Chapter VIII

Planning with Concurrency, Time and Resources:
A CSP-Based Approach

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ABSTRACT

This chapter proposes to model a planning problem (e.g., the control of a satellite system) by identifying a set of relevant components in the domain (e.g., communication channels, on-board memory or batteries), which need to be controlled to obtain a desired temporal behavior. The domain model is enriched with the description of relevant constraints with respect to possible concurrency, temporal limits and scarce resource availability. The paper proposes a planning framework based on this view that relies on a formalization of the problem as a Constraint Satisfaction Problem (CSP) and defines an algorithmic template in which the integration of planning and scheduling is a fundamental feature. In addition, the paper describes the current implementation of a constraint-based planner called OMP that is grounded on these ideas and shows the role constraints have in this planner, both at domain description level and as a guide for problem solving.

INTRODUCTION

The integration of planning and scheduling is often seen as a key feature for solving real-world problems. Several planning architectures produced over the past two decades (e.g., Currie and Tate, 1991, Muscettola, 1994, Laborie and Ghallab, 1995b, Jonsson et al., 2000, Chen et al., 2000) have already included aspects from both planning and scheduling (P&S) theories among their features. In fact, these architectures have always emphasized the use of a rich representation language to capture complex characteristics of the domain involving time and resource constraints. Also, the more recent international planning competitions [IPC] have considered this integration as a direction to follow and specific features appear in the most recent release of PDDL [the planning description language defined for the competition (Fox and Long, 2003)] to extend its expressiveness.

While planning and scheduling have been traditionally separate research lines, both can be seen as an *abstraction* of real-world problems. On one hand, solving a planning problem means finding *how* to achieve a given goal, that is, computing a sequence of actions which realize the goal without considering the problem's time and resource features. The generation of a sequence of moves in the Blocks World domain is a typical example of planning problem. On the other hand, solving a scheduling problem means determining *when* to perform a set of actions consistently with time and resource constraints specified within the domain. In a satellite domain for example, this could be the problem of deploying over time a set of downlink data operations from a satellite to Earth according to visibility windows, channel data rates and onboard memory capacities.

This chapter contributes to an emerging research line that aims at joining results from classical planning, scheduling and constraint reasoning — in particular temporal and resource reasoning — by proposing the so-called Constraint Satisfaction Problem (CSP) (Tsang, 1993) as a common framework for representing both planning and scheduling problems. In particular, this chapter addresses problems in which the domain (e.g., a satellite system) can be decomposed into *components* (e.g., communication channels, onboard memory or batteries) and where both time and concurrency are fundamental elements. In this light, we can think of these components as a set of *threads* in the execution of a concurrent system: each temporal evolution of these variables lies on a timeline which evolves simultaneously with other timelines and where each component can assume one and only one value on a fixed time point. The values that each state of a component may assume on a specific time point are constrained by specifying cause-effect relationships and synchronization constraints among different components. Furthermore, one of the features, which distinguish this approach from so-called "classical planning", is the concept of *goal*, which is not an atemporal state of the world, rather a temporal evolution of a system.

As a conclusive observation, it is worth noting that the direct formulation of an integrated planning and scheduling problem as a Constraint Satisfaction Problem can open new and interesting research lines. In fact, "classical" CSP concepts such as *propagation* (e.g., enforcing arc or path-consistency) or the definition of new *variable* and *value* ordering heuristics can be extended to this framework. For example, a very simple variable ordering heuristic is to first take all the planning decisions and then to solve all the resource conflicts. However, a more effective ordering strategy is to interleave planning and scheduling decisions, in order to prune infeasible planning decisions due to lack of resource support and *vice versa*.

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