Getting help without asking: Stigmergic planning for human-robot collaboration
(Extended Abstract)

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ABSTRACT

A robot may be unable to perform an action necessary for accomplishing its goal even though other agents in the same environment can perform the action. In that case, the robot should develop a composite plan that includes the necessary action and try to recruit the other agents to perform that action. Even if the robot is unable to communicate explicitly, it may be able to modify the shared environment to stigmergically evoke the necessary action.

CCS Concepts

•**Computing methodologies** → *Multi-agent planning; Robotic planning;*

Keywords

Human-Robot Teaming, Stigmergy, Human-Aware Planning, Multi-Agent Planning

1. INTRODUCTION

When a robot is unable to perform one or more actions that are necessary for accomplishing its goals, it should be able to integrate into its plan the capacities of other agents that can perform the action on its behalf. We consider a robot sharing an environment with a single human. However, our methodology is applicable to interactions between more than two agents and to interactions between robots.

First, we demonstrate how the robot can incorporate the human's abilities into a composite plan and ask the human to perform the desired action. We then consider the possibility that the robot is unable or unwilling to talk to the human to ask for help. In this case, the robot can use stigmergy, which involves indirect coordination between agents by means of traces left in a shared environment[2]: the robot modifies the environment in order to cause the human to perform the desired action.

2. MODIFIED-SERENDIPITY

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Previous work[1] has formalized and implemented a human-robot teaming technique whereby a robot creates "serendipitous" conditions to help a human accomplish her goal. In that system, the robot does not make any explicit commitment. Instead, the robot attempts to construct a composite (involving both robot and human) plan with lower total cost that the human's original plan. If the robot can communicate with the human, it tells the human about the new plan. However, if communication is unavailable, and if necessary constraints are fulfilled, the robot uses stigmergy to effect the composite plan. The robot's contribution to the composite plan alters the shared environment in such a way that when the human calculates a new optimal plan the result is the human contribution to the composite plan. This new plan has lower cost than the original plan. This system uses Integer Programming to find composite plans that satisfy the constraints necessary for such "planned serendipity".

We propose a minor modification to this system to take into consideration the robot's goals, which may be independent of the human's goals. As presented, only propositions in the human's goals are constrained to be true at the planning horizon. We modify the system to include the robot's goals in this constraint. We call the modified system *Modified-Serendipity.* We apply Modified-Serendipity to our problem of recruiting agents to help the robot accomplish a task that it cannot achieve alone.

The following algorithm allows the robot to use Modified-Serendipity when appropriate. First, the robot attempts to construct a plan to accomplish its goal state based on its available actions. If it finds a plan, the robot carries out the actions in the plan and the algorithm terminates. Otherwise, the robot creates a representation of a super-agent consisting of all agents sharing the robot's environment. The super-agent has a composite goal state consisting of the union of the goal states of all agents. If the robot can communicate with the other agents, it again attempts to construct a plan to accomplish its goals using the union of its possible actions and those of the other agents. If the robot finds a plan, it asks the other agents to perform the actions that it cannot perform. If communication is not possible (or in order to exploit an antagonistic agent), the robot invokes Modified-Serendipity with the composite goal state. If Modified-Serendipity yields a solution, the robot carries out the actions assigned to it by the plan. Note that the Modified-Serendipity will only return a plan if all parts of the goal state are fulfilled. If multiple such plans exist, it will return the plan with the lowest cost.

3. EXAMPLE SCENARIOS

Our example scenarios share the following assumptions: The human has perfect knowledge of the shared environment but does not know the robots goals or plans; The robot has perfect knowledge of the shared environment and of the human's goals; The robot knows that the human will calculate plans that are optimal given the human's knowledge, and thus the robot has perfect knowledge of the human's plans.

In our first example scenario (Figure 1), the robot has the goal to move to a charging station in Room 1, on the far side of a door which only the human can open. Rooms 1 and 2 contain wrenches, and the human plans to move to Room 2 to get the wrench there. The robot cannot create a plan to achieve its goal using only its own actions because it is unable to open the door. Instead, the robot constructs a composite plan that includes actions that the human can perform. Then the robot asks the human to open the door and, after the door is open, moves to the charging station.

