ANITI Chair on Cognitive and Interactive Robotics

Fachadon: Rachid Alami, François Félix Ingrand, Thierry Siméon, Aurélie Clodic, Arthur Bit-Monnot
Devise and build the **cognitive** and **interactive** abilities to allow **pertinent**, **legible** and **acceptable** behaviors for a robot that is able to perform **collaborative tasks** with a human partner.

→ the assistant and the teammate robot
Ambition to cover the full spectrum of the Robot Decisional Abilities

1. A principled and long-term **multi-disciplinary collaborative research** with philosophers, development psychologists, ergonomists

2. **Incremental Development** of **key components** and their articulation within a **Cognitive Architecture**

3. The **deployment and of AI-enabled robotic** systems with potential users

4. The **Evaluation** in contexts where the robot is used to conduct joint action and/or learn or refine abilities with non-specialist **users**.
Research topics

- **1 - Motion Planning**
  - Socially Aware Motion are and Context-dependent navigation
  - Control-Aware Motion Planning

- **2 - Combined Task and Motion Planning**
  - Integration of Geometric & Symbolic Planning
  - Use of Deep learning to speed up CTAMP problem solving

- **3 - Task Planning and Learning / Human-Aware Task Deliberation**
  - Solver for Planning / Scheduling: Temporal & Hierarchical Planning
  - Refinement–based Acting Engine with a Hierarchical Temporal Planner
  - Learning Plan and Task Operational Models from Demonstrations
  - HR Situation assessment and estimation of Human belief about environment and task
  - Planning shared H&R plans with explicit management of H & R beliefs

- **4 - Architecture, Verification and Certification**
  - Formal Models and Tools to Control and Verify Critical Real-Time Systems (Hi)
  - Architecture to implement an Integrated approach to HR collaboration
1- Socially Aware Motion Planning
CoHAN: Cooperative Human Aware Navigation

- A Human-Aware navigation system which can handle various H&R interaction schemes including cooperative schemes

✓ Human-aware constraints for promoting legibility and acceptability integrated in a reactive optimization process

✓ Several modes (e.g. simple / double elastics band..) depending on context and human behavior

✓ Proactive behavior based on trajectories for human & robot

Code: https://github.com/sphanit/CoHAN_Planner
KHAOS: a Kinematic Human Aware Optimization-based System for Reactive Planning of Flying-Coworker

- Planning Human-aware motion integrating visibility, proxemics and comfort
- Reactive planning UAV + Manipulator

KHAOS adapts the speed to reduce human discomfort resulting in a smooth speed profile during deceleration

Human Aware Reactive kinodynamic Planning of a coordinated motion (UAV + Arm) for a **handover** taking into account **human reach**, visibility, proxemics and comfort

Approach and hand-over in a constrained environment and from behind

Display of the trajectory actually executed by the AAM. It starts behind the big wall far from the human. It can accelerate freely to its maximum speed of 1m/s.

   - Partners: NVIDIA, Stanford, Google, EPFL, Purdue, CMU, UT Austin, MIT, Northeastern, Georgia Tech, Aston UK, Bar Ilan, Adobe, LAAS-CNRS, Sony AI, Honda, Yale, GMU, Apple

2. Editorial board of a Frontiers of Robotics and AI “Human-Aware Navigation for Autonomous Systems”

3. Two workshops at International IROS 2022 and IROS 2023

4. Direct Collaborations
   - Aston University, ISTC-CNR Roma, Sapienza University University of Extremadura, UPC Barcelona, University of Leon, INRIA, CLLE
   - Joint Publications
2- Combined Task and Motion Planning
CTAMP: Intricate problems which cannot resolved in a classical hierarchical decomposition: Symbolic Task Planner then Geometric Planning

Previous contribution to CTAMP: Formulations / Algorithms

→ The combination of discrete symbolic search with continuous geometric planning results often in a combinatorial explosion
Combined Task and Motion Planning (AGFP-Net)

