TOWARD A GOAL-BASED MISSION PLANNING CAPABILITY
Using PDDL Based Automated Planners

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Abstract: This paper proposes a generic goal-based mission planning framework which provides an integration environment to support evaluation of existing planning and task assignment technologies. The framework facilitates planning across a team of heterogeneous assets with a distributed capability for generating plans to collaboratively achieve goals. A human operator assigns a team with a top-level goal which the framework then decomposes into a list of tasks that can either be tackled by an individual asset or collectively by a sub-team of assets with the appropriate capabilities. Each asset can generate individual plans with knowledge of the current world state and a goal state. A selection of candidate planners are investigated using the framework including a Hierarchical Task Network (HTN) Planner for goal decomposition and a Partial Ordered PDDL (Planning Domain Definition Language) Planner for action-based plan generation. The developed framework is applied to a search-and-rescue scenario requiring a team of UAVs (Unmanned Aerial Vehicle) to search a specified area of operation.

1 INTRODUCTION

Successful planning for large scale missions can be a difficult process requiring good understanding of the overall mission objectives, knowledge of the capabilities of available assets and ability to update the top-level plan as new information becomes available. Converting the top-level plan into a list of tasks which are then assigned to individual assets, both manned and unmanned, represents a significant proportion of the effort in the planning problem. Development of a goal-based mission planning framework aims to automate part of that process making it easier for operators to manage a team of assets. The planning solution supports the following features:

- Handling planning within ad-hoc teams of assets which dynamically change over time
- No central point of failure within the system
- Decentralised task allocation and mission planning
- Changes to state requiring regular re-planning

A search and rescue problem involving a team of simulated UAV assets has been defined to evaluate the mission planning framework. This scenario has similarities with the open vehicle routing problem (Li, Golden and Wasil, 2007), and the travelling salesman problem. At each location in the search area a number of tasks may be required to be executed depending on whether a survivor has been found or if the location has previously been searched.

2 PLANNING FRAMEWORK

A generic mission planning framework has been proposed, with the key components illustrated in Figure 1. An instance of this framework will run independently onboard every asset in a team. The components are responsible for the following:

Task Manager: Maintains a task-stack and is responsible for requesting the next task from the list when the current task has been completed.

Coordinator: A central module which supports interfacing between other modules in the framework.

Goal Decomposition Module: Interfaces to an underlying HTN planner which decomposes top-level goals into manageable tasks.

Task Assignment Module: Computes the next available task to be completed by the asset based on a team utility value.

Automated Planner Module: Interfaces to an underlying PDDL planner which computes a list of actions given an initial state and a goal state.

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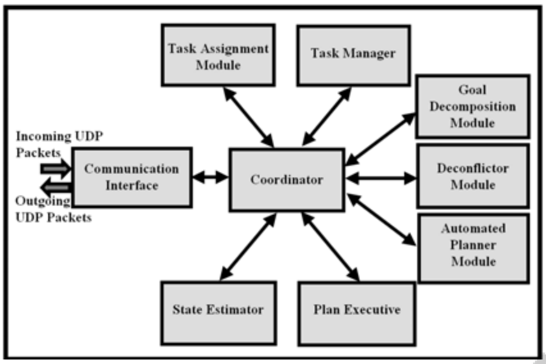

Figure 1: Goal-based planning framework.

State Estimator: Stores current world-state information for assets in a team.
Deconflictor Module: Stores future world-state information determined by assets sharing plan steps and used to detect potential location/resource conflicts in generated plans.
Plan Executive: Responsible for executing deconflicted plans generated by the Automated planner module. Also provides a low-level collision avoidance mechanism to protect against deconfliction errors.
Communication Module: Supports UDP communication of state information and decisions between assets

The modular nature of the framework supports stand-alone implementation of the outlined components with a common interface defined between modules to facilitate easy integration. One novel aspect of the planning framework is the integration of a PDDL based planner, normally applied to deterministic, offline planning problems such as those set at the biennial International Planning Competition (Long et al, 2000). This technology supports on-the-fly goal-based planning and re-planning to complete assigned tasks. This is in contrast to developing a multi-agent framework based on the BDI (Belief, Desire & Intent) paradigm which commonly utilise pre-compiled plan fragment libraries to construct plans (Bellifemine, Poggi and Rimassa, 1999; Howden et al, 2001; d'Iverno et al, 2004).

