Planning for Symbiotic Action

Tathagata Chakraborti
3rd yr PhD Student, Computer Science, ASU
Advisor: Dr. Subbarao Kambhampati
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INTRODUCTION

The field of Artificial Intelligence (AI) has become increasingly prominent in recent times, with the integration of intelligent components into devices and services we use in everyday life. As the capabilities of such systems become increasingly complex, one branch of AI that becomes increasingly relevant is that of automated planning or sequential decision making, in order for these components to participate in diverse long term tasks. A key aspect of such systems is increased interaction with humans...

Challenges in Human-in-the-Loop Planning (HILP). Classical planning has traditionally emphasized on the efficiency or accuracy of the plan generation process. However, in real world applications, especially involving humans, planners must deal with typical challenges including uncertainty and partial knowledge, and issues involving priorities and authority. Technologies that become crucial in this context involve abilities to dynamically predict, anticipate and adapt to changing needs while making task plans. My research focuses on such aspects of “human-in-the-loop planning”.

Modalities of HILP - My Research Focus. As part of my research, I have looked at two specific ways in which automated planners may interact with humans. Section 2 describes how planners can enable different types of autonomous behavior of robots sharing their workspace with humans - i.e. interacting with humans as colleagues. On the other hand, Section 3 will look at possible roles of planning technologies in platforms that involve collaboration with or among human planners. The aim of my thesis is to provide technologies for and motivate principle well-informed design of complex symbiotic man-machine systems of the future.

HUMANS AS COLLEAGUES

Many of today’s robots being built for tasks such as household assistance or hotel/office service robots or security guards, do not operate in human-robot teams, i.e. they do not have common goals and commitments with humans sharing the environment. We postulate that interaction with the human cohabitants in such cases should be similar to how we interact with our human colleagues rather than teammates. This provides many interesting possibilities in modeling autonomous behavior in such service scenarios - the agents show modes of passive or stigmergic collaboration.

2.1 Planning with Resource Conflicts

In [11, 10], we look at how robots sharing their workspace with humans, and using shared resources, can plan to minimize conflicts on resource usage. We propose a planner that models the intentions of the human colleagues and produces plans that decouple its resource demands with that of the humans’. Note that there is no explicit or direct interaction here between the human and the robot, the interaction is successful inasmuch as the human’s plan was successful.
Resource Profiles. We represent information from predicted plans in the form of resource profiles, that enables the robot to reason with how the environment will evolve with time, at different levels of abstraction. This way we compile the complexity of accounting for individual predictions into the number of resources being modeled, which makes our approach independent of both the number of agents being modeled and the size of the hypothesis goal set.

Modes of Behavior. We show how our approach models different behaviors of the robot - (1) compromise, where the robot opts for suboptimal plans in order to respect the human’s plans; (2) opportunism, where the robot predicts favorable changes to the world and produces plans even better than the original optimal ones; and (3) negotiation, where the robot negotiates desired times of use of the resources with the human.

2.2 Planning for Serendipity

In [5, 6], we look at how robots can provide assistance to their human colleagues without the latter expecting help, i.e. the robot plans to produce serendipitous interventions (which appear as positive exogenous events) during execution of the human’s plans. Contrary to the discussion in Section 2.1, here the robot’s actions directly modify the human’s plans rather than just effect it indirectly by avoiding potential conflicts. Note that the human, being unaware, cannot plan to exploit these interventions in advance, which imposes several constraints on the plan generation process.

Plan Interruptibility. In order to produce serendipitous interventions, the robot computes parts of the predicted human plan that can be replaced by a (cheaper) plan involving both the human and the robot.

Plan Preservation. But of course all removable sub-plans do not lead to serendipitous interventions, the robot has to ensure additional constraints that involve preserving the prefix of the original human plan abd the world state he originally intended to be in after the intervention. A demonstration can be viewed at http://bit.ly/1Q6tOBW.

2.3 Interaction in Human-Robot Societies

Even though all of the scenarios discussed so far involve significantly different levels of autonomy from the robotic agent, the underlying theme of autonomy in such settings involves the robot achieving some sense of independence of purpose in so much as its existence is not just defined by the goals of the humans around it but is rather contingent on tasks it is supposed to be achieving on its own. Thus the robots in a way become colleagues rather than teammates. This becomes even more prominent when we consider interactions between multiple independent teams in a human-robot cohabited environment, as shown in the figure. In this work we investigate the different modalities of such interactions in human-robot societies at three levels - plans, resources and goals. We also motivate the need for developing appropriate metrics for measuring and comparing performance in such settings, as has been established in the field of human-robot teaming. Details of this work can be found in [8, 9, 7].

