Learning for Integrated Task and Motion Planning: Application to the 2025 AAAI Bridge Program

Sarah Keren[1], **Brian Williams**[2], **Michael Posa**[3]

[1]Technion - Israel Institute of Technology
[2]Massachusetts Institute of Technology
[3]University of Pennsylvania
sarahk@cs.technion.ac.il, williams@csail.mit.edu, posa@seas.upenn.edu

Introduction

Robotic agents are required to accomplish increasingly complex and longer-horizon tasks autonomously. This requires developing novel approaches for computing increasingly elaborate and robust plans that optimize the agents' behavior and allow them to deal with unexpected events. Effective solution approaches for such settings need to manage a rich coupling between three levels of abstraction - task, motion, and control. At the highest level, there is a need to find a policy that prescribes high-level actions that need to be performed to achieve some abstract task. For example, a high-level plan may require picking up a tool needed to achieve the goal of fixing a faulty machine. The next level of abstraction is responsible for planning the *motions*, i.e., physical movements, of the robot that are required for executing each prescribed high-level action. This means, for example, finding a sequence of motions that reach a robot configuration from which the tool can be grasped. Finally, at the lowest level, there is a need to control and monitor the execution of each planned motion in order to reach the robot position, or robot configuration, prescribed by the motion planner.

Effectively integrating these three components has been established as a challenging sequential decision-making problem that requires integrating skills and tools from different research disciplines, investigated by different research communities. This makes the integration of motions and high-level actions especially challenging and constitutes one of the major bottlenecks towards enabling a variety of applications, including mobile manipulation, household robotics, healthcare robotics, and robots for disaster recovery.

Our proposed bridge program aims to bring together researchers from different research communities and help catalyze the next generation of research in combining AI, machine learning and robotics and developing robots that are capable and efficient at all levels of deliberation and decision-making. We aim to introduce participants coming from different disciplines to a variety of methods of cognitive systems and robotics, thus creating a bridge between robotics and AI and setting the path to the creation of novel methods that combine the tools and expertise from each discipline.

Significance

Until recently, investigations into the three aspects of this problem were fragmented into distinct communities. On the one hand, AI planning community developed approaches for task planning that scale to large discrete domains, by using different forms of factoring to decompose the state space and by incorporating these methods within a repertoire of domain-independent planning algorithms. However, while these approaches have been effective in very large domains, they typically abstract most real-world physical considerations that are esential to planning the motions of robots. On the other hand, research in robotics has achieved great progress in motion planning, which focuses on finding an optimal, continuous motion that respects constraints on kinematics, dynamics and obstacles. However, these approaches typically focus on short-horizon planning, isolated from consideration of the tasks that they support.

Over the last decade the AI planning, control and robotics communities have each been exploring a bridge between tasks and motions. These go under the name of hybrid activity and motion planning within the AI community, logic-based control in the hybrid control community and task and motion planning within the robotics community. We will use TMP hence forward to refer to all three.

Recent advances in TMP have resulted in a flourishing field with multiple approaches, practical demonstrations, and frameworks. The AI community has developed planners that generate actions and motion simultaneously, based on constraint programming plus heuristic forward search, and have developed architectures for coordination task and motion planners, using state plans to mediate between the two. The logic-based control community synthesis hybrid discrete / continuous controllers be synthesizing discrete automata from logical specifications and by synthesizing continuous controllers to implement the transitions of these automarta. Finally, the robotics community generate task plans using methods from the AI planning community, while using policy synthesis or learning methods to construct motion primitives or skills that implement actions within these task plans.

In recent years, there has been a vibrant focus on applying machine learning to combined task and motion planning. This includes using imitation learning, based on diffusion models or LLMs, to learn plans from motion, visual and language input. These include task plans, motion plans and their hybrid. Methods have been developed for learning planing domain models, for example, based on LLMs, variational encoders and inverse reinforcement. Finally, a range of methods have been developed to improve visual interpretation and monitoring, for example, range from graph neural nets to deep hybrid automata.

Learning for task and motion planning will be the focus of our proposed bridge. The objective of our proposed program is to provide the audience with a concrete understanding of learning for task and motion planning, theoretically well-founded and practical formulations and algorithms for addressing learning for TMP problems, as well as knowledge of the open challenges that are yet to be addressed and promising approaches for addressing them.

By introducing the foundations of TMP, learning for TMP, and the perspectives taken by each research community, we aim to enable diverse groups of researchers to develop novel approaches and a unified view that supports compelling applications in a variety of domains, e.g., household robotics, healthcare robotics, wildfire detection and prevention, and agriculture.

Our program will provide a diverse group of researchers a unique opportunity to begin utilizing these methods and to share their views on the ongoing challenges faced by the community.

Program Outline

Our novel bridge program will offer challenge problems, tutorials, laser talks and panels on major elements of TMP and learning for TMP that are required to develop capable and dexterous autonomous robotic systems. The content will center around various related themes including motion planning, task planning, robust execution and control, perception, and manipulation, planning under uncertainty and risk, imitation and reinforcement learning, and more.

We propose a two-day program. Each day will start with two lectures given by prominent researchers, including speakers who perform research at the crossover between learning, robotics, and AI. It will also include one or two vision and challenge talks, to set the context for the field.

Because lectures alone are not enough to have a lasting impact, we will complement them with two hands-on lab sessions each day. During the labs, participants will implement ideas discussed in the talks and will solve problems in a simulated robotic setting. To encourage exchange of ideas, work will be done in groups, with participants from different backgrounds. At the end of each lab session, we will facilitate a discussion on challenges that were encountered during the labs and potential solutions approaches.

To further foster discussions, participants will be asked to provide 1-2 minute laser talks and will be encouraged to bring posters, which will be available throughout the day, with dedicated poster sessions during the breaks.

Target Audience

Our proposed program is relevant to researchers interested in developing capable real-world robotic systems, enabled through task and motion planning systems that combine a balance of model-based and machine learning methods. Of particular relevance are researchers from machine learning, perception, AI, Robotics and control who are interested in this enterprise.

The intended audience includes graduate students, postdocs, and junior researchers from both the cognitive AI and robotics disciplines. We anticipate around 50 participants.

Foundations for a New Research Community

Our goal is to catalyze a new community focused on learning for task and motion planning. Thus, participants of our program will benefit not only from the new knowledge they will acquire from our speakers and from the hands-on labs, but also from meeting each other and from the opportunity to exchange ideas with researchers from different backgrounds. We aim to create a collaborative research community and foster potential interdisciplinary collaborations around the bridge's theme. For this purpose, participants will be encouraged to stay connected and to share our open-source community with their colleagues and peers. The bridge program will provide the foundation for what we hope will be a more cohesive and more collaborative community in cognitive robotics.

Prior Initiatives

The proposed program is inspired by the Summer School on Cognitive Robotics series that was held at MIT and USC between 2017-2019 and brought together students from AI task planning, robotics motion planning and control (see https://sites.usc.edu/cognitive-robotics/ for details).

It is further inspired by the ICAPS 2024 Summer School program, which focused specifically on task and motion planning, while again bringing together students from AI, robotics, and control (see https://icaps24.icaps-conference.org/summerschool for details; technical sessions can be found at https://github.com/CLAIR-LAB-TECHNION/ICAPS-24).