Semester/Master's Thesis, Guided Research, Interdisciplinary Project (IDP)

Risk-Aware and Composable Skill Learning from Demonstrations with Language-Conditioned Feasibility

Background & Motivation

Learning from Demonstrations (LfD) is a powerful paradigm for enabling robots to perform complex manipulation tasks in human-centered environments. Our previous work [1], Demonstration to Adaptation, proposes a unified framework for learning object-centric task constraints from demonstrations and adapting them online to dynamic environments. The framework enables smooth trajectory generation and real-time constraint relaxation, allowing robots to robustly execute sequential tasks under disturbances. However, several important challenges remain open, including how to reason about risk in constraint relaxation, how to compose multiple demonstrated skills into longer-horizon behaviors, how to interface skill execution with high-level language instructions, and how to efficiently incorporate human feedback when failures occur.

Description

This master thesis project aims to extend our previous work on demonstration-based adaptation toward a more general, composable, and interactive skill learning framework. The project will focus on learning coordinate-invariant task constraints from demonstrations and modeling them as distributions, enabling risk-aware execution and controlled constraint relaxation. Building on this representation, demonstrated subtasks will be organized into a composable skill graph defined on *SE(3)*, with continuity guarantees to ensure smooth and physically consistent execution when switching or stitching skills. In addition, the project will explore language-to-skill interfaces, where each skill exposes symbolic preconditions/postconditions and a continuous-domain feasibility score. This allows high-level language instructions to be grounded in low-level control feasibility. Finally, the framework will support low-burden human-in-the-loop correction, where user feedback is requested only when necessary and is attributed to specific failure modes for efficient reuse.

Your Tasks

- Study and extend an existing demonstration-based manipulation framework
- Implement risk-aware constraint modeling and online adaptation
- Implement and evaluate a composable skill graph with smooth switching
- Integrate language-conditioned skill selection with feasibility verification
- Validate the system in simulation and/or real-robot experiments

Requirements

- Master student in Robotics, Computer Science, or a related field
- Solid background in robotics, control, and linear algebra
- Experience with C++ and ROS are a plus
- Familiarity with optimization, motion planning, or learning from demonstrations is preferred
- Strong motivation for research and experimentation

We Provide

- Collaboration opportunities with different university research staff
- Close supervision and mentoring throughout the project
- Authorship on resulting publications, depending on the contribution

Supervisor:

Prof. Dr.-Ing. Matthias Althoff

Advisors & Contact:

Yue Zhang (yue22.zhang@tum.de),

Kuanqi Cai(Kuanqi.cai@epfl.ch)

TUM School of Computation, Information and Technology

Associate Professorship of Cyber-Physical System

References

[1] K. Cai *et al.*, "Demonstration to Adaptation: A User-Guided Framework for Sequential and Real-Time Planning," *2024 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, Abu Dhabi, United Arab Emirates, 2024, pp. 9871-9878, doi: 10.1109/IROS58592.2024.10802661.