Pierre-Yves Oudeyer
46 years old
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Short summary: I contributed to create and grow the scientific field of **developmental AI**, at the crossroads of artificial intelligence and cognitive sciences. In particular, together with my colleagues, and the interdisciplinary teams I created at Sony CSL and Inria/University of Bordeaux (Flowers), we pioneered concepts and algorithms of **curiosity-driven learning** in real world robots. We developed the framework of **autotelic deep reinforcement learning**, where agents learn diverse skills in an open-ended manner by learning to generate, sample and pursue their own goals. We recently showed how to leverage **large language models as cognitive tools in creative curiosity-driven exploration**, and vice versa **ground LLMs** by using them as agents that learn to solve tasks through interaction with an external environment. In cognitive sciences, we proposed a **new theory for understanding curiosity-driven learning in humans (the Learning Progress Hypothesis)**, as well as its links with language acquisition and evolution. In this context, I contributed to create and grow an international interdisciplinary community focused on scientific understanding of curiosity, e.g. through co-organizing the Neurocuriosity symposium series. We worked on several impactful applications in fields ranging from personalized educational technologies, automated scientific discovery, or adaptive human-machine interfaces. These works were translated in **large-scale real world applications**, e.g. **adaptive personalization algorithms are now used in EdTech software deployed in > 70000 classrooms in France** (e.g. AdaptivMaths, MIA Seconde), open-source educational robotic kits we developed have been used by > 30000 students and formed the basis of a startup and a large-scale NGO, speech synthesis algorithms were used in Playstation video games, and curiosity-driven learning algorithms were used in Sony entertainment robots.

Domains: developmental artificial intelligence, machine learning, cognitive sciences, educational technologies, curiosity, intrinsic motivation, language, open-ended learning
Google Scholar: https://scholar.google.com/citations?user=gCqGj4sAAAAJ&hl=en

Professional experience

2012-present : **Research director, Inria** (DR1), Head of Flowers Lab (Inria, Univ. Bordeaux and Ensta ParisTech, 25 persons with 4 senior researchers)
2016-present: Consulting in machine learning and AI (currently with EvidenceB company)
2021-22: Research visitor at Microsoft Research Montreal
2008-2012 : **Research scientist, Inria** (CR1), Founder and head of Flowers Lab.
2003-2007 : **Senior researcher at Sony Computer Science Lab.**, Paris.

Community building

I played a key role in building the developmental robotics community at the European and International level in the early 2000s. In particular, after being general chair of several Epigenetic Robotics conference (gathering the European developmental robotics community), I co-steered the merger of the Epirob and ICDL developmental robotics communities and conferences into one community gathering at the new IEEE ICDL conference series, and associated to journal IEEE Transactions on Cognitive Developmental Systems. I then became chair of the IEEE CIS technical committee on Cognitive Developmental Systems, coordinating this community, including the conference and the journal

I played a key role in creating and growing an international interdisicplinary community on the science of curiosity, studying curiosity from AI, cognitive science and neuroscience perspectives, e.g. co-organizing with J. Gottlieb the Neurocuriosity conference series, in 2014 (Bordeaux), 2016 (London), 2018 (Philadelphia), 2023 (New-York). I am also co-organizer of the interdisciplinary symposium Life, Structure and Cognition (IHES, Paris)

Collective responsibilities

2008-present : **Associate editor of** IEEE Transactions on CDS, Frontiers in Neurorobotics
2008-2018 : **Editor-in-chief of** IEEE CIS Newsletter on Cognitive and Developmental Systems (for 10 years, I organized twice a year an interdisciplinary dialog on developmental and learning at the crossroads of AI, neuroscience, psychology, linguistics)
2015-2016 : **Chair of** IEEE Technical Committee on Cognitive and Developmental Systems (Comput. Intelligence Society), prev. co-steered the merger of the Epirob and ICDL developmental robotics communities and conferences into one community gathering at the new IEEE ICDL conference series.

2008-present : **Supervision of 25 PhD thesis**
2006-present : **co-chair/organisation/steering committee of international conferences** (co-org. ICML Workshop on Interactive Learning with Implicit Feedback 2023 // co-chair. Curiosity, Complexity and Creativity Symposium, NY, 2023 // co-org. Daghsuhl seminar on developmental learning, 22 // steering committee of Life, Structure and Cognition seminar, IHES, Paris 2022, 2023 // Inria workshop on Archaelogy and AI, 2022 // co-org. workshop on Exploration in RL at ICML 19 // co-chair of conference on Curiosity : Emerging Sciences and Educational Innovations, Univ. Pennsylvania, 2018 // co-general chair of conference on Intrinsically Motivated Open-Ended Learning, IMOL (Roma), 2017 // co-general chair, Designing for curiosity workshop at CHI 2017 // co-general chair of the series of Neurocuriosity Symposia 2014 (Bordeaux), 2016 (London) // Workshop chair IJCNN 2015 // steering committee of fOSSA conference // Program Chair Epigenetic Robotics conference, Venice, 09 // General chair Epigenetic Robotics Conference, Paris, 06).

Education
2011 : **Habilitation to direct research**, Université de Bordeaux, France
2003 : **PhD doctoral thesis (AI and cog. sci.)**, Univ. Paris VI, with honours of the jury (dec. 2003).
1997-2000 : **Master in theoretical computer science**, ENS Lyon, France.

Distinctions and awards
2023: co-author of Best Paper Award at the Alife conference
2019-25: **ANR Chaire IA individuelle** "DeepCuriosity"
2019 : Distinguished lecturer of the IEEE Computational Intelligence Society
2021: finalist of the 2021 Roberval prize, for the popular science book for children I co-wrote with D. Roy
2019: Excellence in science prize (PES), Inria
2018 : Prize Inria of National Academy of Science (in computer science, researcher under 40)
2017: 29th Eleanor J. Gibson and James J. Gibson Lecturer, by Cornell University, US.
2016: Lifetime Achievement Award, awarded by the Evolutionary Linguistics Association
2015 : Excellence in science prize (PES), Inria
2014: Global Fab Award Finalist (for Poppy Project), at international conference Fab 10
2014: **Finalist of prize Tangente for best books in popular science** (for my book "Aux sources de la parole", Odile Jacob, 2013.
2011: IEEE ICDL-Epirob Second Best Student Paper award (with M. Nguyen and A. Baranes as student authors), awarded by ICDL-Epirob Conference.
2009: ERC Starting Grant EXPLORERS, awarded by the European Research Council. (was awarded with grade 7.2/8).
2009: IEEE ICDL Best student paper award (with T. Schatz as student author), awarded by ICDL Conference and sponsored by the Cognitive Science Society.
2005: Implemented Invention Award (4th prize, with F. Kaplan), awarded by Sony Corporation for our US patent No. 6760645 "Taming robots with clicker training".
2005: Prize "ASTI 2005" for the best pluridisciplinary 2003-2004 PhD thesis in the sciences and technologies of information and communication in France, awarded by the "Association des Sciences et Techniques de l'Information et de la Communication (ASTI)".
2005: Prize "Le Monde de la recherche universitaire", which honours every year the 15 best PhD theses in French in all exact scientific domains, awarded by journal "Le Monde".
2001: "Best application paper", awarded at Int. Conf. on Artificial Evolution, 2001.
2000: Best paper award in Sony Technical Forum 2000, which is the yearly worldwide conference that gathers the engineers of Sony Corporation
Several of PY Oudeyer's PhD students obtained PhD awards : C. Colas (Best French AI PhD 2022, Afia; 2nd place ERCIM Cor-Bayen prize 2022) J. Grizou (prix Le Monde de la recherche universitaire), M. Lapeyre (CNRS GdR robotics), T. Cederborg (Region Aquitaine prize).

Publications: 72 international journals, 4 books (co-author), 3 conf. proceedings (editor), 17 book chapters, 117 articles in international conferences, 24 newsletters articles/editorials.
https://scholar.google.com/citations?user=gCqGj4sAAAAJ&hl=en Citations (Google schol. 2023) : 14365, h-index : 58

Keynote speeches at international conferences/workshops: Intrinsically Motivated and Open-Ended Learning 2023, Paris; Vision Science Society conference Japan, 2022; Ecological Theory in RL workshop at Neurips 2021; Deep Reinforcement Learning Workshop at Neurips 2020, EGC 2020, ***International Conference on Learning Representations (ICLR 2019***), ACM IVA 2019, WMLAI 2019, ReWork Deep Learning Summit 2019, ICIS 2016, Evostar 2015, BICA 2015, Devoxx 2015, AAAI Spring Symposium 2014, WACAI 2014, AAAI Fall Symposium 2013, AAMAS 2011, IEEE Alife 2011, Robolift 2011, Epirob 2009, Interspeech 2007.

Selected publications (see below for full list):

Carta, T., Romac, C., Wolf, T., Lamprier, S., Sigaud, O., & Oudeyer, P. Y. (2023). Grounding large language models in interactive environments with online reinforcement learning. ***ICML*** 2023.
Forestier, S., Portelas, R., Mollard, Y., & Oudeyer, P. Y. (2022). Intrinsically motivated goal exploration processes with automatic curriculum learning. ***Journal of Machine Learning Research.***
Colas, C., Karch, T., Lair, N., Dussoux, J. M., Moulin-Frier, C., Dominey, P., & Oudeyer, P. Y. (2020). Language as a Cognitive Tool to Imagine Goals in Curiosity Driven Exploration. *Advances in Neural Information Processing Systems (**Neurips 2020**), 33.*
Colas, C., Fournier, P., & Chetouani, M., Sigaud, O., Oudeyer, P. Y., (2019). CURIOUS: Intrinsically Motivated Modular Multi-Goal Reinforcement Learning. In International Conference on Machine Learning (***ICML 2019***).
Baranes, A., Oudeyer, P-Y. (2013) Active Learning of Inverse Models with Intrinsically Motivated Goal Exploration in Robots, ***Robotics and Autonomous Systems***, 61(1), pp. 49-73.
Gottlieb, J. and Oudeyer, P-Y. (2018) Towards a Neuroscience of Active Sampling and Curiosity, ***Nature Reviews Neuroscience,*** 19(12), 758-770.
Oudeyer, P-Y. and Smith. L. (2016) How Evolution may work through Curiosity-driven Developmental Process , ***Topics in Cognitive Science, 1-11.***
Ten, A., Kaushik, P., Oudeyer, P. Y., & Gottlieb, J. (2021). Humans monitor learning progress in curiosity-driven exploration. ***Nature communications***, *12*(1), 5972.

Technology transfer work and societal impact: 11 international patents (4 exploited commercially): http ://www.pyoudeyer.com/patents/
2018-present: Coordination of transfer of curiosity-based personalization algorithms for educational apps to edTech consortium of companies.
2014-2018: Coordination of team who developed **large-scale open-source educational robotics** projects, including Poppy Education kits (http://www.poppy-education.org) and the Inirobot project disseminated to > 25 000 schoolchildren in France, integrated in Main à la Pâte program ; https://goo.gl/u31gYE. This lead to the creation of Poppy Station (**non-governmental association**, http://poppy-station.org) and Pollen Robotics (**start-up company**, https://www.pollen-robotics.com) for large scale dissemination.
2013-present: Head of the team who designed, developed and disseminated the Poppy Platform (http://www.poppy-project.org and) which is the **first complete open-source 3D printed humanoid platform in the world**, for education, science and art. Poppy has been presented in highly visible and prestigious wide audience venues (François Hollande at Elysée, Axelle Lemaire in Bordeaux, Sénat, Le Web conference, Tedx Cannes), in numerous high quality media/press articles (full pages in Le Monde, Les Echos, Libération, interviews on France Inter, France Info as well as in international press such as Scientific American, El Mundo, japanese TV, https://www.poppy-project.org/in-the-press/). It was featured in the report of "Stratégie Nationale de Recherche France 2020".

