2015 international conference on Biologically Inspired Cognitive Architecture, entitled “Developmental robotics and open-ended learning”, https://liris.cnrs.fr/bica2015/wiki/doku.php/start, nov. 2015.
- PY Oudeyer gave a Spotligh talk at the OEB 2015 international conference on technology supported learning and training
- PY Oudeyer gave a talk at “Journée Brain”, Univ. Bordeaux, entitled “Open-source baby robots: modelling sensorimotor development with robots”, may 2015.
- PY Oudeyer gave a talk at Colloque GEII entitled “Poppy: Open-sour ce educational robot platform”, june 2015
- PY Oudeyer, “Modélisation robotique du développement cognitif’, sensoritmoteur et social”, CogTalk, Zig Zag bar/Association of cognitive science students of Univ. Bordeaux, feb. 2015.
- PY Oudeyer, “Robotique développementale et sociale”, Workshop Interactions Homme-Robots dans le contexte d’applications culturelles, La Rochelle, sept. 2015.
- PY Oudeyer, “Online optimization and personalization of teaching sequences: from developmental robotics to e-learning”, International Teacher’s Cognition workshop, Ecole Normale Supérieure, Paris
- PY Oudeyer, “Auto-organisation et curiosité dans le développement et l’évolution du langage”, Séminaire du laboratoire du LATTICE, Ecole Normale Supérieure de Paris.
- PY Oudeyer, “Histoire et enjeux éducatifs de l’intelligence artificielle et de la robotique”, dialog with JG Ganascia and M Doueihi at the Artificial Intelligence and Society seminar at College des Bernardins, Paris, oct. 2015.
- F. Stulp, Robot Skill Learning: Back to the Future, 22.10.2015, Josef Stefan Institute, Ljubljana, Slovenia.
- F. Stulp, Many regression algorithms, one unified model - A tutorial”, 23.10.2015, Josef Stefan Institute, Ljubljana, Slovenia
- A.-L. Vollmer, Teaching, a bidirectional process: Evidence from adult-child and human-robot interaction, 09.09.2015, Tenth International School on Mind, Brain and Education, Ettore Majorana Foundation, Erice, Italy.
- M. Lopes, Interactive Learning for Cooperative Human-Robot Tasks, Algorithms for Human Robot Interaction Workshop, University of Berkeley, USA
- M. Lopes, Exploration Biases for Task Learning In Machines and Animals, Redwood Center for Theoretical Neuroscience, USA
- W. Schueller, Active Learning and Active Control of Complexity Growth in Naming Games, Complexity & Quantitative Linguistics Lab, Universitat Politècnica de Catalunya, Barcelona, Spain
- Boussoles du numérique (october 2015), Didier Roy, Stéphanie Noirpoudre, Thibault Desprez
- Assises nationales de la médiation numérique (novembre 2014), Didier Roy, Pierre-Yves Oudeyer
- Escales de l’éducation (ligue de l’enseignement) (september 2015), Didier Roy
- Symposium Scratch Amsterdam (août 2015) : presentation of Snap! programming
- Cap Sciences (several events during the year), Didier Roy
- Forum EIDOS 64 Pau : talks about educational robotics, Didier Roy

10.1.5. Leadership within the scientific community

PY Oudeyer has been Chair of IEEE CIS Autonomous Mental Development Technical Committee, and leaded its transformation into the IEEE CIS Cognitive and Developmental Systems Technical Committee.

Through his role of editor-in-chief of the IEEE CIS Newsletter on Cognitive and Developmental Systems, PY Oudeyer contributed to strengthn the interdisciplinary exchanges among developmental sciences, and in particular organized two interdisciplinary dialogs on key scientific issues: http://icdl-epirob.org/cdsnl.

10.1.6. Scientific expertise

- PY Oudeyer was expert for the EU Commission scientific programme.
- PY Oudeyer was expert for the OPECST office at Assemblée Nationale, about the role and evolution of robotics within society.
- PY Oudeyer was an expert for the Cherry Project, IPB, Bordeaux.

10.2. Teaching - Supervision - Juries

10.2.1. Teaching

Freek Stulp is responsible for the coordination of the 5 first year computer science courses at ENSTA-ParisTech (140 students per year). He organized, gave lectures and was a tutor in the courses “IN101: Algorithmics and Programming (in Python)” and “IN104: Computer Science Project” (140 students each). He was a tutor in the course “IN102: Algorithms and Systems (in C)”. With Michele Sebag he organized the course “Reinforcement Learning” (20 students) as part of the M2 “Machine Learning, Information and Content” at the Université Paris Saclay.