The Goal Decomposition module uses the JSHOP2 HTN planner to determine the required tasks to complete an assigned goal. The Task Assignment module applies a brute-force method, but future research will consider integrating auction-based approaches such as CBBA (Brunet, Choi and How, 2009), or meta-heuristic approaches such as simulated annealing (Osman, 1993). Plan deconfliction currently assigns priorities based on the assigned task, but future work will consider spatial and temporal deconfliction to locally repair plans and resolve conflicts.

3 SCENARIO

A Search-and-Rescue scenario has been defined to provide a test case for the prototype framework. This is based on a team of helicopter UAVs which can be tasked with searching for survivors in an area of operation, perhaps following the occurrence of a natural disaster. The problem was simplified by considering only four possible moves for each UAV - north, south, east and west. A turning circle was modelled in the problem such that a vehicle could not directly move in the opposite direction to which it is facing. Additionally, it was assumed that once a survivor was identified, they would remain fixed at that location.

To tailor the framework to handle the scenario required a set of tasks and their relationship to top-level goals to be represented as a HTN domain, and the set of low-level actions and their relationships to tasks to be represented as a PDDL domain. The output list from the Goal decomposition module will be composed of a combination of the low-level tasks which are required to achieve the assigned top-level goal. The output plan from the Automated Planner module will be composed of a list of the low-level actions which achieve the assigned task.

The following processes are performed whenever the distributed team is assigned a new top-level goal:

1) A Top-level goal is assigned to all team members
2) Each team member decomposes the goal into a list of sub-tasks which are stored in a task stack
3) The Task Assignment module is invoked to select the next task from the stack which the asset can complete
4) If a plan is required, the Automated Planner module generates a problem definition file and the PDDL planner is invoked
5) The output plan is checked for potential conflicts by the Deconflictor module and the plan steps are shared with other assets via the Communication Interface. If conflicts exist a replan may be required
6) Once conflicts have been resolved, the plan is passed to the Plan Executive which executes the actions

Steps 3-6 are repeated until the task stack is empty. Updates to the state data which may require additional tasks will result in Step 2 being executed again to update the task stack (such as discovery of a survivor). If a new goal is assigned to the team then Steps 1 and 2 are repeated.

4 COMPARISON BETWEEN PDDL PLANNERS

To demonstrate how the framework can be used to evaluate planning technology, some candidate planners were selected for comparison. Due to the modular architecture of the developed framework, it is easy to switch between planners. This is an advantage of using the generic PDDL planning language to express the scenario (Fox and Long, 2003). The performance of two candidate PDDL planners were compared – POPF and SGPlan.

The POPF planner was selected following collaboration with SciSys UK Ltd and the Strathclyde University Automated Planning group (Coles, Coles, Fox and Long, 2010). SGPlan was selected as an alternate planner as it was a winner in the Deterministic Planning track of the 2006 International Planning Competition (Hsu and Wah, 2008).

A mission scenario was defined where 6 assets with sensor capability are tasked with searching an area with no hidden survivors. However a range of search area sizes were tested varying from a 5x5 to an 8x8 grid. Results for the number of required team moves and plan generation times were recorded using both the SGPlan and POPF planners.

Figure 2 demonstrates a comparison of the plan generation times between the two planners executed on a 2.2GHz processor. For the 5x5 case POPF and SGPlan have comparable times, 0.58 secs and 2.5 secs respectively. However, the POPF planner takes a lot longer to generate a valid plan in the 8x8 case, 78.6 secs compared with 3.7 secs for SGPlan.

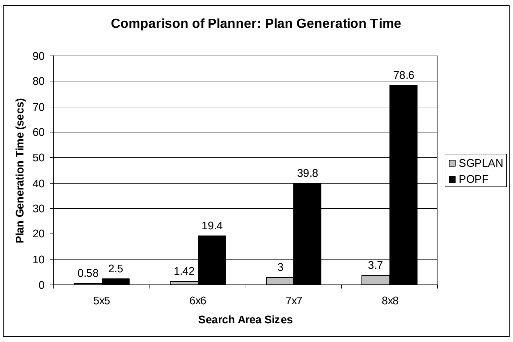

Figure 2: Plan generation time.

