

Backdoors to Planning

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Abstract

Planning is one of the central formalisms in Artificial Intelligence. Unfortunately, the expressive power of planning comes at the cost of high computational complexity. In general, already propositional STRIPS planning is PSPACE-complete for unbounded plan length. In order to cope with this high complexity, several fragments of planning have been considered where planning becomes tractable. For propositional STRIPS a comprehensive complexity analysis was performed [3]. Later, a similar analysis for the SAS⁺ formalism was presented [2], where the state variables range over multi-valued domains.

A more fine-grained understanding of the hardness of a problem can be obtained from the viewpoint of parameterized complexity theory [4]. Here one is interested in identifying one or multiple features of the instance – the so-called parameters. The class of efficiently solvable problems is called FPT (*fixed-parameter tractable*), i.e., the problem can be solved by an fpt-algorithm in time $f(k) \cdot n^{\mathcal{O}(1)}$, where n denotes the size of the problem instance and $f(k)$ is a computable function depending on parameter k only (and not on n). The exponential time complexity is thus confined to the parameter, i.e., the function $f(k)$. Therefore, an fpt-algorithm can be considered efficient as long as the parameter values of an instance are sufficiently low. Techniques from parameterized complexity have been successfully used to tackle hard problems, e.g., in Knowledge Representation & Reasoning [6]. For planning a parameterized complexity analysis was initiated by Downey, Fellows, and Stege [5]. In recent works, several fpt-results have been obtained for SAS⁺ [1] and propositional STRIPS [7]. Despite this success the desire for additional fpt-algorithms remains.

A powerful tool to obtain fpt-algorithms are so-called *backdoors*. The basic idea is that the size of a backdoor set measures the distance to a tractable fragment of the problem. In the past, the backdoor approach has been used to obtain fpt-results for SAT, QBFs, ASP, and Argumentation. However, backdoors for planning have not been considered yet.

In contrast to other problems such as SAT, where backdoors can be defined in a direct way, the situation is different for planning. Here, the challenge is to find a suitable notion capturing the underlying structure of the planning instance, which in the next step can be used to define the desired notion of backdoors.

We present two natural notions of backdoors for planning, which are based on the underlying *causal graph* of the planning instance. For both new notions of backdoors, we have performed a comprehensive parameterized complexity analysis. We analyze the complexity of the two central tasks of the backdoor approach: (i) finding a small backdoor (*detection phase*), and (ii) using the additional information given in the backdoor to solve the planning instance (*evaluation phase*). In the evaluation phase, we additionally consider a bound on the plan length and/or on the domain of the variables as additional restrictions. For each of the above settings we present either an fpt-result, or show parameterized intractability. This gives us a *complete* picture of the parameterized complexity of the backdoor approach with respect to the considered notions of backdoors. In three cases we achieve the most desirable outcome: detection and evaluation are fpt. Among our fpt-results is the first fpt-algorithm for planning with unbounded plan length that does neither limit the number of variables nor actions in the planning instance.

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