- Simultaneous Action and Grasp Feasibility Prediction for Task and Motion Planning through Multi-Task Learning:
  - **AGFP-Net** predicts the feasibility of pick and place actions separately
  - A complete pick-place action is feasible only if there is at least one common feasible grasp between the separate pick and place actions
  - **Rich geometric information** given to the TAMP algorithm by the neural network
  - Handle fully-specified and partially-specified goals
    → **Tackle problems with higher combinatorial complexity**
### Performance of Feasibility-Informed TAMP

<table>
<thead>
<tr>
<th>Domain</th>
<th>Method</th>
<th>Heuristic</th>
<th>Infeasible Task Plans</th>
<th>Total Planning Time (s)</th>
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<td>Bouhsain et al. 2023</td>
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<td>108.3</td>
<td>599.1</td>
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<tr>
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<td>Bouhsain et al. 2023</td>
<td>Planning Failure</td>
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<tr>
<td></td>
<td>Proposed</td>
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<td>339.3</td>
<td>1500.1</td>
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<tr>
<td></td>
<td></td>
<td>AGFP-Net</td>
<td>1.9</td>
<td>95.2</td>
</tr>
</tbody>
</table>

- **94% speedup**
- **92% speedup**
Recent extensions

Smail Ait Bouhsain, Rachid Alami, Thierry Siméon, **Learning to Predict Action Feasibility for Task and Motion Planning in 3D Environments**, IEEE ICRA 2023, London:

Smail Ait Bouhsain, Rachid Alami, Thierry Siméon, **Simultaneous Action and Grasp Feasibility Prediction for Task and Motion Planning through Multi-Task Learningments**, IEEE IROS 2023, Detroit
3- Task Planning
• Solver for Planning / Scheduling: Temporal & Hierarchical Planning

• Refinement–based Acting Engine with a Hierarchical Temporal Planner

• Learning Plan and Task Operational Models from Demonstrations

• HR Situation assessment and estimation of Human belief about environment and task

• Planning shared H&R plans with explicit management of H & R beliefs
Hybrid CP-SAT for Planning & Scheduling

In-house solver for disjunctive scheduling

Fluid integration of approaches from CP and SAT
- Focus on variables with large domains

State of the art on Disjunctive Scheduling (jobshop, openshop) [1]

Experimental exploitation for temporal/hierarchical planning [2]

[1] A. Bit-Monnot, Enhancing Hybrid CP-SAT Search for Disjunctive, A. Bit-Monnot. ECAI 2023

[2] A. Bit-Monnot, Experimenting with Lifted Plan-Space Planning as Scheduling, IPC 2023
Adapts STNU to work in partially observable environments
  • Temporal plans with exogenous events & uncontrollable duration
  • Subset of events non-observable

Check for **dynamic controllability** of network

Derives **execution strategies** (dependent on observation)

A. Bit-Monnot, P. Morris, *Dynamic Controllability of Temporal Plans in Uncertain and Partially Observable Environments*, JAIR 2023
Learning Hierarchical Planning Models from Demonstrations

Input: demonstrations of a task
- Action sequences
- From human teacher or optimal solver

Output: hierarchical planning models (HTN)
- Decomposition of task in several alternatives (methods)
- Generic with respect to parameters & state

Exploited to improve quality and scalability of existing planners

P. Hérail, A. Bit-Monnot, Leveraging Demonstrations for Learning the Structure and Parameters of Hierarchical Task Networks. FLAIRS 2023
Guiding A Robotic Actor

- Architecture for (high-level) robot control
- Focus concurrency & time => fleets
- Automatic analysis for robot programs to identify decision points
  - Method selection for task
  - Access priority to resources
- Planning to provide guidance over decision points
  - Optimize behavior with a global view (resource efficiency, makespan, ...)

J. Turi, A. Bit-Monnot. Extending a Refinement Acting Engine for Fleet Management: Concurrency and Resources. ICTAI 2022
1- Situation assessment and estimation of Human beliefs about environment and task

- **Visual Perspective-taking** estimated by the Robot
- Management and maintenance of **semantic knowledge**, and **chronicles** for the robot and estimation of the beliefs its of Human partner
- **Simulation-based physics reasoning** for consistent scene estimation

Robot able to track the state of the **yellow object** manipulated by the **Human** even when it is inside the **blue box** or poured into the **green box**, then the **red object** poured from the **green box** to the **blue box**.