Alternatively, if communication is impossible or undesirable, for example, because the human finds that talking to the robot takes too long, the robot can try to get the human to open the door without asking. The robot uses stigmergy to effect the composite plan. Since the human knows that there is a second wrench in Room 1, the robot assumes that she will go there if she does not find the wrench in Room 2. Thus, the robot makes the following composite plan: the robot moves the wrench from Room 2 to Room 3; the human goes to Room 2, sees that the wrench is missing, and goes to Room 1 (opening the door) to get the other wrench; the robot goes through the open door and moves to the charging station.

This composite plan requires the robot to deceive the human. Furthermore, it requires the human to do more work than her original plan. Either or both of these considerations might be admissible in the case of a collaborative relationship, i.e. if the human wants the robot to achieve its goal. However, the robot will have to consider any added costs to the human when making a composite plan. Alternatively, in an indifferent or adversarial setting, the robot might disregard the increased cost.

In our second scenario (Figure 2), the robot has the goal to move to the charging station in Room 5, but is again barred by a door that only the human can open. The human plans to move to Room 4 to get the wrench and the hammer. The robot constructs the following composite plan: the robot moves the wrench from Room 4 to Hall 8; the human enters Hall 8, sees the wrench there, and calculates a new optimal plan for retrieving a wrench and hammer; the human gets the wrench from Hall 8 and the hammer from Room 5 (opening the door); the robot goes through the open door and moves to the charging station.

Unlike our previous example, this composite plan is less work for the human than her original plan. It not only permits the robot to accomplish its goal, it is also serendipitous for the human.

4. CONCLUSIONS

In this preliminary presentation we have proposed to apply a planning algorithm developed in previous work to a novel problem: How can a robot use stigmergy to recruit help and overcome the inability to perform an action? Next, will perform a suite of experiments to test and evaluate our approach in a variety of scenarios. Finally, while we have assumed perfect knowledge and human planning optimality; future work will relax these assumptions by incorporating belief models [3] into the framework.

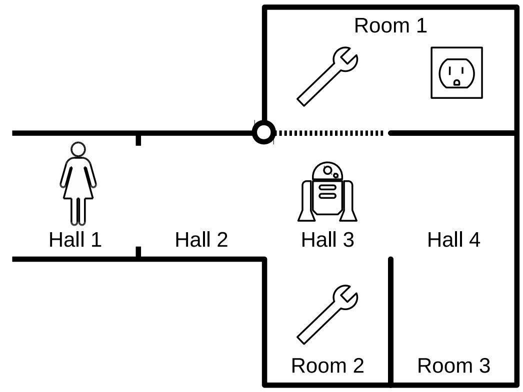

Figure 1: The robot's goal is to move to the charging station in Room 1, but it is barred by a door (dotted line). The human's goal is to move to Room 2 to retrieve the wrench. There is also a wrench in Room 1.

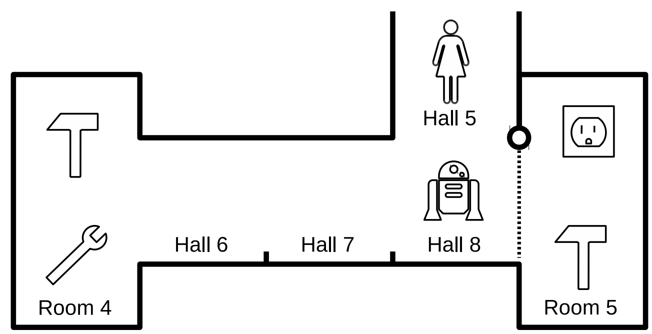

Figure 2: The robot's goal is to move to the charging station in Room 5, but it is barred by a door (dotted line). The human's goal is to move the Room 4 to retrieve the wrench and the hammer. There is also a hammer in Room 5.

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