Expertise, reviewing and recruitment juries

2018-present: **Expert and reviewer** for ERC (starting grants, consolidator grants), EU ITN projects, EU Marie Curie projects, EU Pathfinder projects, EU FET projects, ANR, Schmidt Futures, Bi-national US/Israel Foundation, University of Bordeaux (jury of the docIA PhD grants), University of Strasbourg (Idex project proposal), University of Grenoble (PhD grant); Leverhulme Trust UK; Fondation des Sciences du Patrimoine ; auditions at French Senate/OPCST.

2018-present: Reviewer for top **journals in AI** (e.g. JAIR, Speech Communications, IEEE TCDS) and **cognitive/interdisciplinary sciences** (e.g. Nature Scientific Reports, Child Development, Trends in Cognitive Science, Cognitive Science, Frontiers in Psychology, Journal of the Royal Society Interface, Motivation and Emotion), **top AI conferences** (ICLR, ICML, Neurips, AAAI); Associated editor of Frontiers in Neurorobotics and Frontiers in Robotics and AI. Previously associate editor of IEEE Transactions on Cognitive and Developmental Systems.

2005-2018: Reviewer for international journals IEEE T-RO, IEEE Transactions on TAMD/TCDS, Frontiers in Neurorobotics, International Journal of Social Robotics, International Journal on Humanoid Robotics, Autonomous Robots, Speech Communication, Journal of Phonetics, IEEE Transactions on Audio, Speech and Language Processing, IEEE Transactions on Evolutionary Computation, IEEE Transactions on Circuits and Systems (TCAS-2), Neural Networks, Connection Science, Artificial Intelligence Journal, Artificial Life, Adaptive Behavior, International Journal of Humanoid Robotics, Infancy, Interaction Studies, Cognitive Science journal, Journal of Infant Behavior and Development, Frontiers in Cognitive Science.

2020-21: Member of **jury of the Inria CR1 and CRCN** competition

2020-2021: Member of « comité de pilotage » of the Adaptiv'Maths project, and eFRAN project Perseverons in the domain

of educational technologies

2020: Participation to the elaboration and writing of Inria's contribution to PEPR Education et Numérique

2015-2018: Expert for Main à la Pâte for the textbook project "1, 2, 3: Codez!" to teach computer science in primary schools.

2005-present**: Regular expert and reviewer for European Commission** FP6, FP7 and H2020 ICT and FET programs (selection of projects to be funded and yearly reviews of funded projects in robotics, machine learning, language processing, assistive technologies).

2008-2015: **Expert for the ANR** (French national research agency) for robot-related projects.

2016: Member of Gdr CNRS Robotique jury for the best robotics PhD thesis

2015-2016: Scientic expert for the pedagogical program "1,2,3 codez" (primary school) from Main à la Pâte.

2015: Expert for OPCST on ethical dimensions of digital technologies

Teaching:

2018-present: Teaching introductory courses to Developmental AI at CogMaster (Paris), Option IA and Option Robots at Enseirb-Matmeca (Bordeaux), Numerics seminar of the graduate program of University of Bordeaux.
2016: Univ. Mons, Belgium, course in developmental and cognitive robotics, 4 hours/year.
2015-2016: Master in Cognitive Sciences, Univ. Bordeaux (Master 2), courses in developmental and cognitive robotics (12 hours/year)
2015-2016: ENS Rennes (1st year), courses in developmental and cognitive robotics (12 hours/year)
2013-2016: ENSEIRB/ENSC option robots (3rd year), Courses in developmental robotics at, 3 hours/year.
2013-2016: CogMaster (ENS, EHESS, Univ. Paris Descartes)Courses in developmental robotics within, 3 hours/year
2006 – 2010: Ensta-ParisTech, Paris, 3rd year engineering diploma, "Concepts and Algorithms for Social and Entertainment Robots" (creation of the first course in developmental and social robotics in France, one of the first in Europe), 24.5 hours/year.
2008 –2009: Irrcyn, Nantes, EMARO European Master on Advanced Robotics, "Social and developmental robotics", 15 hours/year.
2008: Institut de Cognitique, Bordeaux, "Social robotics", Master M1 "Sciences Cognitives", 15 hours.
2005: ENS/EHESS/Univ. Paris Descartes, "Computational models of language origins", 5 hours.
2004-2007: ENSEA, Cergy-Pontoise, "Computational Cognitive Modeling", 3rd year engineering students, 6 hours/year.

Current funding: Academic grants: Inria, Région Nouvelle-Aquitaine, French National Research Agency. Industrial grants: HuggingFace, Microsoft Research, Poietis, evidenceB.

PhD students supervision:

A major part of my job focuses in (co-)supervising and working with PhD students. I have been organizing a way of working in the team that involves setting up dynamic collaborations among them (in groups that evolve along their PhD paths, so that each PhD has a unique research path), as well as fostering opportunities for them to collaborate with other labs in the world (including international research visits). This is particularly important given the interdisciplinarity of the team (with people and topics ranging from machine learning, developmental AI, developmental psychology, educational technology, assisted scientific discovery).

To achieve this, I use various tools to set up an open science approach within and beyond the team, enabling everyone to understand and potentially help what others do. In particular, I have across the years introduced open lab notebooks as a tool and general approach to organize this open science culture, which I have summarized in the following document:

Oudeyer, PY (2022) **Open Lab Notebooks as Tools for Thinking and Communicating in Science Teams**
http://pyoudeyer.com/openLabNotebooks22.pdf

I would like to highlight that **Cédric Colas** (co-supervised with Olivier Sigaud, Sorbonne Université) was awarded the 2nd place for the ERCIM Best PhD Award in AI at European Level
https://www.ercim.eu/news/517-fabio-carrara-is-the-winner-of-the-2022-ercim-cor-baayen-young-researcher-award and

Best PhD Thesis in France (2022) from the French Association for AI (AFIA)
https://afia.asso.fr/les-prix-de-these-en-intelligence-artificielle/. Furthermore, **Rémy Portelas** (co-supervised with Katja Hofmann, Microsoft Research Cambridge) was awarded the Best PhD prize 2023 **(special International Prize across all disciplines) from University of Bordeaux:** https://ed-mi.u-bordeaux.fr/Actualites/Prix-de-these-2023

Previously, Jonathan Grizou won the prize "Le Monde de la recherche universitaire" 2015 for his PhD (co-supervised with M. Lopes), Matthieu Lapeyre, 2nd prize for the best PhD thesis in robotics 2015, by GdR Robotique/CNRS, Olivier Mangin, Best PhD poster 2014 (Bordeaux doctoral school of mathematics and computer science), Thomas Cederborg won the Best PhD award in Region Aquitaine 2014, awarded at NOVAQT science and technology festival.

Julien Pourcel (2023-starting), **supervision**: 50% (wth C. Moulin-Frier@Inria, 50%); **Topic**: Autotelic large language models that learn how to code (associated with the Inria Défi LLM4Code).

Chloë Devaux (2023-starting), **supervision**: 50% (wth H. Sauzéon@Inria, 50%); **Topic**: Educational technologies for training meta-cognition in children and field evaluation in primary schools

Clément Romac (2021-present), **supervision** : 50% (wth Thomas Wolf@HuggingFace, 50%); **Contribs:** Grounding large language models with online reinforcement learning. **Web**: https://clementromac.github.io
Key publications: ICML 21, ICML 23

Grgur Kovac (2022-present), **supervision** : 50% (wth Peter Ford Dominey@Inserm); **Contribs**: Development of social skills in autotelic agents and large language models; **Web**:
https://scholar.google.com/citations?user=ZLA7iioAAAAJ&hl=en **Key publications**: IEEE TCDS and Theory of mind workshop at ICML 23.

Thomas Carta (2021-present), **supervision**: 50% (wth O. Sigaud@Sorbonne Univ. and S. Lamprier@Univ. Angers, 25% each); **Contribs**: Language-guided deep reinforcement learning; **Web**:
https://scholar.google.com/citations?user=-Vi3OBsAAAAJ&hl=fr **Key publications**: Neurips 2022 and ICML 2023)

Rania Abldelghani (2021-present), **supervision**: 50% (wth H. Sauzéon@Inria and C. Vulpuillères@evidenceB); **Contribs**: Educational technologies that foster curiosity-driven learning and meta-cognition in primary school children; **Web**:
https://scholar.google.com/citations?user=L5WCl5MAAAAJ&hl=fr
Key publications: IJAIED 2023, IJHCS 2022, ACM IDC 2023)

Maxime Adolphe (2021-present), **supervision**: 50% (wth H. Sauzeon@Inria and A. Delmas@OnePoint); **Contrib**.: Personalization of attention training system using machine learning, evaluation on adults/elderly people; **Web**:
https://scholar.google.com/citations?user=QLtZ3cAAAAAJ&hl=en **Key publications**: Frontiers Psychology 2022

Laetitia Teodorescu (2020-2023), **supervision**: 50% (wth K. Hoffmann@Microsoft Research Cambridge); **Contribs**.: Transformers and relational architectures for autotelic language agents; **Key publications**: Neurips 2021; Collas 2023; Frontiers in AI 2022
Co-organizer of the Language in Reinforcement Learning (Larel) workshop at Neurips 2022 (https://larel-workshop.github.io) and Intrinsically Motivated Learning workshop at Neurips 2023 (https://imol-workshop.github.io)

Mayalen Etcheverry (2020-2023), supervision: 50% (C. Moulin-Frier, 50%); **Contribs.**: Assisted scientific discovery with curiosity-driven AI. **Web**: https://mayalenetcheverry.com;
Key publications: Neurips 2020 (oral presentation); Alife 2022 (Best paper award); ICLR 2019 (oral presentation)
Co-organizer of the workshop on open-endedness in learning agents at Neurips 2023
https://sites.google.com/view/aloe2023/home

Tristan Karch (2019-2022), supervision: 50% (wth C. Moulin-Frier@Inria, 50%); Topic: Language learning and self-organization in autotelic agents; Web: https://tristankarch.com
Key Publications: Nature Machine Intelligence 2023; ICLR 2022; Neurips 2021; Neurips 2020
Co-organizer of the Language in Reinforcement Learning (Larel) workshop at Neurips 2022 (https://larel-workshop.github.io)
PhD manuscript: https://tristankarch.com/

Rémy Portelas (2018-2022)**, supervision:** 50% (K. Hoffmann@Microsoft Research, 50%); **Topic**: active teacher algorithms with adaptive procedural generation of sequences of environments for driving curiosity-driven learning agents. **Web**: https://scholar.google.com/citations?user=8xxuvpoAAAAJ&hl=en (currently research engineer at Ubisoft);
Key Publications: JMLR 2022; IJCAI 2020; CorL 2020; ICML 2021
PhD manuscript: https://www.theses.fr/2022BORD0038
Awards
- Best PhD Prize (special International Prize across all disciplines) from University of Bordeaux:
https://ed-mi.u-bordeaux.fr/Actualites/Prix-de-these-2023

Cédric Colas (2017-2021, now postdoc at MIT with Josh Tenenbaum in the context of a Marie Curie grant in collaboration with Flowers Lab)**, supervision:** 50% (O. Sigaud, ISIR, 50%); **Contrib.:** Algorithms for multi-task multi-goal intrinsically motivated deep reinforcement learning **Web**: https://scholar.google.fr/citations?user=VBz8gZ4AAAAJ&hl=fr (currently postdoc at MIT)
Key publications: ICML 2019; Neurips 2020; JAIR 2020; JAIR 2021; ICLR 2021; Nature Machine Intelligence 2023; Collas 2023; ICML 2023
Co-organizer of the Language in Reinforcement Learning (Larel) workshop at Neurips 2022 (https://larel-workshop.github.io) and Intrinsically Motivated Learning workshop at Neurips 2023 (https://imol-workshop.github.io)
PhD manuscript: https://ccolas.github.io/data/cedric_colas_manuscript.pdf
Awards:
- 2nd place for the ERCIM Best PhD Award in AI at European Level
https://www.ercim.eu/news/517-fabio-carrara-is-the-winner-of-the-2022-ercim-cor-baayen-young-researcher-award
- **Best PhD Thesis in France (2022) from the French Association for AI (AFIA)**
https://afia.asso.fr/les-prix-de-these-en-intelligence-artificielle/

Alexander Ten (2018-2021), **supervision**: 50% (J. Gottlieb, Univ. Columbia, 50%); **Topic.**: Computational models of active multi-task exploration in humans. **Key publications**: Nature Communications 2021;
PhD manuscript: https://www.theses.fr/2022BORD0152 (currently postdoc at Univ. Tubingen)

Sebastien Forestier (2016-2019), **supervision**: 100%; **Topic**: Intrinsically motivated goal exploration in open-ended learning robots; **Web**: https://forest.bio **Key publications**: JMLR 2022; ICLR 2018; CogSci 2017
PhD manuscript: https://forest.bio/thesis.pdf (currently head and founder of Massa Labs startup).