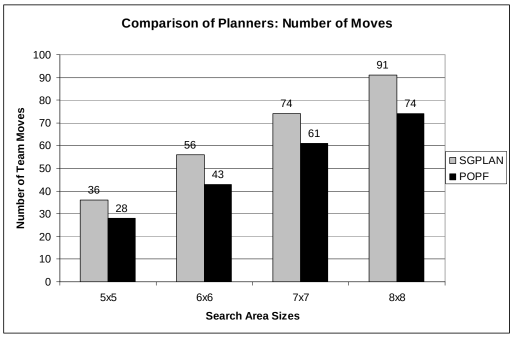

Figure 3: Number of team moves.

Figure 3 shows that the required number of plan moves produced by POPF is better than that produced by SGPlan. In the 8x8 case, SGPlan requires 91 moves to complete the search where as POPF requires 74 moves. This was found to be due to a number of inefficient steps in the plan produced by SGPlan whereby assets would transition over unsearched grid locations and not perform a search operation, requiring an asset to return later in the plan. The observed performance difference between the planners is comparable to those highlighted by the Strathclyde Automated Planning Group (Coles, Long and Rendell, 2010).

Although both planners found valid solutions in all cases, platform utilisation in the plans generated by SGPlan was not evenly distributed across the team, compared with the results produced by POPF. For the case of an 8x8 search area, Figure 4 and Figure 5 demonstrates the area search coverage for each asset executing plans produced by SGPlan and POPF respectively. Most of the search actions in the plan produced by SGPlan are performed by UAV5 and it can be seen that UAV1, 2 and 3 only search the squares they initially occupy with no further movement. Not visible in Figure 4, there are also a number of unnecessary moves in the generated plan whereby an asset does not perform a search as it passes over an unsearched location, requiring a transition back to that location later in the plan.

The results for the POPF planner, illustrated in Figure 5, demonstrate improved asset utilisation. The number of moves performed per asset varies between 11 and 14 in this case. The generated plan is not optimal but significantly improves upon the number of unnecessary moves observed with SGPlan.

This highlights that there is a trade-off between the solutions produced by the two planners. SGPlan can generate a valid plan quicker than POPF and was found to be able to handle slightly larger search areas. However, this is at the expense of plan quality

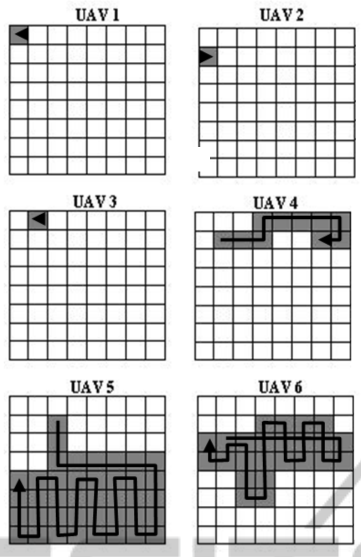

Figure 4: Asset coverage for SGPlan software.

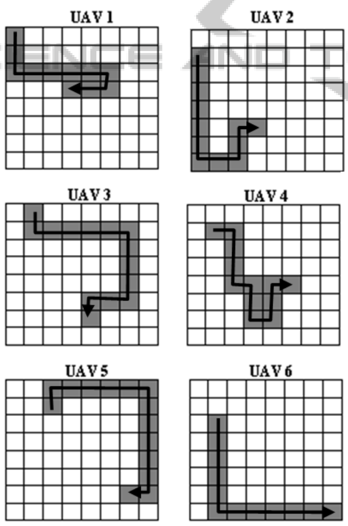

Figure 5: Asset coverage for POPF software.

for this particular scenario where asset utilisation is not evenly distributed and there are a number of inefficient steps inserted in the plans. These are the factors which should be considered when selecting an appropriate planning solution.

5 CONCLUSIONS

Tailoring the prototype framework to a simple Search-and-Rescue scenario has enabled a proof-of-concept evaluation to be performed. This has demonstrated that it is feasible to construct a decentralised mission planning system which is capable of performing goal-decomposition, task allocation, automated planning and plan deconfliction.

The framework's modular architecture facilitates integration of algorithms such that it could be used as a test-bed to evaluate and compare planning technology. Future work will consider the following framework updates:

- Updates to the interface between the framework and the automated planners to support scalability to larger search spaces
- Handling of dynamic environments investigating extensions to PDDL, such as PDDL+ which enables modelling of external events and processes (Fox and Long, 2002)

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