Referring Expression Generation (REG) in Human Robot Interaction

- Exploits **Distinct Human and Robot Perspectives** (Visibility / Affordances)
- Ontology based: using object attributes, relations between objects, hierarchical task description
- Cost-based Algorithm:
  - ensures **non-ambiguity** of the target entity in the REG
  - uses **shared knowledge** about past Human-Robot collaborative **activity**
  - **integrated** within a task planner

« (?0, isA, Pen), (?0, In, ?1), (?1, isA, Cup), (?1, Color, blue) »

« the knife with which Tony prepared the salad »


A Robot Task Planner specially dedicated to Human-Robot collaborative task achievement

- Maintains and reasons about **distinct beliefs of the robot and the Human** and their evolution over time
- Plans for the robot and Anticipates Human Planning
- Can **Anticipate** and/or **Elicit** Human Decisions and Actions
- Plans **communication** actions when needed
- Considers situations where H&R **share a joint goal or not**
Robot asks for punctual help

Human acts differently

Robot asks to share a joint task

Robot able to anticipate human decisions and to determine when and how to elicit Human contribution
Robot Control Architectures – V&V
Constructive approach:

- Adoption and Adaptation of Joint Action Concepts and Mechanisms
- Models of Human beliefs, intentions, abilities and preferences

- Situation Assessment in H&R context
  - Perspective-Taking
  - Estimation of Human Mental State (ToM)

- Human-Aware Task and Motion Reactive Planning for
  - Collaborative Task Achievement
  - and Situation-based Dialog

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Functional components specification

- **GenoM specification language**

- **Autonomous robots at RIS follow a component based architecture**

- **Example:**
  Components for
  - localisation (pom and optitrack or GPS),
  - flight control (nhfc),
  - navigation (maneuver),
  - rotorcraft (IMU / mag / propellers measure and velocity control)
Fiacre Formal Framework: TINA (offline), Hippo (Runtime)

Process:
- automata, guarded and timed transitions on ports interaction, with code execution
- local variables
- building components connecting ports

Model checking the resulting TTS with TINA,

Runtime verification with Hippo
Skill language which maps in a formal framework (Fiacre)

- Offline validation and vérification with model checking (TTS/TINA)
- Online runtime verification with TTS execution with Hippo
A formal toolchain for offline and run-time verification of robotic systems
Silvano Dal Zilio, Pierre-Emmanuel Hladik, Félix Ingrand, Anthony Mallet

Composing Complex and Hybrid AI Solutions
Peter Schüller, João Paulo Costeira, James L. Crowley, Jasmin Grosinger, Félix Ingrand, Uwe Köckemann, Alessandro Saffiotti, Martin Welss

Hippo: A Formal-Model Execution Engine to Control and Verify Critical Real-Time Systems
Pierre-Emmanuel Hladik, Félix Ingrand, Silvano Dal Zilio, Reyyan Tekin
*Journal of Systems and Software*, 2021, 181

Verification of Autonomous Robots: A Roboticist’s Bottom-Up Approach
Félix Ingrand
On-line Evaluation of Quality of Interaction

QoI = a measure by the robot indicating how good is the interaction

- Assessment of the QoI at 3 levels: session, task, action
- A set of metrics

→ A guide robot performing a Direction giving Task

A confused human

A non-cooperative human

A. Mayima
Collaborative Research Projects
Contribution as a key member of the European Robotics and AI community:

- **euROBIN (2022-2026)**: Core partner in euROBIN initiative: European Robotics and AI Network
- **AI4EU (2018-2021)**: Partner in AI4EU (Europe's AI-on-Demand Platform) [https://www.ai4europe.eu/](https://www.ai4europe.eu/)
- **AIPlan4EU (2021-2023)**: Partner in AIPlan4EU/H2020 [https://www.aiplan4eu-project.eu/](https://www.aiplan4eu-project.eu/)

**REUBEN (2022-2023)**: Referring Expressions for hUman roBot intEractioN: Défi Clef « Robotique Centrée sur l’Humain »: Collaboration with Madalina Croitoru (LIRMM, Equipe GraphiK)