Florian Golemo (2015-2018), **supervision**: 50% (A. Courville, MILA/Montreal, 50%); **Contrib**.: algorithms for sim-2-real transfer using policy learning and neural-augmented simulator (CoRL 18) + design of several novel benchmark environments for reinforcement learning; **Web**: https://scholar.google.de/citations?user=qvRf9xsAAAAJ&hl=en

Thibault Desprez (2015-2018), **supervision**: 100%; **Contribs.**; design and study of pedagogical activities for learning computer science concets in high-school using Poppy Ergo Jr platform + large scale experimentation in > 15 high-schools in Aquitaine. Web: https://www.poppy-education.org/

William Schueller (2015-2018), **supervision**: 70% (V. Loreto 30%); **Contrib.**: Computational and mathematical study of the impact of active learning and active teaching algorithms in controlling the growth of complexity in models of the formation of linguistic conventions. Web : http://wschuell.github.io

Benjamin Clément (2015-2018), **supervision**: 70% (M. Lopes: 30%); **Contrib.**: **Kidlearn project**, design of machine learning algorithms for personalizing sequences of pedagogical activities in educational software + large-scale experimentation (> 1000 children in primary schools) + ongoing transfer to ITWell and Nathan companies, https://flowers.inria.fr/research/kidlearn/ Current position: chief AI engineer at EvidenceB company

Alexandra Delmas (2015-2018), supervision : 50% (H. Sauzéon 50%) ; **Contrib** : combination of participative design and machine learning in the design of an e-learning system enabling children with chronic diseases to understand better their illness and be more motivated to comply with treatment ; see https://www.frontiersin.org/articles/10.3389/feduc.2018.00099/full). Current position: researcher at Onepoint company.

Didier Roy (2015, thèse sur travaux, CNAM) **co-supervision**: 70% myself, 30% M. Lopes; Contributions: Development and evaluation of techniques for adaptive personalization of exercises in intelligent tutoring systems; Development and evaluation of educational robotic kits (Inirobot, disseminated to more than 8000 children in French primary schools, now integrated in the national program “1,2,3 Codez” of Main à la pâte.

Jonathan Grizou (2012-2014, coming from INSA Lyon), **co-supervision**: 50% Manuel Lopes, 50% **myself**; Contributions: development and study of a new family of algorithms allowing to infer the meaning of human guidance signals in an unsupervised manner; Application to the design and evaluation of one of the first calibration-free brain-computer interface systems. Won prize "Le Monde de la recherché universitaire" for his PhD thesis. Web: http://jgrizou.com **Current position**: assistant professor at Univ. Glasgow, Scotland.

Matthieu Lapeyre (2010-2014, coming from ENS Cachan, Master in Mechanics) **co-supervision**: 80% myself, 20% Olivier Ly; **Contributions**: **Designed the first worldwide open-source 3D printed humanoid robot, and developed applications in science, education and art:** http://www.poppy-project.org**.** Studies of the role of morphological and maturational constraints in learning humanoid dynamic biped locomotion; Morphology of vertebral column; Elaboration of several new cost function, evolving through maturational constraints, and integrated in a multi-objective optimization framework; Experimentation with the Acroban humanoid robot and design of new versions.
2nd Best PhD thesis in Robotics, GdR CNRS Robotique (national prize for PhD theses in robotics in France). **Current position**: co-creator of the startup company Pollen Robotics (spin-off from the Flowers team).

Fabien Benureau (2011-2014, coming from ENS Lyon, magistère informatique), **supervision**: 100%; **Contributions**: New algorithms for autonomous exploration and transfer learning in sensorimotor skill acquisition; Web: http://fabien.benureau.com/ **Current position**: researcher at Univ. Tubingen.
Olivier Mangin (2010-2014, coming from Ecole Polytechnique and Master MVA at ENS Cachan), **co-supervision**: 100%; **Contributions**: Techniques based on sparse dictionary learning, especially Non-Negative matrix factorization, for inferring jointly motor and speech primitives from multimodal (speech-motor) human demonstrations combining simultaneously motor primitives. **Web**: http://olivier.mangin.com
Best PhD thesis poster — Bordeaux doctoral school of mathematics and computer science. **Current position** : researcher at Bosch company.

Thomas Cederborg (2009-2013, coming from Master in statistical physics, Chalmers University, Sweden), co-**supervision**: 50% Manuel Lopes, 50% myself; **Contributions**: Imitation learning algorithms of context-dependent motor skills and modelling of language bootstrapping in robots as a particular case of context-dependant learning; incremental online regression for motor learning (ILO-GMR), proposed a new advanced general formalization of imitation learning. **Best PhD award** in Region Aquitaine, awarded at NOVAQT science and technology festival, 2014.

Mai Nguyen (2010-2014, coming from Ecole Polytechnique and Master in Cognitive Robotics, University of Osaka, Japan), **supervision**: 100%; **Contributions**: Interaction of socially guided motor learning and intrinsically motivated motor learning; SGIM algorithm based on SAGG-RIAC architecture; Bridging the work done so far in the team in HRI on the one hand and intrinsically motivated motor learning on the other hand. **Current position**: Maitre de conference at ENSTA ParisTech.

Pierre Rouanet (2008-feb. 2012), coming from Master Informatique, University Bordeaux I), **supervision**: 100%; **Contributions**: Studying the role of human-robot interfaces for robot teaching of new words; Elaboration of new interfaces for efficient and intuitive joint attention and joint intention between the robot and the human (with touchpads, wiimotes and laser pointers); Showed in large-scale user studies with non-specialist users that interfaces can increase considerably learning efficiency. **Current position**: co-creator of the startup company Pollen Robotics (spin-off from the Flowers team).

Adrien Baranes (2008-dec. 2011, coming from Master "Robotique et systèmes intelligents", University Paris VI – and he did his master's thesis in FLOWERS under my supervision), **supervision**: 100%; **Contributions**: Algorithms for intrinsically motivated active learning of motor primitives in robots in high-dimensional spaces; Introduction of new competence-based algorithms; Formalization of maturational constraints and their interaction with intrinsic motivation in the context of motor learning (McSAGG); **Follow up positions**: postdoc in computational neuroscience, Univ. Columbia, NY with a **Fullbright grant** (2012-2014); **Research scientist at Google NY** (2015-).

PhD juries

2018-present: **member of 23 PhD juries**, including **reviewer of 10 PhD** manuscripts (Aubret, Akakzia, **Bourrier**, **Chatzilgeroudis**, **Choffin**, Donancio, **Geisert**, Guillet, **Hangl**, **Hussenot, Jacq**, Jacquey, Lair, **LeGoff**, Mayer, Mladenovic, Moerland, Mezghani, **Ota**, Pashevich, **Philipsen**, Toromanoff, Thero), **reviewer of 2 Hdr** manuscripts (**Gustaffsson, Zenon**) and member of **14 "comité de suivi de these"** (Appriou, Hyseni, Pagliarni, Rashidi, Segas, Zerbib, Chenu, Gaya, Josserand, Martin, Menager, Najarro, Poupard, Welter)

2005-2018: **member and reviewer of 16 PhD thesis** (Konstantinos Chatzilygeroudis, 2018; Héloïse Thero, 2018; Matthieu Geysert, 2018 ; Anja Philippsen, 2018, Miguel Cornudella, 2017 ; Arthur Prat-Carrabin, 2017 ; Gabriel Sulem, 2017; Maxime

Carrere, 2016 ; Remy Frenoy, 2016 ; Vieri Santucci, 2015 ; Adam White, 2015 ; Renaud Gervais, 2015 ; Alain Droniou, 2015; Riad Akrour, 2014; Raphael Laurent, 2014; Kirill Makukhin, 2014)

Popular science and dissemination to scientific knowledge to diverse audiences:

2022-23: Coordination of the design and dissemination of a **series of pedagogical videos aiming to explain large language models to adolescents (college, lycée)**: https://developmentalsystems.org/chatgpt_en_5_minutes/ This series has already been reused in the AI4T European project, within an online course dedicated to training teachers AI literacy, as well as in reports from Direction du Numérique Educatif (Ministère de l'Education) on the topic of AI in education

2021: Coordinator of the production of an interactive web demonstration to illustrate properties of deep reinforcement learning agents to a large audience (this was used in public demonstration in the Cap Sciences museum)

2021: Participation to "Procès du robot", a popular science intervention organized by Cap Sciences museum

2020: **Co-author (with Didier Roy) of a book introducing AI and robotics to children** (7-11 years old): "Les robots et l'intelligence artificielle", collection Questions/Réponses, Nathan. We were finalists of the 2021 Roberval prize, in the category "popular science books for children". With D. Roy, we are currently writing another book to introduce generative AI to adolescents (Nathan).

2019: member of the **scientific committee** for setting up the permanent exhibition on robotics at Cité des Sciences et de l'Industrie
2018-present : "Parrain scientifique" du collège Anatole France de Cadillac dans le cadre d'un programme de médiation de la Maison des Sciences et de l'association Main à la pâte

2019-present: Intervention in high-schools (incl. within the **Chiche program**) + interventions in primary schools to present the job of "researcher/scientist"

2018-present: Many popular science interventions in Newspapers (e.g. New Scientist, Le Monde, etc), Radio (e.g. France Inter, France Culture, etc), TV (e.g. I participated in the Netflix documentary on cognitive development in babies, France TV, TV7 etc)

2018-present: Editor of blog "Developmental systems" (e.g. http://developmentalsystems.org/language_as_cognitive_tool_vygotskian_rl) of the Youtube channel InriaFlowers (>1000 subscribers, and of two twitter accounts with >5000 followers (https://twitter.com/pyoudeyer and https://twitter.com/FlowersINRIA) to present the work of the Flowers lab to a larger audience.

2015: Co-author of popular science bool: Audouze, J., Chapouthier, G., Laming, D., Oudeyer, P-Y. (2015) Mondes Mosaiques : Astres, villes, vivant et robots, CNRS Editions.

2013 : Author of wide audience book : Oudeyer, P-Y. (sept. 2013) Aux sources de la parole: auto-organisation et évolution, Odile Jacob, Paris.

