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Hybrid Planning and Scheduling

Bernd Schattenberg[1]

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1 Introduction

Planning and scheduling (P&S) constitute fundamental cognitive capabilities for systems to reason about plans and their causal structure. They are essential for producing a goal-oriented system behavior and supporting a user's decision making. While planning is the method of creating courses of action that achieve goals or perform tasks, scheduling assigns consistent allocations of time and resources to activities. "Hybrid planning" refers to a distinct paradigm, which integrates building plans based on the individual action's causal structure with obtaining plans from iteratively implementing abstract actions by pre-defined partial solutions. Combined, hierarchical model aspects represent regular solutions provided by domain experts, while causality-based techniques complete underspecified procedures and address exceptional cases. Applications of the technology range from planning out disaster relief missions [4] to assessing cyber-security measures [7].

2 Results

2.1 A Formal Framework for Refinement Planning

The outlined thesis [8] has developed a novel formal framework for an integrated treatment of hybrid P&S. Plan generation is based on a well-founded conceptualization of the *refinement planning* paradigm: an abstract problem specification is incrementally transformed into a concrete, executable solution. In doing so, the framework iteratively identifies uncompleted or defective portions of the plan, which in turn triggers the computation of appropriate plan transformations to resolve them. By taking all sound transformation options into consideration, it systematically explores a space of possible refinements for flawless plans, viz. the solutions to the given problem specification. All participating entities are explicitly represented in this approach and thus the refinement process becomes transparent to the framework. This is the basis for two essential results of this dissertation: first, any P&S method can be expressed in terms of the universal deficiency announcement and plan transformation principle and hence can be realized by *configuring* the formal framework. Second, the framework allows for developing novel planning strategies that take into account the plans' deficieny and transformation options.

2.2 Configurations of the Framework

The thesis presents classical paradigms like partial-order causal-link planning, hierarchical task-network planning, and classical scheduling as configurations of the framework. Based on their modules, it develops a formally well-founded, integrated treatment of action and state abstraction, which combines reasoning about causality with hierarchical, procedure-oriented methods: *hybrid planning*. Its implementation is capable of constructing and reasoning about a plan's causal and hierarchical structure across multiple levels of abstraction.

The framework is also used to realize an *integrated P&S* system. For the first time, a system combines a user-defined ensemble of P&S technologies on an operational level and

✉ Bernd Schattenberg
mail@berndschattenberg.de

[1] Büro für intelligente Technologie-Beratung, Laupheim, Germany

addresses the respective deficiencies adaptively by the available transformation operations. The respective representation of application domains incorporates temporal phenomena and resource manipulations for basic actions as well as on the abstract action level. This leads to the novel notion of *hierarchical scheduling*, in which the concept of abstraction is extended to resource representation and reasoning, e.g. resource aggregation and approximation.

2.3 Planning Strategies

The explicit representation of the refinement process allows for a novel class of *flexible* search strategies, which operate on problem characteristics as well as the current state of plan generation. *HotSpot* and *HotZone* strategies are representatives of this new breed. They take into account the structural dependencies between presumably problematic elements in a plan when deciding upon a deficiency's resolution prospect. In spirit of the least commitment principle, they focus on solving issues in "independent" plan parts, irrespective of the framework configuration or the application domain. These ideas have been recently extended to the notion of landmarks in hybrid planning [5].

2.4 Implementation and Evaluation

The formal entities of the framework are mapped onto software artefacts in a multiagent architecture. The corresponding implementation constitutes a planning *environment* in which any P&S system can be easily configured from a rich collection of functional components. It has been successfully deployed as a testbed in a large-scale empirical evaluation and analysis of dozens of strategy combinations, ranging from well-known classical strategies to the new flexible ones. This was the first extensive experimental effort in the domain of hybrid P&S.

3 Perspectives

Since hybrid P&S embraces the notion of knowledge-rich plans, it is a powerful and versatile component in implementing *Companion-Technology*, in which systems significantly benefit from adapting their functionality to the users' current situation and emotional status as well as providing assistance in operating complex appliances [3, 6]. The results of this dissertation are part of several implementations of *Companion-Technology*with further fields of research derived from and contributing to its methods. Building an assistance sytem for setting up a home-theater [1] uses hybrid planning as a core technology for guiding its dialogue management component, including extensions of this work such as *plan repair* [2] for addressing unforeseen issues in the execution environment and novel *plan explanation* techniques [11] for verbally explaining system decisions to human users. The approach has also been extended to *mixed-initiative planning* [9], in which human users actively participate in finding a solution. Last, but not least, hybrid P&S has been successfully applied in modeling cognitive processes that are involved in biological learning [10].

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Bernd Schattenberg is a freelance developer and consultant for P&S technology since 2013. Before that, he was a Research Assistant at the Institute of Artificial Intelligence of Ulm University, where he received his Ph.D. in 2009. He coordinated the Network of Excellence PLANET, funded by the European Commission, and the Transregional Collaborative Research Centre SFB/Transregio 62 "A Companion-Technology for Cognitive Technical Systems", funded by the German Research Foundation (DFG). His interests include knowledge engineering methods, mixed-initiative aspects, and novel application areas of hybrid P&S.