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

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

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 and diffusion of IniRobot pedagogical kit (see highlights), Didier Roy, Thomas Guitard et Pierre-Yves Oudeyer

Licence, Master: Seminar Developmental Robotics, 21 heures, Bielefeld University, Germany (Anna-Lisa Vollmer)

Master: Robotique Développementale, 3 hours, CogMaster, http://sapience.dec.ens.fr/cogmaster/www/e_01_portail.php (PY Oudeyer)

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

Design of the conceptual framework and educational objectives of the Poppy Education courses to be finalized in 2016 (PY Oudeyer and D Roy)

Master: Robotique et Desig, 2 hours Master Design, Univ. Bordeaux.

Teaching at EPFL (3 interventions per year, 2 days each), Didier Roy

Teachers training for ESPE Aquitaine (1 day), teachers training of partner schools for Poppy Education, Didier Roy

Training facilitators TAP Pessac (3h), Talence (3h), CapSciences (3h), Petits débrouillards (3h), Didier Roy

Teacher trainings and education consultants DSDEN : 2015, 24 participants, Didier Roy

10.2.2. Supervision

HdR : Manuel Lopes, Autonomous Learning in Intelligent Agents and Robots, University of Bordeaux, September 2015

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: 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: Adrien Matricon : Task dependent visual feature selection for optimising and generalizing robotics skills (superv. David Filliat, Pierre-Yves Oudeyer, and Freek Stulp).

PhD in progress: Clement Masson, Unsupervised learning of sensori-motor representations, started Oct. 2015 (superv. David Filliat, Olivier Sigaud and Freek Stulp).

PhD in progress: José Magno Mendes Filho, Planning and control of an autonomous AGV in environment shared with humans, started Oct. 2015 (superv. David Filliat and Eric Lucet (CEA))

PhD in progress: Joris Guery, Domain adaptation for visual object recognition, started Oct. 2014 (superv. David Filliat and Bertrand Le Saulx (ONERA))

PhD in progress: Benjamin Clement, Intelligent Tutoring Systems, started oct 2015 (superv. Manuel Lopes and Pierre-Yves Oudeyer).

PhD in progress: Thibaut Munzer, Learning from Instruction, started oct 2013 (superv. Manuel Lopes).

PhD in progress: Baptiste Busch, Interactive Learning, started oct 2014 (superv. Manuel Lopes).

PhD in progress: Alexandra Delmas, Auto-Apprentissage Auto-Adaptable pour la compliance au traitement, started oct 2014 (superv. Manuel Lopes).

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

10.2.3. Juries

Ben-Manson Toussaint, Modeling Perceptual-Gestural Knowledge for Intelligent Tutoring Systems, supervised by Vanda Luengo, University of Grenoble, France

Emanuel Sousa, Emergence de Concepts Multimodaux, supervised by Estela Bicho, and Wolfram Erlhagen, University of Minho, Portugal

Antoine Cully (21/12/15, David Filliat, Rapporteur) : Creative Adaptation through Learning

Elena Stumm (23/11/2015, David Filliat, Rapporteur) : Location Models For Visual Place Recognition

Alexandre Ravet (13/10/15, David Filliat, Examinateur) : Introducing Contextual Awarness within the State Estimation Process

Cédric Le Barz (30/06/15, David Filliat, Rapporteur) : Navigation visuelle pour la navigation autonome des petits drones

Romain Drouilly (29/06/15, David Filliat, Rapporteur) : Cartographie hybride métrique topologique et sémantique pour la navigation dans de grands environnements

Erwan Birem (12/03/2015, David Filliat, Rapporteur) : Localisation et détection de fermeture de boucle basées sur la saillance visuelle : algorithmes et architectures matérielles

Alain Droniou (09/03/2015, David Filliat, Examinateur) : Apprentissage de représentations et robotique développementale : quelques apports de l’apprentissage profond pour la robotique autonome.

PY Oudeyer was in the PhD jury of Alain Droniou (Univ. Paris VI, France, reviewer), Adam White (Univ. Alberta, Canada, reviewer), Vieri Santucci (Univ. Plymouth, UK, reviewer), Didier Roy (Univ. Bordeaux, examiner), Renaud Gervais (Univ. Bordeaux, examiner).

PY Oudeyer was in the HdR jury of Julien Diard (Univ. Grenole, reviewer), Jean-Baptiste Mouret (Univ. Paris, reviewer), Manuel Lopes (Univ. Bordeaux).