Mediation activities highlights:
I have been coordinating the development of two large-scale educational projects for computer science education at all school levels: Inirobot and Poppy Education.

Inirobot project. I worked on the development and dissemination of the IniRobot pedagogical kit, for teaching introductory computer science and robotics in primary schools. This was done in strong collaboration with Didier Roy, a math teacher (college) and specialist of ICT in education which I recruited in the team to work on educational technologies. IniRobot provides a microworld 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. A dedicated web site has been created, allowing all users and contributors to access the kit (Creative Commons) and share their experiences (https://dm1r.fr).
Impact: The kit is free of use (under Creative Commons CC-BY-SA licence) now **used by more than 30000 children in France**, with around 900 adults educators/teachers, covering more than 1000 primary schools in 35 towns. This scaling up has been achieved through collaboration with Rectorats structures as well as the Canope network, with the organization of systematic training of teachers of educators, supported by projects such as the eFran project "Perseverons". An adaptation

of the kit has been included in the education book "1, 2, 3 codez" for the initiation to computer sciences and in preparation by Main à la Pate foundation, to which I have directly contributed as scientific consultants and co-author of several parts (http://www.fondation-lamap.org/fr/123codez).

Poppy Education/Poppy Station educational projects. I have coordinated the Poppy Education project (a spin-off of the Poppy project) aimed to create, evaluate and disseminate complete pedagogical kits "turnkey solutions" (with Creative Commons licences), open-source and low cost, for teaching computer science and robotics in "colleges" and "lycées" and higher education. We have designed a complete kit of pedagogical activities + software + hardware platform available on http://www.poppy-education.org . After evaluating it at a large scale in > 15 lycées and colleges of Académie de Bordeaux, we decided to create a non-profit organization to sustain and disseminate this project on the long term. In this context, with the key collaboration of Didier Roy, the Poppy Station association was created: https://www.poppystation.org/ . It involves several large-scale French educational institutions (Ligue de l'enseignement, HESAM Université, IFE, EPFL, Arts et Métiers, CESI, CNAM) and educational companies (Generation Robots, Pollen Robotics, Konex).

Selected list of popular science articles, videos and events: http://www.pyoudeyer.com/popular-science/
Selected list of interventions in the press (e.g. Le Monde, Les Echos, France Inter, France Info, France Culture, …): http://www.pyoudeyer.com/press/

Art-science projects

As I am also strongly involved in the interaction between science and society (see Section on "Médiation Scientifique"), I also collaborate with non-scientist, such as artists, to explore various ways of expressing and explaining science to the general public. Key collaborations include:

- David Lynch (filmmaker, US) in the context of exhibition "Mathématiques, Un Dépaysement Soudain" (2011-2012) at Fondation Cartier pour l'Art Contemporain, see by around 50000 visitors and associated to a series of events for scientific mediation (public conferences, radio an TV programs);
- 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/
- Magali Desbazeille and Sigfried Canto (Independent artists, Boulogne Billancourt), as scientific consultant for the elaboration of a live artistic show on the history of language codes and its interaction with technology (2011-2012);

Summary of research activity

My work has been focusing on the computational study, modelling and experimentation of open-ended lifelong learning processes in machines and humans. This includes **natural and artificial intelligence** processes for progressively and continuously discovering sensorimotor and language skills with high-dimensional bodies, with limited resources of time and energy, and in rich and changing environments. With my team, we have been focusing on studying how this can be enabled by the interaction of two families of mechanisms:

1) internal mechanisms associated to **curiosity-driven exploration**, and in particular **autotelic learning** (= agents that sample their own goals and learn to represent them);

2) external mechanisms associated with **social learning**, and in particular **language and its internalization as a cognitive tool** for creative goal generation, planning and abstraction.

Over the last decade, this work developed in a series of results and publications with strong impact in several synergetic domains: fundamental research in developmental robotics, **machine learning and artificial intelligence** [J68;J59;J44;C115;C113;C106;C98], as well as **psychology and cognitive neuroscience** [J58;J50;J39]; as well as applied research in **educational technologies** [J71;J69;J62;J36] and for **assisted scientific discovery** [C97;C94;C112; also preprint).

Fundamental research in AI and cognitive sciences: curiosity and language for open-ended learning

Curiosity-driven exploration algorithms in artificial intelligence: Intrinsic motivations are mechanisms that drive spontaneous curiosity-driven exploration in animals and humans, for whom they are central to organizing autonomous acquisition of novel skills and knowledge [J39, J50]. Together with my team, I played a leading role for introducing, formalizing and developing technically this concept, first in developmental robotics [J12;J21], and then more broadly in machine learning [J68; J63; J59]. In a first phase of this work, we developed models self-organizing exploration by focusing on parts of the environments/activities **maximizing learning progress** [J12; J44; C88], leveraging advanced hierarchical bandit algorithms [J21]. We showed that is enables to generate **automatic curriculum learning** [J59, C92], in turn enabling sample efficient learning, good generalization and robustness to catastrophic forgetting in Deep RL agents in complex high-dimensional spaces [C88]. Recently, we focused on introducing and developing ***Intrinsically Motivated Goal Exploration Processes as a new machine learning framework with autonomous goal setting*** [J59], combined with deep reinforcement learning techniques [J68], enabling machines to self-generate, self-select and self-order its own goals, i.e. achieving a form of **autotelic learning**. We showed that: 1) with only one general task-independent cost function an autotelic machine can learn autonomously a diverse and organized repertoire of reusable skills [C88; J59] as well as high-quality inverse models of the world [J21]; 2) this enables to solve very difficult reinforcement learning problems with rare or deceptive rewards [J59]. **Impact**: This contribution played a central role in setting curiosity-driven learning as a central scientific topic in artificial intelligence and machine learning. While we initially developed some of these techniques in the developmental robotics domain, we have succeeded in publishing and improving them in top highly selective machine learning conferences (ICML, ICLR, CoRL, Neurips) and journals (JMLR, JAIR, IEEE TCDS). In particular, these algorithms are **becoming a fundamental topic for autonomous learning, and large AI companies/labs** like Google Deepmind, Nvidia or Stanford/Berkeley/MIT AI labs are using it to solve difficult deep reinforcement learning problems (see Contribution 1 below).

Language as a cognitive tool for creative exploration in autotelic AI agents and links with LLMs/foundational models. In order to enable autotelic agents to represent and sample goals that are both more abstract and more aligned with human's interests, we have studied how language could be used [J63]. First, we showed in systematic experiments with simulated social peers how language, beyond being learned as a tool for communication, could also be used as a cognitive tool enabling to sample and learn goals outside the distribution of language goals provided by social peers, leading to self-improvement and generalization beyond the training distribution [C98]. We then scaled up this approach leveraging pre-trained LLMs as cognitive tools for generating relevant goals, for self-assessment of goal achievement, and for hindsight learning [C115]. Recently, we used this approach to enable autotelic LLMs to self-improve their coding skills through interaction with a python interpreter (in review). We also showed how feedback from the environment enables to update, align and ground LLMs using online Deep RL [C113]. **Impact:** This recent approach is starting to be reused in major contributions from other labs, e.g. Google Deepmind, Meta or Jeff Clune's Lab at Univ. Vancouver.

Computational theory of curiosity for developmental psychology and cognitive neuroscience.
To address limits of qualitative theories of curiosity and intrinsically motivated learning in cognitive sciences, I led a collaborative effort to design a novel unified formal framework that integrates quantitative behavioral and neuronal measures with computationally defined theories of learning and decision making [J50, J44, J39]. This framework includes

several key concepts, including the learning progress hypothesis (LPH) and autotelic learning. It enabled to formulate new theories and several associated testable and original theoretical predictions: 1) the human brain monitors learning progress to orient curiosity-driven exploration (Learning Progress Hypothesis, J44]) 2) fundamental aspects of developmental trajectories, defined as the successive formation of stages of behavioural and cognitive structures of increasing complexity, can be self-organized as a side-effect of the dynamical interactions between intrinsically motivated learning, the body and the environment [J39, J26; C78]; 3) The discovery and learning of elementary social skills such as imitation and the first steps of speech and language can be generated as a result of general mechanisms of curiosity-driven learning [J39; J26; J45; C81]; 3) Empirical measure of learning progress in the brain could be achieved by dopaminergic circuits in the brain; 4) we validated several of these hypotheses through designing novel behavioural experimental paradigms in humans [J58, J38, J31]. **Impact**: This work directly contributed to ***renew and organize research on curiosity at the international level in psychology and neuroscience***, in particular through direct collaborations and joint publications with high-profile neuroscientists (J. Gottlieb at Univ. Columbia, NY, US) and psychologists (e.g. Linda Smith, Indiana Univ.) and. These collaborations led to a major milestone publication [J50] in a prestigious Nature Neuroscience Reviews journal (impact factor: 38.6). I also co-coordinated the organization of a series of Neurocuriosity interdisciplinary international symposiums on curiosity, which was instrumental in structuring an interdisciplinary international research community. See Contribution 2 below.

Models of language acquisition and evolution. I have also used algorithmic modelling as a tool to contribute to novel theories and understanding of language acquisition and evolution. In particular, I have contributed several theories about the evolution of speech sounds and the discovery of language through curiosity-driven learning [B2]. I developed a series of models and theoretical perspectives showing how coupled unsupervised learning mechanisms in local peer-to-peer language interaction could self-organize speech and language conventions at the scale of a population [J6, J7, J8, J11, J35, J39]. This has led to the writing of a book published at Oxford University Press [B2]. This work is now reused and cited in the human language evolution literature and in associated textbooks [E161, E162]. Recently, I have shown with my students how the dynamics of convergence of linguistic conventions in these models could be accelerated by the use of active learning and teaching mechanisms [C76, C74]. For this series of work, I have received in 2016 the Lifetime Achievement Award from the Evolutionary Linguistics Association.

Applied research

Educational technology: personalization of pedagogical sequences, training curiosity, attention and meta-cognition. With my team, I extended algorithmic models of curiosity-driven learning to active teaching algorithms [J36, C79, C63], allowing a software teacher to personalize sequences of exercises for human students. This was first experimented (KidLearn project) in a tablet based tutoring software to teach maths to schoolchildren and positively tested at large scale in primary schools of Gironde (> 1000 schoolchildren). The very positive results led to a large-scale industrial transfer project with a **consortium of French educational companies** (Nathan, evidenceB, Daesign, Isograd, Schoolab) and official educational institutions (Académies, APMEP): our algorithms are now integrated in platforms like AdaptivMaths (primary schools), as well as MIA Seconde (high schools) **disseminated at large in France (available to all French schools)** and in other countries. In parallel, the technology has been adapted for medical education of children with chronic diseases (KidBreath project [J51]), for math education of children with cognitive handicap on the autistic spectrum [J64], and for cognitive training of attention in young adults and aging populations (ongoing). Also leveraging our models of curiosity-driven learning, we have developed pedagogical conversational agents (leveraging LLMs, J71) that help children learn to ask curious questions [J62] and train their meta-cognition [C116], evaluated positively through field experiments in primary schools. See Contribution 3 and associated team.

Assisted scientific discovery with curiosity-driven exploration algorithms. A major challenge for physicists, chemists or biologists studying self-organizing complex systems is that they often do not know what is the space of possible behaviours of these systems, how to represent them, and how to explore and navigate in them given resources of time and energy are very limited. We have studied how autotelic curiosity-driven exploration algorithm can be very helpful to solve these challenges, in various domains ranging from discovering forms of sensorimotor agency in cellular automata [C95;C97;C112] to discovering novel suprising behaviours in gene regulatory networks and mapping their space in collaboration with M. Levin's biology lab at Tufts, US (preprint). This led us to improve autotelic exploration algorithms by introducing meta-diversity search, which incrementally learns a diversity of representation spaces in which one targets a growing diversity of goals, combined with the ability for human users to drive exploration in preferred directions [C97].