**AI4HRI (2021-2024)**: (Trilateral AI Japan-Germany-France) Artificial Intelligence for Human-Robot Interaction (A. Clodic, R. Alami)

**The Flying Coworker (2019-2023)**: Projet ANR en collaboration avec INRIA-Nancy

**TRAIL (2022-2027)**: Marie Curie MSCA Research Network - 2023-2026 (T. Siméon, R. Alami)

**INNOVCARE (2024-2028)**: Care-led innovation: the case of eldercare in France and in Japan – Autonomie : Vieillissement et situations de handicap 2021-2026 (France 2030) - Starts Feb. 2024.

AIPlan4EU (H2020 Project)

- Python library for AI Planning
- Modeling tools & Planner integration
- Strong community involvement
- Ends in December 2023
  - transition to open source organization (4 maintainers, incl. LAAS)
Mummer: Giving Directions in a mall

- Planning and verbalizing a route for the human

- Planning HR shared perspective

- Adapting to human action and requests

- Executing Human-Aware Motion
Chair Activity: some indicators

Plenary Keynotes:
- ROBOPHILOSOPHY 2022, August, Helsinki (Finland)
- ICRES 2022, International Conference on Robot Ethics and Standards, Seoul, July 2022,
- European Robotics Forum 2022 Rotterdam (Netherland)
- 5th CyPhySS 2021, Bangalore (India)
- 17th Int. Conf. on Principles of Knowledge Representation and Reasoning, 2020, Rhodes (Greece)
- 28th IEEE RO-MAN, New Delhi, Oct 2019 (India)

Invited Talks and Seminars in the period (>30) : Université du Québec (Montréal), PlanRob ICAPS 2020, Samsung AI (Cambridge, UK), Dagstuhl Cognitive Robotics (Germany), ERF Malaga (Spain), MBZIRC Symposium 2020 (Abu Dhabi), Institutional Robotics Lisboa (Portugal), Future Intelligence 2021 (Toulouse), NII-Shonan (Japan), …..

Important Dissemination Activity : 15 events
PhD Award: Kathleen Belhassein, Prix de Thèse 2022 de la Maison des Sciences de l’Homme et de la Société de Toulouse
Paper Awards: 1 Best paper, 2 Finalist Best and Student Paper
Organized events: 7 events


1. **Anthony Favier (2021-2024)** : Human-Aware Task Planning *(ANITI)*


4. **Smail AIT BOUHSAIN (2021-2024)** : Combined Task and motion planning *(T. Siméon, R. Alami)*

5. **Simon Wasiela (2021-2024)** : Control-Aware Motion Planning *(T. Siméon)*

6. **Emmanuel Bazucchi (2021-2024)** - co-advised with Anne-Laure Gatignon Turnau

7. **Kevin Alcedo (2023-2026)** – co-advised with Prof. Pedro Lima *(IST Lisbonne)*

2. **Hendry Ferreira Chame (2020-2021):** Sensori-motor processes for Human-Robot Interaction – Joint Intention *(ANITI)*


4. **Shashank Shekhar (2021-2024):** Integration of Semantic reasoning and Epistemic Planning in Human-Aware Task Planning –
Visiting researchers

- **Vicente Matellán Olivera**, Universidad de León (September 2021-July 2022)
- **Camino Fernandez Llamas**, Universidad de León (September 2021-July 2022)
- **Alessandro Umbrico**, CNR Rome (November 2022)
- **Gerardo Pérez González**, Universidad de Extremadura (June 2023- October 2023)


• R. Bailon-Ruiz, A. Bit-Monnot, S. Lacroix, Real-time wildfire monitoring with a fleet of UAVs, *Robotics and Autonomous Systems*, Volume 152, 2022,


• A. Mayima, A. Clodic, R. Alami, Towards Robots able to Measure in Real-time the Quality of Interaction in HRI Contexts, *International Journal of Social Robotics*, Springer


Futuristic pictures by Jean-Marc Côté issued in France in 1900 (cited by I. Asimov)

« Science et Vie » magazine
June 1960