10.3. 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. It is now used by more than **7000** primary school children. 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

The Flowers team was a partner of several art/science projects studying various dimensions of the role and evolution of robots and society, and in particular

- The Comacina project exploring the role of movements and light in expressing emotions: http://comacina.org. This project was implemented through several residencies during the year, and several performances at various cultural places in Aquitaine, including at Pole Evasion in Ambares-et-Lagrave. a report is available at https://flowers.inria.fr/RencontreAutourDuGeste.pdf. It benefitted from funding from the Art/Science Idex call for project.
- The Marionnettes Electriques project studies animation techniques allowing to express fast and rich interaction in real-time on the stage. Various realizations can be seen from https://www.poppy-project.org/project/marionnettes-electriques/.
- The School of Moon project, from the Shonen dance company (headed by Eric Minh Cuong Castaing), is working on the design of a dance show about robots and posthumanity. It is using multiple robots, including the Poppy Humanoid robot in dynamic physical interaction with dancers. The premiere will happen in january 2016 at Ballet de Marseille. Web site: http://shonen.info/schoolofmoon/.

PY Oudeyer published a milestone popular science book together with astrophysicists Jean Audouze, biologist Georges Chapouthier, architect Denis Laming, on the common threads related to the origins of complexity at different scales in the universe. The tile is “Mondes Mosaiques, Astres, Villes, Vivant et Robots”.

PY Oudeyer wrote a popular science article about developmental robotics in “Pour la Science” (the french version of Scientific American), entitled: “L’éveil des bébés robots”, available here: http://www.pyoudeyer.com/eveilRobotsPourLaScienceOudeyer15.pdf

PY Oudeyer gave several interviews in the general press and at radio and TV programs (e.g. Le Monde, Les Echos, Sciences et Avenir, RFI, Nova/PBS, Arte) to explain societal issues of robotics, http://www.pyoudeyer.com/press/

January 29, 2015: Pierre Rouanet, Matthieu Lapeyre and Nicolas Rabault presented the Poppy Project in the TTFX conference in Bordeaux.

Robots Makers’day (january) : First Lego League, Poppy and Thymio workshops

January 31, 2015: Aquitec 2015, Yoan Mollard presented the Poppy platform to students and visitors

February 11, 2015: Benjamin Clément, Manuel Lopes, Pierre Rouanet, and Pierre-Yves Oudeyer were invited to present the Kidlearn and Poppy projects to the French senate in Paris.

May 28 to 29, 2015: William Schueller, Baptiste Busch and Yoan Mollard participated to the jury of students option "Informatique et Sciences du numérique", Lycée Saint Genes, Bordeaux

June 03 to 06, 2015: Didier Roy, Sébastien Forestier and William Schueller participated to the event "Science and You" in Nancy, by presenting Poppy and Inirobot projects.

June 13, 2015: Thibault Desprez, Antoine Darfeuil, Amandine Spriet, Theo Segonds and Pierre Rouanet participated to the Robot Makers Day where they organized a half day workshop on how to program Poppy Torso in Bordeaux.

August 08, 2015 : David Filliat gave a Talk at "Festival de Fleurance", a science festival in Fleurance (south of France) : Les robots, bientot nos egaux ?

August 11-14, 2015: Theo Segonds and Pierre Rouanet were invited to present their work on the connection between Snap and Poppy robots to the 2015 Scratch conference in Amsterdam.

August 25, 2015 : David Filliat gave a Talk at "Rencontre enseignant-entreprises" at Ecole Polytechnique : Remplacer les hommes par les robots :jusqu'ou ira-t-on ?

September 28 to October 2, 2015: Baptiste Busch, Yoan Mollard, and other participants of the 3rd hand consortium presented the project on a booth among other EU projects at the IROS conference, Hamburg, Germany

October 13, 2015: Rencontre Inria Industrie: Baptiste Busch, Benjamin Clément and Alexandra Delmas presented respectively the projects 3rdHand, KidLearn and 5APC on a booth, Bordeaux

October, 16, 2015: Pierre Rouanet and Yoan Mollard presented the Poppy robots to the Bdx I/O Conference in Bordeaux.

October 20 to 22, 2015: Baptiste Busch, Pierre Rouanet, Yoan Mollard and Manuel Lopes showcased 3rd hand and Poppy robots to the ICT Forum in Lisbon, Portugal

November 16, 2015: Yoan Mollard gave a talk to the ESAC Alumni meeting 2015 about the 3rd hand project, European Space Agency, Madrid, Spain

October, 5, 2015: Nicolas Rabault presented the Poppy platform at the developer day from orange lab, Bordeaux.

March, 30 to 31, 2015: Nicolas Rabault presented "what is robotics" to primary school children for the "Festival jeune public du documentaire scientifique"

May, 29 to 30, 2015 : Matthieu Lapeyre and Nicolas Rabault : participated to the "open bidouille camp", Aix en Provence

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