Social, multimodal and language learning in robots, and applications to BCI. I have, with my team, developed algorithmic approaches allowing robots to learn from the social guidance of non-engineer humans, including: 1) multimodal perceptual and language learning techniques [J37]; 2) techniques combining active imitation learning and curiosity-driven learning for language acquisition and tool use [J23, J27, J28, C82,C78] ; 4) techniques allowing a robot learner to

simultaneously learn to interpret the meaning of teaching signals and a task [C106;C60;C59], and this found **impact** through a groundbreaking application for calibration-free ***Brain-Computer Interfaces*** [J37B; C61].

Emotional speech synthesis and recognition. While I was working at Sony Computer Science Lab, I developed several new technologies for emotional speech synthesis and emotional speech recognition, which led to several international patents and were integrated in several Sony products such as the Qrio humanoid robot and Playstation video games.

Open-source 3D printed Poppy robot platform for education. I coordinated the team who designed, developed and disseminated the Poppy platform [C71,C67], which was the first complete open-source 3D printed humanoid platform in the world. This led to an international community of users (> 1000), to the ***Pollen Robotics start-up company***, as well as reuse in several large scale artistic projects (e.g. http://www.shonen.info/lesson-of-moon). As all aspects of the platform were designed to be highly modular, modifiable, robust, easily replicable, cheap, and accessible to beginners, this allowed us to apply and initiate its **transfer towards education** in high-schools, engineering schools and universities (in collaboration with Rectorat and Canope educational institutions), but also FabLabs, science museums and art/science projects (4 dance companies used the platform in their official performances/shows). It has become a major **pedagogical innovation** (Poppy educational robotic kits were commercialized by the Generation Robots company), targeting education to the digital world and its interaction with the physical world through integration of the robotic platform with software web tools to support the community (> 600 users on the Poppy forum) and with interdisciplinary pedagogical content co-designed with users.

Focus on major contributions

Contribution 1: Developmental AI and open-ended learning: from curiosity-driven exploration to autotelic large language models

1. *Description of the contribution*

In artificial intelligence, a major goal of my career so far has been to understand what mechanisms enable **lifelong open-ended autonomous learning in humans and machines**, i.e. how is it possible to learn continuously new skills of increasing complexity, and to be robust to diverse and novel environments, without intervention of an engineer. In particular, together with my team and colleagues, we have been interested in modeling and understanding the role of : 1) **curiosity-driven learning**, also called intrinsically motivated exploration and learning (internal mechanism, Forestier et al., 2022); 2) **language as a cognitive tool** for abstraction and generalization (Colas et al., 2020; 2023), beyond its communicative functions (external mechanism).

In terms of fundamental research, a general approach I have been taking is to advance in synergy:

1) **cognitive science research** (see **Fiche 2**) aiming to advance our understanding of human curiosity, combining computational modeling and psychology experiments;

2) **AI research** (**Fiche 1**) aiming to transpose these insights into AI systems by integrating them within the set of modern deep learning techniques.

Then, I have complemented this fundamental research by working on important **societal real-world applications**, including personalized **educational technologies leveraging curiosity and language (see Fiche 3)**, and using curiosity-driven exploration algorithms for **assisted scientific discovery** (Etcheverry et al., 2020, see **Fiche 4**).

On the AI research side of this research program, during a previous period of my career (2003-2017), together with my team we **pioneered the design of curiosity-driven learning systems, in particular showing how these can be made to work in real-world robots**, enabling them to acquire open repertoires of skills in high-dimensions including omnidirectional locomotion, object manipulation or use of soft tools. A key concept we introduced was intrinsically motivated goal exploration proceses (Forestier et al., 2022), i.e. **autotelic learning**, whereby agents learn to generate, sample and pursue their own goals. This work was achieved mainly within the context of the developmental robotics community in which building and growing I played a key role (I was general chair/member of steering committee of several conferences (Epirob, IEEE ICDL, IMOL) and chair of the associated IEEE Technical Committee on Cognitive Developmental Systems which supervised the growth of the community). The concepts and techniques of curiosity-driven learning we introduced were very influential in this research community, but they were still largely unknown at this point in the more traditional machine learning community.

Thus, since 2018, I have been working successfully towards a new objective: **integrate, extend and scale up these curiosity approaches within modern deep learning approaches and disseminate them in the classical machine learning community** (Neurips, ICML, ICLR, JMLR, JAIR, IJCAI, CoRL, CoLLas etc). From a technical point of view, we showed how population-based IMGEP algorithms can solve very hard sparse reward challenges in real humanoid robots and Minecraft environments (Forestier et al., 2022); we leveraged goal-conditioned deep reinforcement learning techniques to design a new family of autotelic deep RL agents (= a form of curiosity where deep RL agents set their own goals): we first designed deep RL algorithms sampling goals in pre-defined modular goal spaces, and self-organize their learning curriculum using learning-progress based mechanisms, enabling to address the challenge of catastrophic forgetting (Colas et al., 2019) as well as to train agents that generalize robustly (Portelas et al., 2020); we then designed systems enabling agents to learn incrementally the representation of their goal spaces (Reinke et al., 2020; Kovac et al., 2022); and we introduced the concept and technique of meta-diversity search to enable agent learn a diversity of goal representation spaces and explore a diversity of outcomes from the perspective of these spaces (Etcheverry et al., 2020).

As a way to **extend the generality, robustness and abstraction capabilities of these autotelic agents**, we also started a line of research studying the role of **language as a cognitive tool**: in the IMAGINE system (Colas et al., 2020), we showed how language compositionality could enable autotelic Deep RL agents to explore creatively and self-improve on tasks beyond the distribution of tasks shown by a social peer; we then showed how transformer-based architecture could enable agents to learn goal-achievement functions enabling to deal with abstract complex spatio-temporal goals expressed in language (Karch et al., 2021); we also studied algorithms enabling agents to self-generate questions, either to themselves (Carta et al., 2022) or to social peers (Liu et al., 2022), enabling to self-organize exploration in difficult environments. Recently, we started to **leverage large foundational models as proxies to human culture/social peers**, showing how autotelic agents can use them for sampling new relevant goals, for self-generating feedback and for hindsight learning (Colas et al., 2023b). We also pioneered an approach for **grounding and aligning large language models in interactive environments using online Deep RL** (Carta et al., 2023), enabling to address one of the main major limits of language models.

In order to further help **structure the development of these ideas** and techniques within the field of modern machine learning, we also wrote several key **review papers**, one on autotelic Deep RL (Colas et al., 2022), and one on automatic

curriculum learning (Portelas et al., 2020), as well as two perspective papers proposing a **long term research program**, one on the design of autotelic agents that leverage language and foundational models (Colas et al., 2023), and one more specifically on how to align the development of autotelic agents with the values and needs of a population of human users (Sigaud et al., 2022).

Following an **open-science approach** for all these contributions, I have coordinated the team effort for providing quality open-source code enabling to reproduce the vast majority of the results of all our papers, in addition to benchmarks (TeachMyAgents) and libraires enabling academic labs to run easily experiments mixing Deep RL and large language models (Lamorel). We have also designed best practice methods and associated python librairies for conducting robust reproducible experiments in Deep RL using robust statistical methods (Colas et al., 2022b, https://github.com/flowersteam/rl-difference-testing). Note that my role was focused on coordination, specification of code objectives and general approach, and feedback (code writing was achieved by PhD students/postdocs/engineers of the team). All these codes are available at: https://github.com/flowersteam

2. *Personal contribution of the applicant*

I have been the coordinator of this research program, building the overall research vision, the strategy and tactics to achieve it, and assembled and supervised the team that has been working on it. Overall, this is a major team effort and the successes we have encountered would not have been possible without the many outstanding talents both inside the Flowers team (incl. PhD students, postdocs, engineers, senior researchers) and key outside collaborations (e.g. O. Sigaud at Sorbonne Université, P. F. Dominey at CNRS, MSR Montreal and Cambridge colleagues).

3. *Originality and difficulty*

Originality. Conceptually, the contribution strongly contrasts with most of previously existing work in machine learning, and in particular in (deep) reinforcement learning (as noted below, the approach has had major success and has now been adopted by many labs in the world): before, it was assumed that an engineer pre-programmed a cost function specific to each new task an agent shall learn to solve, and researchers tried to build optimization methods without assuming particular properties of the cost function. This classical approach had two major limits: classic RL methods do not work properly in sparse reward environments, and such methods lacked autonomous multi-task learning abilities. With curiosity and autotelic exploration, one introduces the idea that agents will learn to generate, sample and order their own goals, leading them to acquire autonomously a diversity of skills that can later on help agents solve downstream sparse reward problems (Oudeyer, 2018). Also, we have shown how it is possible to orient such diversity search methods towards goals that align with the needs of human users, through language and social learning (Colas et al., 2023; Sigaud et al. 2022).

Difficulty. The algorithms for curiosity-driven autotelic exploration are complex and it required substantial work to end up with systems that could scale up to the real world (and this can be seen through the fact that few other teams in the world came up with models running on real-world continuous robot sensorimotor spaces). Furthermore, the conceptual originality required us to develop a new set of evaluation methods (Colas et al., 2022), as well as to show diverse pedagogical examples of how these methods can be used in relevant manners in more classical problems of interest to the classical deep learning community.

4. *Validation and impact*

While until 2017/2018 the concept of curiosity-driven exploration algorithms was confined to the developmental robotics community, and not integrated within modern deep learning approaches, **we had great success in scaling up technically these approaches and disseminating them within the broad AI community**, starting with our ability to **publish every year several papers in the main ML conferences (Neurips, ICLR, ICML)**. In terms of impact, our work was in a first phase leveraged by a few key AI labs in the worlds that used it to solve previously unsolvable Deep RL benchmark sparse reward tasks (e.g. Google Deepmind or here; Berkeley; Uber AI Labs), which sparked major visibility and reuse for such purposes to such a point that using curiosity-bonuses and automatic curriculum learning in RL has now become a very common approach, including in labs focused on very practical engineering problems, as shown in our review (Portelas et al., 2020). In a second phase, beyond specific algorithmic components, our general conceptual approach to open-ended learning using autotelic RL has strongly **influenced the growth of a whole new body of work on open-endedness and general AI**, again in key major AI labs (e.g. Google Deepmind here or here, Berkeley AI lab, ETH Zurich, Meta, MIT), which we review in (Colas et al., 2022). Quantitatively, this influence can be seen by the change in dynamics in citations of our papers since 2018, as in the 2018-2023 period we had 7785 citations and h-index 39 (vs an overall count of 13298 citations and h-index of 55 across my career, see https://scholar.google.com/citations?user=gCqGj4sAAAAJ&hl=en).

This impact and visibility is also accounted by the prize Inria/Académie des Sciences 2018 (Jeune Chercheur);
Major keynote talks I have been invited to (ICLR 2019, ACM IVA 2019; WMLAI 2019; ReWork Deep Learning Summit 2019; MIT Embodied AI seminar 2020; Cross Modal Learning Center Autumn School 2020; Deep RL workshop@Neurips2020; EGC 2020; Vision Science Society 2023; Ecological Theory in RL workshop@Neurips2021); invitation to presentations in a CIFAR meeting by Yoshua Bengio and Yann LeCun; **Oral accept papers at Neurips 2020 (Etcheverry et al., 2020) and ICLR 2020 (Reinke et al., 2020)**, both around 0.01% best papers among >9000 submissions; co-organization of Dagstuhl seminar on developmental learning, 2022 // ICML Workshop on Interactive Learning with Implicit Feedback 2023 // workshop on Exploration in RL at ICML 19; my recruitment as visiting research at Microsoft Research Montreal.