2.4 Tools for Synergy in Human-Robot Teaming/Cohabitation

Role of Belief Modeling. One necessary requirement for generating such behaviors of the robot is the ability to model the capabilities and intentions of other agents in its environment. In [14] we represent such information in first order logic, and cast the evolving and complex structure of beliefs, and inference over
them, as a planning and plan recognition problem, and show how this may be used to inform the planning process of the robot. In [16] we look at how the human’s expectations should inform the planning process of an AI collaborator in terms of how explainable a robot’s task plans are to its human colleague. Video demonstrations of these concepts are available at http://bit.ly/1oqZSu3 and http://bit.ly/1TbWqA4.

**Role of Plan Recognition.** Perhaps the most important tool required to enable such technologies as the ones discussed till now is plan recognition. In [15] we investigate how humans respond to the robot’s ability to anticipate their actions and provide proactive assistance. Specifically, we look at to what extent plan recognition really improves teaming performance, and its role on mutual trust, situational awareness and cognitive overload. I also have ongoing work that looks at developing plan recognition technology specifically designed for resource-constrained agent interactions (adversarial or cooperative).

**Humans as Collaborators**

In this section we will look at the role of automated oversight in human computation tasks - specifically we investigate how an automated planner can contribute to a plan generation process carried out by humans. In order to collaborate with human planners, we postulate that automated planners must be able to perform two fundamental tasks -

*Interpretation.* In order for the planner to make useful contributions, it must first comprehend the current state of the planning process, as well as the intentions and (often implicit) preferences of the human planners.

*Steering.* The planner must iteratively refine, validate and critique the planning process, while respecting the authority of the human planners. The goal of this work is to augment the vast domain knowledge of humans with the superiority of automated components in constraint checking and plan validation.

### 3.1 Crowdsourced Planning - AI-MIX

In [12, 13] we investigate how planners can work with a crowd, using extremely shallow models (in the tour planning domain). We show how a PDDL domain may be used to support and critique the plan generation process, and how declarative logic programs (like ASP) can be used to compile all the constraints to generate the final plan. Our system is the proud winner of the People’s Choice Best System Demonstration Award at ICAPS’14.

### 3.2 Proactive Decision Support - RADAR

We are currently working on a system [4] that can use more complete domain models to collaborate with experts on specialized tasks (like disaster response). An aspiration video is available http://bit.ly/1KEJZKj. I am more involved in the planning aspect of the project. Planning applications include plan recognition for preemptive assistance with both the plan generation and the proactive context-based information integration process, and plan validation and refinement using techniques like landmark generation and plan robustness. A preliminary demonstration of these capabilities can be found http://bit.ly/1o22ajr.

**Miscellaneous Work**

Besides the two main themes discussed so far, I am working on planning algorithms and applications to build smarter AI agents that can be integrated into human ecosystems. Some of them are mentioned below.
4.1 Learning Preferences in Higher Level Plan Execution

Execution of task plans has traditionally involved decomposing each higher level action in a plan into lower level action primitives more or less independently, with little consideration for constraints that might be imposed by the larger context of the plan of which they are a part of. However, such constraints or preferences from the underlying task plan can make some execution pathways undesirable or even infeasible (even though they may be correct when viewed separately). In [2] we propose an approach that can model these constraints and show how it can affect long-term trajectory or motion planning in general.

4.2 Integration of Automated Planning in Smart Systems

Centralized architectures for systems such as smart offices and homes are rapidly becoming obsolete due to their inherent inflexibility in design and management. Further to fully harness the capabilities of these massively integrated systems, higher level reasoning engines are required so that it can plan for and achieve long-term goals. This is the focus of [3], where we address these challenges by outlining a set of properties that can accommodate the desired capabilities, and develop a general architecture for the same.

4.3 Robust Planning and Safety

The notion of robust plans was originally developed to process uncertainty when planning with incomplete domain models. In [1] we argue that one area where such models are not only useful, but necessary, is in the context of safety in planning under uncertain interactions with humans-in-the-loop. To this end, we discuss how the concept of plan robustness, and associated techniques for robust planning, lend themselves to interpretations of provably safe AI agents.

REFERENCES


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