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Search Complexities for HTN Planning

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1 Introduction

From home assistance robots [7] tointeractive instructions and diagnostics [6], Hierarchical Task Network (HTN) planning is key formalism for systems that intelligently respond to human interaction. HTNs represent procedural knowledge on how to break down complex tasks into executable steps, and have also been used in planning for robotics [14], security testing [13], and plan recognition [5]. In large part, HTN planning extends classical planning [10], which focuses on using domain-independent heuristics to search for a sequence of actions to obtain a goal. Over the past 15 years, there have been significant advances in heuristics and heuristic search algorithms for classical planning [11, 12, 15], but for the most part, these techniques have not been incorporated into modern HTN planners.

This thesis [1] lays out the theoretical foundations necessary to adapt domain-independent heuristic search to HTN planning. To that end, this thesis discusses three areas: decidable subsets of HTN planning and their decision procedures, the theoretical difficulty of directly adapting domain-independent heuristics, and a translation of certain HTN problems directly into classical planning, so that any classical planner can be used for heuristic HTN search.

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2 Results

Although HTN planning is in general undecidable [8], this thesis identifies a number of widely-met restrictions on problem syntax that restore decidability, as well as algorithms that solve these problems. Analyzing decidable fragments of HTN planning allows for theoretical guarantees on planner performance, and more practically useful, the decision procedures for these fragments can identify unsolvable problems, which is required by a number of planning applications [4]. Later work has extendedthe results of this thesis to provide tight complexity bounds for a wide variety of syntactically constrained HTN problems [2, 3].

Even though the decision procedures provide termination guarantees, their worst case performance is still highly impractical, and so HTN planners may need heuristics to effectively search for solutions. Many of the successful domain-independent heuristics for classical planning rely on a technique called *delete relaxation* [12]. Delete relaxation makes a problem easy to solve by transforming the problem's actions so that actions can only add information to the problem's state. One can trivially solve delete-relaxed problems by greedily applying actions until a fixed point is found, and then checking whether the goal holds in the fix-point state. However, this thesis shows that deciding whether a delete-relaxed HTN planning problem has a solution is NP-complete. Barring a major breakthrough, any algorithm for solving such problems will take exponential time in the worst case.

Although efficiently computable delete-relaxation derived heuristics with full HTN semantics are out of reach (unless P = NP), the thesis gives two potential paths to HTN heuristic search. The first, more theoretically focused, is that an alternate set of HTN semantics, called HTN

Fig. 1 Fast-Forward's (FF's) CPU time in an office-delivery domain, with and without the translated HTN knowledge. In the graph at *left*, the number of packages to deliver is fixed at 40 and the number of reachable rooms varies. In the graph at *right*, the number of rooms is fixed at 40 and the number of packages varies
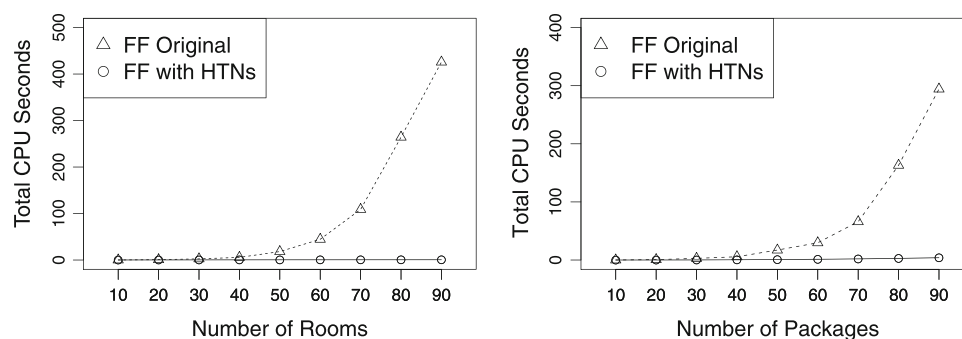
planning with Task Insertion [9], is polynomial-time decidable when delete-relaxed. Secondly, the thesis gives a translation of a common class of HTN problems into classical planning problems. Experiments from the thesis, excerpted in Fig. 1, show that a small amount of translated HTN knowledge can dramatically improve a classical planner's performance.

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