5. ***Dissemination, main related publications (for scientific contributions)***

- Carta, T., Romac, C., Wolf, T., Lamprier, S., Sigaud, O., & Oudeyer, P. Y. (2023). Grounding large language models in interactive environments with online reinforcement learning. In International conference on machine learning. **ICML 2023**.
- Colas, C., Karch, T., Moulin-Frier, C., & Oudeyer, P. Y. (2022). Language and culture internalization for human-like autotelic AI. **Nature Machine Intelligence**, 4(12), 1068-1076.
- Colas, C., Karch, T., Sigaud, O., & Oudeyer, P. Y. (2022). Autotelic agents with intrinsically motivated goal-conditioned reinforcement learning: a short survey. **Journal of Artificial Intelligence Research**. 74 citations.
- Forestier, S., Portelas, R., Mollard, Y., & Oudeyer, P. Y. (2022). Intrinsically motivated goal exploration processes with automatic curriculum learning. **The Journal of Machine Learning Research**, *23*(1), 6818-6858. 218 citations
- Portelas, R., Colas, C., Hofmann, K., & Oudeyer, P. Y. (2020). Teacher algorithms for curriculum learning of deep rl in continuously parameterized environments. In **Conference on Robot Learning** (pp. 835-853). PMLR. 119 citations.
- Colas, C., Karch, T., Lair, N., Dussoux, J. M., Moulin-Frier, C., Dominey, P. F., & Oudeyer, P. Y. (2020). Language as a cognitive tool to imagine goals in curiosity-driven exploration. **Neurips 2020**. 79 citations.
- Colas, C., Fournier, P., Chetouani, M., Sigaud, O., & Oudeyer, P. Y. (2019). Curious: intrinsically motivated modular multi-goal reinforcement learning. In International conference on machine learning (**ICML 2019**), 190 citations

Full list: https://scholar.google.com/citations?user=gCqGj4sAAAAJ&hl=en&oi=sra

Contribution 2: Theories of human curiosity-driven learning and interdisciplinary community building

1. ***Description of the contribution***

In synergy with the AI research presented in Fiche 1, I have been continuing my long-term research research program on computational modeling of human curiosity-driven learning, aiming to make fundamental contributions to cognitive sciences. This contribution has been three-fold:
1) **Advancing computational theory of human curiosity-driven learning**: To address limits of qualitative theories of curiosity in cognitive sciences, I led a collaborative effort to design a novel unified formal framework that integrates quantitative behavioral and neuronal measures with computationally defined theories of learning and decision making (Gottlieb and Oudeyer, 2018). This framework includes several key concepts: the learning progress hypothesis (LPH); autotelic learning; proximal and distal functionalities of curiosity (Oudeyer et al., 2018). It enabled us to formulate several testable and original theoretical predictions.
2) **Testing predictions of theory in novel experimental paradigms**: A major achievement on which I have been working for many years has been the design of a novel experimental paradigm enabling to test the LP hypothesis: we succeeded in implementing it, and this led to the validation of predictions that humans use learning progress in curiosity-driven exploration (Ten et al., 2022). We robustified these studies leveraging data from educational technology experiments (see Fiche 3, Abdelghani et al., 2022)

3) **Building an interdisciplinary scientific community studying curiosity at the international level**: Across the years, I have been a key actor building an international community studying curiosity at the crossroads of developmental psychology, neuroscience, education and AI, through structuring reviews in prestigious journals and co-organizing a series of international conferences: Curiosity, Complexity and Creativity conference New-York 2023 // Life, Structure and Cognition Paris, 2022/2023 // Dagstuhl seminar on developmental learning, 22 // conference on Curiosity : Emerging Sciences and Educational Innovations, Univ. Pennsylvania, 2018; and co-edited one journal special issue.

2. ***Personal contribution of the applicant***

This research involved strong interdisciplinary collaborations with J. Gottlieb (neuroscience, Columbia Univ., NY) and H. Sauzéon (psychology, Inria) with whom I co-supervised several PhD students. I am the main contributor of the computational theory, co-designed experimental paradigms with humans, and co-led the conference organization effort.

3. ***Originality and difficulty***

The theory was deeply contrasting with theories of learning in neuroscience and psychology, which traditionally conceptualized learning and exploration mechanisms in the perspective of solving an externally defined problem (similar perspective as the traditional AI in Fiche 1). Thus, we had to work very hard to design completely new experimental paradigms and explain the theoretical perspective to the wide cognitive sciences community. It took us around 8 years and several iterations to succeed in testing experimentally the LP hypothesis.

4. ***Validation and impact***

We have been pioneering at the international levels both the theory and experimental paradigms aimed to study human curiosity-driven learning, publishing our contributions in high-profile journals such as Nature Reviews Neuroscience (IF: 34,96) and Nature Communications (IF: 14,9). These theories and paradigms are now widely reused in key cognitive science labs (e.g. MIT, Tubingen, Donders, Berkeley, NYU, UCL), and our main experimental results about the LP hypothesis were confirmed later on by two independent studies in two different international labs, published in the prestigious Cognition journal (here and here). The conferences I co-organized were all very successful (around 100 participants).

5. ***Dissemination, main related publications (for scientific contributions)***

- Abdelghani, R., Oudeyer, P. Y., Law, E., de Vulpillières, C., & Sauzéon, H. (2022). Conversational agents for fostering curiosity-driven learning in children. ***International Journal of Human-Computer Studies***, *167*, 102887.
- Ten, A., Kaushik, P., Oudeyer, P. Y., & Gottlieb, J. (2021). Humans monitor learning progress in curiosity-driven exploration. ***Nature communications***, *12*(1), 5972. (50 citations)
- Ten, A., Gottlieb, J., & Oudeyer, P. Y. (2021). Intrinsic rewards in human curiosity-driven exploration: An empirical study. In ***Proceedings of the Annual Meeting of the Cognitive Science Society*** (Vol. 43, No. 43).
- Gottlieb, J., & Oudeyer, P. Y. (2018). Towards a neuroscience of active sampling and curiosity. ***Nature Reviews Neuroscience***, *19*(12), 758-770. (293 citations)
  Oudeyer, P-Y. (2018) Computational theories of curiosity-driven learning, in The New Science of Curiosity, ed. Goren Gordon (82 citations). (82 citations)

Contribution 3 : Large scale real-world applications in educational technologies

1. **Description of the contribution**

Fundamental research in AI and cognitive sciences on curiosity-driven learning described in Fiches 1 and 2 has formed the conceptual and technical basis of **several large scale applications I coordinated in the domain of educational technologies**.

First, together with my team, and in collaboration with the AdaptivMath consortium with several EdTech companies (evidenceB, Nathan, Daesign, etc), we **scaled up and transposed our machine learning algorithm (ZPDES, Clement et al. 2015) for personalizing sequence of exercises into the AdaptivMaths intelligent tutoring system** (ITS). This relied on prior scientific validation of the learning and motivational impact on >1000 children in Aquitaine primary schools (Clement et al., in prep), leveraging a large scale partnership we set up with Académie de Bordeaux. Thanks to massive support from Ministry of Education which bought the educational solution to evidenceB (associated to a licence between Inria and evidenceB), **the AdaptivMaths ITS is now available in all primary schools of France (with several thousand active users)**: https://adaptivmath.fr. We have also made scientific proof-of-concepts that this approach can be used with educational benefit for diverse users (children with autisms, Mazon et al., 2022), for helping children learn and comply with treatment of chronic illness (Delmas et al., 2018), and for attention training in adults (current collaboration with the OnePoint company).
We also developed a new series of **educational technologies aimed to foster curiosity and train meta-cognition, divergent and critical thinking in children**. In particular, we developed a series of educational interventions, leveraging **conversational agents**, teaching children to ask curiosity-driven questions in the classrooms, and we conducted several field studies in Aquitaine primary schools showing great benefit (Alaimi et al., 2020; Abdelghani et al., 2022). **We also pioneered at the international level the use of LLMs (GPT-3) to generate educational content evaluated in a field study** (Abdelghani et al., 2023). We also developed a teacher-centered approach to using robots in the classrooms (Ceha et al., 2022).
The large scale Poppy Education project (Feder) I coordinated in 2016-18 generated multiple educational robotic kits as well as a large educational community in France and beyond that formed the basis of the creation of the Poppy Station educational NGO and the Pollen Robotics startup company.
We also developed a series of educational videos to introduce language models to adolescents ("ChatGPT en 5mn").

2. Personal contribution of the applicant

I co-designed the ZPDES algorithm, built the general vision for its use and transfer in large scale educational applications, and coordinated the team for achieving the actual industrial transfer within the AdaptivMaths project. For proof-of-concepts of use for diverse populations and attention training, I am a co-supervisor of PhD students working on this topic (with H. Sauzéon). I am co-supervisor of our project on training curious question asking in children, and I led the conceptual effort to use LLMs in this context. I co-designed the strategy for translating Poppy Education into an NGO and startup, but the operational translation was respectively made by Didier Roy and M. Lapeyre/P. Rouanet. I proposed the original idea of building the educational video series of LLMs and I am co-supervising its implementation.

3. Originality and difficulty

Transposing academic research in educational technologies used large scale in real classrooms is highly challenging for two reasons: 1) it requires first to be able to deploy sufficient large evaluation experiments in classrooms, requiring to deal with complex interactions with the French public educational institutions, as well as long and tedious experimental work; 2) it requires building synergies with EdTech companies so that the approach used in commercial products is as close as possible to the scientific ideas we developed. These challenges are such that only very few teams in France have managed to translated AI-based educational technologies to the real world, thus making our contribution quite original.

4. Validation and impact

The AdaptivMaths educational software is now available in >68k classrooms in France and actively used by thousands of students and their teachers, thanks to strong support from Ministry of Education. The ZPDES algorithm has now been reused in two other large scale ITS: AdaptivLang and Remédiation Seconde. Our partnership with Académie de Bordeaux served as basis of a larger partnership between the Inria center as a whole and Univ. Bordeaux. The Pollen Robotics startup won the 2nd place of the Ana Avatar XPrize. Our series of educational videos on LLMs has been reused by Direction du Numérique Educatif in various platforms. Our scientific papers on these topics have been published I key conferences (CHI 19, CHI 20, IDC 23) and journals (AIED 23, EIT 23, International Journal of Social Robotics 22, IJHCS 22).

5. Dissemination, main related publications (for scientific contributions)

- Abdelghani, R., Wang, Y. H., Yuan, X., Wang, T., Lucas, P., Sauzéon, H., & Oudeyer, P. Y. (2023). GPT-3-driven pedagogical agents to train children's curious question-asking skills. ***International Journal of Artificial Intelligence in Education***, 1-36.
- Abdelghani, R., Oudeyer, P. Y., Law, E., de Vulpillières, C., & Sauzéon, H. (2022). Conversational agents for fostering curiosity-driven learning in children. ***International Journal of Human-Computer Studies***, *167*, 102887.

- Alaimi, M., Law, E., Pantasdo, K. D., Oudeyer, P. Y., & Sauzeon, H. (2020). Pedagogical agents for fostering question-asking skills in children. In ***Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems*** (pp. 1-13).
- Clement, B., Roy, D., Sauzéon, H., Oudeyer, P-Y. (in prep) Improved Performances and Motivation in Intelligent Tutoring Systems through Combining Machine Learning and Learner Choice.
- Delmas, A., Clément, B., Oudeyer, P. Y., & Sauzéon, H. (2018). Fostering health education with a serious game in children with asthma: pilot studies for assessing learning efficacy and automatized learning personalization. In ***Frontiers in Education*** (Vol. 3, p. 99).

Contribution 4 : Assisted scientific discovery with curiosity-driven exploration algorithms

1. Description of the contribution

In many areas of natural and engineering sciences, researchers aim to study complex systems that can self-organize diverse structures and properties (e.g. new materials, biological networks such as GRNs, etc). **One major challenge they face at the early stage of research is that it is very hard to explore and build maps of the possible behaviours of such systems: they are high-dimensional, and at the same time there are often scarce resources of time and energy to explore them. Furthermore, scientist often do not initially know how to represent structures and behaviours of a new complex system**. With my team, we have recently proposed the idea, and showed experimentally that **curiosity-driven AI exploration algorithms** (especially autotelic learning systems that incrementally learn goal representations) can be very useful to help scientist **explore and learn models of these systems and learn representations of the self-organized behaviours.**

We focused so far mostly on abstract models of morphogenetic processes such as high-dimensional continuous cellular automata (e.g. Reinke et al., 2020). This allowed us to show not only that such exploration processes were orders of magnitude more efficient than unguided exploration algorithms, but also to discover patterns (such as glider guns) that were previously unknown to exist in continuous CAs. We recently extended this work by improving the autotelic exploration algorithm. First, we introduced the concept and technique of meta-diversity search, where the system incrementally learns a diversity of representation spaces in which to sample diverse goals, and we combined it with a mechanism allowing human scientists to drive exploration in direction they prefer using very simple visual feedback (Etcheverry et al., 2020). Then, we leveraged differentiable CAs, gradient descent and curriculum learning to show the existence of surprisingly robust self-organized sensorimotor "agents", showing abilities like self-maintainance and obstacle avoidance, with strong generalization abilities (Hamon et al., 2023, under review). We further developed this line of research by introducing mass conservation and parameter localization in CAs, enabling bootstrapping of evolutionary processes (Plantec et al., Best paper award at Alife 2023).

Recently, we collaborated with Michael Levin**'s biology lab in Harvard** and showed how this approach can be used to map the space and characterize new behaviours in models of **gene regulatory networks**, setting the stage for new approaches to design or leverage self-organized functionalities in biological networks (see preprint).

2. Personal contribution of the applicant

I introduced the general idea and approach in the team, building up the projects funding the postdoc of Chris Reinke (who I supervised) and the PhD of Mayalen Etcheverry (who I co-supervised with C. Moulin-Frier). I played a key role in the design of the algorithmic approaches, in the choice of the targeted systems, and in setting up the evaluation methods. Experimental work and code was mostly done by M. Etcheverry, C. Reinke, C. Romac and J. Lin.

3. Originality and difficulty

This line of work was completely new in the team when we started working on it, and we were unsure whether our intuitions about this application domain would actually work in non-trivial target systems and lead to impactful results. We were also not well connected to communities in biology and physics we aimed to impact.

4. Validation and impact

We first validated successfully the approach through very advanced results on exploration of self-organization phenomena in high-dimensional continuous CAs, to such a point that we made discoveries of high interest to the research community developing and studying CAs, as illustrated in the collaboration we developed across several years with Bert Chan at Google Deepmind, the creator of the reknown Lenia system. We also made key new discoveries in this domain, leading to the Best paper award at Alife, and a major paper under review at PNAS. Our two foundational papers in this domain were accepted as oral presentations at ICLR 2020 and Neurips 2020 (only 0.01% papers among >9000 submitted papers were accepted as oral presentations). We also developed a strong collaboration with Michael Levin's biology lab in Harvard, who is a key international researcher in the study of non-conventional forms of intelligence in biological systems, and this led to another major paper under review at Elife. Another collaboration was made with D. Cattaert's neuroscience team at Incia, where we studied the use of autotelic exploration algorithms for exploring the behaviour of complex spinal sensorimotor circuits (paper in review). Using this approach, the team finished 2nd of the Minecraft Open Endedness Challenge in 2021.
Beyond these collaborations, our algorithms were also used in advanced roboticized chemistry research in L. Cronin's lab in Glasgow, helping to uncover novel properties of oil droplet systems relevant to research on the origins of life. In University of Chicago, A. Murugan's team used these algorithms to to explore and map the space of behaviours of Kuramoto models, iteratively discovering and learning initially unknown order parameters.
This work was also disseminated in the context of my participation to the steering committee and organization of the Life, Structure and Cognition 2022, 2023 and 2024 meetings at IHES.

6. Dissemination

- Etcheverry, M., Moulin-Frier, C., & Oudeyer, P. Y. (2020). Hierarchically organized latent modules for exploratory search in morphogenetic systems. *Advances in Neural Information Processing Systems* ***(Neurips 2020)***, *33*, 4846-4859. (Oral presentation, 0.01% best papers) Videos and web site. Code
- Reinke, C., Etcheverry, M., & Oudeyer, P. Y. (2020). Intrinsically Motivated Discovery of Diverse Patterns in Self-Organizing Systems. In *International Conference on Learning Representations* ***(ICLR)***. (Oral presentation). Blog, Code.
- Etcheverry, M., Moulin-Frier, C., Oudeyer, P-Y., Levin, M. (2023) AI-driven automated discovery tools reveal diverse behavioural competencies of biological networks, in review, Interactive paper, interactive tutorial (notebook).
- Hamon, G., Etcheverry, M., Chan, B. W. C., Moulin-Frier, C., & Oudeyer, P. Y. (2022). Learning sensorimotor agency in cellular automata. in review, interactive paper and code.
- Plantec, E., Hamon, G., Etcheverry, M., Oudeyer, P. Y., Moulin-Frier, C., & Chan, B. W. C. (2023). Flow-Lenia: Towards open-ended evolution in cellular automata through mass conservation and parameter localization. In *ALIFE 2023: Ghost in the Machine: Proceedings of the 2023* ***Artificial Life Conference***. MIT Press. Best paper award. Code.

Software: My team produced various open-source softwares (MIT Licences) to share these exploration algorithms with the wider scientific community, and in particular the large software framework adtool made for non computer scientists (project co-supervised with C. Moulin-Frier and C. Romac), and a library made by M. Etcheverry (PhD student) for simulating biological networks, with various associated tutorial notebooks, e.g. or optimizing them, or exploring them (also here), or other tutotrial notebooks showing how to use exploration algorithms to study self-organization in continuous CA, such as here (made by G. Hamon). All our papers are also associated with MIT Licence code enabling to reproduce results.

Contribution 5: Computational models of the evolution of speech sounds

1. Description of the contribution

I have also used algorithmic and robotic modelling as a tool to contribute to novel theories and understanding of language acquisition and evolution. In particular, I have developed a series of models and theoretical perspectives showing how coupled unsupervised learning mechanisms in local peer-to-peer language interaction could self-organize speech and language conventions at the scale of a population [J6, J7, J8, J11, J35, J39]. Recently, I have shown with my students how the dynamics of convergence of linguistic conventions in these models could be accelerated by the use of active learning and teaching mechanisms [C76, C74].

2. Personal contribution of the candidate

I conducted this contribution entirely on my own.

3. Originality and difficulty

Before the models I developed, no theory or models existed that could propose a unified approach of the three questions above. Some models existed to explain the most frequent sound systems in terms of various optimality criteria

[E124,E142,E94], but did explain neither the diversity of sound systems nor how a community can converge on a particular code. De Boer elaborated a model of population convergence, but assumed complex interaction capabilities and did not address evolutionary questions. Furthermore, my models introduced in the Evolution of Language research community novel original ideas of the way self-organization and Darwinian evolution could interact to generate organized communication systems. The design of such a theory and associated computational models was very challenging since it required to synthesize knowledge and techniques from very difference fields (phonetics, evolutionary biology, evolutionary linguistics, physical modelling of vocal tract and auditory system, computational neuroscience, attractor dynamics in dynamical systems, computer science).

4. Validation and impact

This theory and computational models have had an important impact outside my own field, especially in evolutionary linguistics and phonetics. I first published these results in the computational modelling literature but their scope also allowed me to publish them in high-ranking evolutionary linguistic and biology journals and venues (Journal of Theoretical Biology, Infant and Child Development, Cognitive Processing, Evolution of Language conference,…). Key high-profile researchers, international specialists of language evolution and phonology, strongly supported and publicized my work: M. Studdert-Kennedy (Yale Univ., US) and J. Hurford (Edinburgh Univ., UK), general co-chair of several Evolution of Language conferences, both invited me to publish a book [B2] at Oxford University Press, in the Oxford Studies in the Evolution of Language series, for which Hurford is editor and translated my book. L. Goldstein (linguist, USC, US), J. Pierrehumbert, (linguist, Northwestern Univ., US) and J. Blevins, (linguist, Max Planck Inst., Germany), regularly quote my models as a reference. B. Lindblom, internationally renowned Swedish phonetician, highlights my computational models in the Cambridge Encyclopedia of Language Sciences [E161, E162]. I have been invited as a keynote speaker at the Interspeech'07 conference, which gathers annually 1500-2000 attendees, and in Colloque de rentrée du Collège de France, 2008. The set of my associated articles is cited 653 times (Google scholar, sept. 16). For this series of work, I have received in 2016 the Lifetime Achievement Award from the Evolutionary Linguistics Association.

5. Dissemination

Selected Academic publications (see Form 5): Book: [B2,B5]; Journals: [J6, J7, J8, J11, J35, J39];

Contribution 6: Participation to the growth of a new scientific field: Developmental Robotics and Developmental AI

I have played an important role in the growth and structuring of the new scientific field "*Developmental Robotics*" at both the national and international levels, with several aims:

- To help building a strong unified and integrated scientific identity of the field, and a good positioning relative to connected fields (especially relative to *Robotics*, and in particular *Robot Learning* and *Human-Robot Interaction* on the one hand, and *Cognitive Sciences/Developmental Psychology/Neuroscience/Linguistics* on the other hand);
- To develop tools for focused, efficient and impactful scientific interactions in the community (conferences, journals,newsletters);
- To gather and train young scientists to become competent in this field, requiring pluridisciplinar integration and formation;
- To bootstrap a sustainable group of scientists in my team in order to have the critical mass to attack the research challenges of my research program, and then later on disseminate these competences in the French scientific structures;

To reach those goals, my specific contributions are organized along the following dimensions:

- **Chairing of the IEEE Computatinal Intelligence Society on Cognitive and Developmental Systems** (2015-2016): https://openlab-flowers.inria.fr/t/ieee-cis-tc-on-cognitive-and-developmental-systems/41
- **Organization of the two main conferences in the field** (IEEE ICDL and Epirob): I have been general co-chair and program co-chair of Epirob 2006, program co-chair of Epirob 2009, member of the organizing committee of IEEE ICDL 2009 and IEEE ICDL-Epirob 2011. Since, 2009 I am member of the steering committee of Epirob. Until around 2006-2007, the Epirob and ICDL conferences gathered, for historic reasons, relatively separate groups of researchers (around US for ICDL, around Europe and Asia for Epirob). This separation was an obstacle for the further growth of the field. As one of the rare researchers present and active in the two groups, and through my organizational role in the two conferences, I acted in 2009-2010 as the key mediating person between the two steering committees to have them converge and agree on the idea of organizing for the first time the joint event ICDL-Epirob in 2011 (can be attested by Angelo Cangelosi or Jochen Triesch, chairs of ICDL-Epirob 2011).
- **Editorial role in key publications in the field:** I am editor of the open-access IEEE CIS Newsletter on Cognitive and Developmental Systems since 2008 [N1-N19], in which twice a year I entirely organize a scientific debate (dialog) by soliciting a well-known researcher on a specific topic, then inviting other key researchers (typically 6) to respond and

editing and coordinating their contributions. This newsletter is the main electronic communication channel in the community, and is distributed to a dedicated mailing list counting around 1700 subscribers. I am associate editor of IEEE Transactions on Cognitive and Developmental Systems, flagship journal of our community created in 2008, and helped its bootstrapping by organizing the first special issue.

- **Survey and tutorial talks, survey and encyclopaedia articles:** I regularly introduce and present overviews of the whole field of Developmental Robotics in talks made at various interdisciplinary venues, as well as contributed a survey article [J19] and an encyclopaedia article [BC9] surveying our field and targeted to other disciplines in order to maximize the visibility of our community.

Introduction of Developmental Robotics in France and at INRIA: I have also played a major role for introducing developmental and social robotics in France by creating the second research group in France (after P. Gaussier's lab) and the first one in this field at Inria. I dedicated major personal efforts to create from scratch the INRIA team Flowers in 2008, which was first an "action exploratoire", and then through successive national and international grants and creation of a joint INRIA-Ensta-ParisTech EPC, I have gathered a team which is currently composed of 30 members. The building of this team was in particular strongly supported by my ERC Starting Grant EXPLORERS, obtained in 2009 and which was the first ERC grant in Europe in the field of Developmental Robotics.

1. Representative publications

Colas, C., Karch, T., Moulin-Frier, C., & Oudeyer, P. Y. (2022). Language and culture internalization for human-like autotelic AI. ***Nature Machine Intelligence***, 4(12), 1068-1076.
This paper presents major dimensions of the research vision and program that resulted from our recent exploration at the interface of autotelic learning, language as a cognitive tool, and large language models: we explain here the major objective of building open-ended autotelic machines that can be integrated and aligned on human culture and values, and we outline a long-term research roadmap involving using, adapting, aligning and grounding large language models, leveraging many of the building blocks we have recently developed. See Fiche 1.

Colas, C., Karch, T., Lair, N., Dussoux, J. M., Moulin-Frier, C., Dominey, P., & Oudeyer, P. Y. (2020). Language as a Cognitive Tool to Imagine Goals in Curiosity Driven Exploration. *Advances in Neural Information Processing Systems (**Neurips 2020**)*, *33*.
This paper was foundational in our approach to build curiosity-driven autotelic learning agents that use language as a tool for creative genearation of new abstract goals, self-assessment of goal-achievement and hindsight learning. It also involved a very systematic experimental campaign to evaluate the contributions of this mechanisms in many dimensions, and illustrates well the methodological know-how of the team. This paper was the basis of our more recent work leveraging foundational models to scale up the approach. See Fiche 1.

Gottlieb, J. and Oudeyer, P-Y. (2018) Towards a Neuroscience of Active Sampling and Curiosity, ***Nature Reviews Neuroscience,*** 19(12), 758-770.
This paper results from a decade of collaboration with Jacqueline Gottlieb, aiming to build a theoretical and experimental framework for studying curiosity in humans, as well as aiming to structure the community by writing reviews such as this one, and associated to the co-organization of a series of interdisciplinary international symposia. See Fiche 2.

2. Publication policy

Publication strategy: As I have been aiming to have impact in several domains and communities, it has been strategic to the team to publish in key venues of these communities. Thus, for machine learning and IA we recently focused on ICML/Neurips/ICLR/JMLR/JAIR; for cognitive science research we targeted journals like Nature Reviews Neuroscience, Topics in Cognitive Science, Nature Communications, Nature Human Behaviour; for educational technologies we targeted journals like IJAIED, IJHCS, JEDM; and for assisted scientific discovery we targeted the Alife conference, and we have currently one paper submitted to eLife. This is also the reason why around 2018, when we decided to have impact in the machine learning community after having disseminated our work in the developmental robotics community, we significantly changed our target journals and conferences accordingly.

Authors order: Many projects in our domain involve advanced team work, often with several PhDs or postdocs doing extensive experimental work. The general scheme we follow is to have the main PhD students/postdocs contributors (e.g. achieving a large part of the experimental work) be the first author(s), and to have the main supervisor(s) be last author(s), then authors in the middle have a more secondary level of contribution. In an increasing number of publications venues, the actual contributions of authors are listed at the end of papers.

3. Publications

Full list of publications

7 books, 72 journals, 20 newsletters (16 as editor), 16 book chapters, 117 international conference, 11 patents
Google Scholar (Oct. 2023) : 13374 citations, h-index: 56 (since 2018: 7854 citations, h-index: 39)
https://scholar.google.fr/citations?user=gCqGj4sAAAAJ&hl=en

Books

[B7] Roy, D., Oudeyer, P-Y. (2020) Les robots et l'intelligence artificielle, Collection Questions/Réponses, Nathan Jeunesse.

[B6] Audouze, J., Chapouthier, G., Laming, D., Oudeyer, P-Y. (2015)Mondes Mosaiques: Astres, villes, vivant et robots CNRS Editions.

[B5] Oudeyer, P-Y. (2013) Aux sources de la parole: auto-organisation et évolution, Odile Jacob, Paris.

[B4] (as co-editor) Salah, A. Ruiz-del-Solar, J., Mericli, C., Oudeyer, P-Y. (2012) Human Behavior Understanding, LNCS 7559, Springer.

[B3] (as co-editor) Canamero, L., Oudeyer, P-Y., Balkenius, C. (2009)Proceedings of the 9th International Conference on Epigenetic Robotics, Lund University Cognitive Studies.

[B2] Oudeyer, P-Y. (2006, **new edition 2019**) Self-Organization in the Evolution of Speech, Studies in the Evolution of Language, Oxford University Press. (Translation by James R. Hurford).
http://www.pyoudeyer.com/Self_Organization_in_the_Evolution_of_SpeechWebSept19.pdf

[B1] (as co-editor) Kaplan, F., Oudeyer P-Y., Revel, A., Gaussier, P., Nadel, J., Berthouze, L., Kozima, H., Prince, G.C., Balkenius, C. (2006) Proceedings of the Sixth International Conference on Epigenetic Robotics,Lund University Cognitive Studies.

Journals

[J72] Brinkmann, L., Baumann, F., Bonnefon, J-F., Derex, M., Muller, T., Nussberger, A-M., Czaplicka, A., Acerbi, A., Griffiths, T., Henrich, J., Leibo, J., McElreath, R., Oudeyer, P-Y., Stray, J., Rahwan, I. (2023) Machine Culture, ***Nature Human Behaviour***.

[J71] Abdelghani, R., Wang, Y. H., Yuan, X., Wang, T., Lucas, P., Sauzéon, H., & Oudeyer, P. Y. (2023). GPT-3-driven pedagogical agents to train children's curious question-asking skills. ***International Journal of Artificial Intelligence in Education***, 1-36.

[J70] Gasse, M., Grasset, D., Gaudron, G., & Oudeyer, P. Y. (2023). Using Confounded Data in Latent Model-Based Reinforcement Learning. ***Transactions on Machine Learning Research***.

[J69] Ceha, J., Law, E., Kulić, D., Oudeyer, P. Y., & Roy, D. (2022). Identifying functions and behaviours of social robots for in-class learning activities: Teachers' perspective. ***International Journal of Social Robotics***, 1-15.

[J68] Colas, C., Karch, T., Sigaud, O., & Oudeyer, P. Y. (2022). Autotelic agents with intrinsically motivated goal-conditioned reinforcement learning: a short survey. ***Journal of Artificial Intelligence Research***, 74, 1159-1199.

[J67] Sigaud, O., Akakzia, A., Caselles-Dupré, H., Colas, C., Oudeyer, P. Y., & Chetouani, M. (2022). Towards teachable autotelic agents. ***IEEE Transactions on Cognitive and Developmental Systems***.

[J66] Kovač, G., Laversanne-Finot, A., & Oudeyer, P. Y. (2022). Grimgep: learning progress for robust goal sampling in visual deep reinforcement learning. ***IEEE Transactions on Cognitive and Developmental Systems***, (99), 1-1.

[J65] Adolphe, M., Sawayama, M., Maurel, D., Delmas, A., Oudeyer, P. Y., & Sauzéon, H. (2022). An open-source cognitive test battery to assess human attention and memory. ***Frontiers in Psychology***, *13*, 880375.

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Patents

I am the inventor or co-inventor of 11 patents covering 5 different technological issues. The full list of my patents is available at: http://www.pyoudeyer.com/patents/

Selecteed list of patents:
[P1] **Technology**: Human-robot interface for teaching novel visual objects to a robot
Title: *Mobile communication terminal, and method and device for recognizing shapes for a robot*
Zones: Europe
Patent number: WO2010116057 ; Publication date : 2009-04-08 ; Inventor : ROUANET PIERRE ; OUDEYER PIERRE-YVES ; Applicant : INRIA.
Actual use: Not used in a commercial product.

[P2] **Technology:** System for transforming the output of a text-to-speech system into emotional speech
Title : *Method and apparatus for speech synthesis, program, recording medium, method and apparatus for generating constraint information and robot apparatus*
Zones : Europe, Etats-Unis, Japon
Patent number:US2004019484 Publication date:2004-01-29 Inventor:KOBAYASHI ERIKA [JP]; KUMAKURA TOSHIYUKI [JP]; AKABANE MAKOTO [JP]; KOBAYASHI KENICHIRO [JP]; YAMAZAKI NOBUHIDE [JP]; NITTA TOMOAKI [JP]; OUDEYER PIERRE YVES [FR], Applicant : Sony France S.A. Application number:US20030387659 20030313 Priority number(s):EP20020290658 20020315 Also published as EP1345207 (A1) JP2003271174 (A)
Actual use: Used in Sony humanoid robot Qrio.

[P3] **Technology**: System for generating and transforming emotional speech through signal processing.
Title : *Method and apparatus for synthesizing emotion conveyed on sound*
Zones : Japon, Etats-Unis
Patent number:JP2003084800 Publication date:2003-03-19 Inventor:OUDEYER PIERRE YVES, Applicant : Sony France S.A., Application number:JP20020206012 20020715 Priority number(s):EP20010401880 20010713, Also published as: US2003093280 (A1)
Actual use: Used in Sony humanoid robot Qrio and Sony Playstation 3 audio-speech library.

[P4] **Technology:** System for automatic recognition of emotion in speech signals
Title : *Emotion recognition method and device*
Zones : Japon, Etats-Unis
Patent number:JP2003099084 Publication date:2003-04-04 Inventor:OUDEYER PIERRE YVES, Applicant : Sony France S.A., Application number:JP20020206011 20020715 Priority number(s):EP20010401879 20010713, Also published as: US2003055654 (A1)
Actual use: Not used in a commercial product.

[P5] **Technology**: Human-robobt interface and system for teaching new motors skills to a robot.
Title : *Training of autonomous robots*
Zones : Europe, Etats-Unis, Japon
Patent number:US2002183895 Publication date:2002-12-05 Inventor:KAPLAN FREDERIC (FR); OUDEYER PIERRE-YVES (FR), Applicant : Sony France S.A., Application number:US20020134909 20020429 Priority number(s):EP20010401127 20010430 Also

published as: EP1254688 (A1) US6760645 (B2) JP2003039363 (A)
Actual use: Used in one of the commercial robot game of the "AIBO Mind" suite.