Capturing (Optimal) Relaxed Plans with Stable and Supported Models of Logic Programs

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Abstract. We demonstrate that logic programs can accurately represent relaxed planning problems. We introduce one encoding based on stable model semantics and two encodings based on supported model semantics for relaxed planning. Experimental results highlight enhancements in the computation of optimal relaxed plans using these encodings.

1 Introduction

AI Planning involves finding plans to achieve goals from an initial state. A given Planning problem can be relaxed into a delete-free problem, optimal solving of which provides a lower bound, denoted by h^+, of the optimal cost of the original problem. However, calculating h^+ is challenging [2, 1]. Various methods, like SAT-based encoding and integer programming, have been proposed for this purpose [6, 4, 5, 3]. Here, we present a new approach using stable and supported models of Answer Set Programming (ASP). These encodings enable off-the-shelf answer set solvers to compute h^+.

2 An encoding based on stable models

Let $\Pi = \langle X, I, A, G, cost \rangle$ be a relaxed STRIPS planning problem, where X is a finite set of Boolean state variables. The initial state I and the set of goal conditions G are subsets of X. The finite set A is the set of actions. Each member $\boldsymbol{a}$ of A is a triple $\langle pre(\boldsymbol{a}), add(\boldsymbol{a}), del(\boldsymbol{a}) \rangle$, where $pre(\boldsymbol{a})$, $add(\boldsymbol{a})$ and $del(\boldsymbol{a})$ are sets of atomic propositions denoting the set of preconditions, positive effects, and negative effects of $\boldsymbol{a}$. The cost function $cost$ maps members of A to a non-negative integer. Let P be a logic program consisting of rules of the form (1) $g \leftarrow \texttt{not}\ g$ for every $g \in G$; (2) $\{a\} \leftarrow q_1, \ldots, q_n$ for every $\boldsymbol{a} \in A$ with $pre(\boldsymbol{a}) = \{q_1, \ldots, q_n\}$; (3) $p \leftarrow a$ for every $\boldsymbol{a} \in A$ and $p \in add(\boldsymbol{a})$. It can be shown that P captures the relaxed plans of Π as its stable models.

3 Encodings based on supported models

Our causal encoding P_c is produced by adding rules produced by a vertex elimination process of the dependency graph of program P described in the previous section. In our diagnostic encoding P_d, we assume that all atoms could possibly be in the model by using the rule $\{p\}$ for every $p \in X$. However, if p is in the model, then it must have well-support by at least one action. We establish this by adding $\{\texttt{ws}(a, p)\} \leftarrow p$ for every $\boldsymbol{a} \in A$ such that $p \in add(\boldsymbol{a})$, and also

$f \leftarrow p, \texttt{not ws}(a_1, p), \ldots, \texttt{not ws}(a_m, p), \texttt{not } f$ for $p \in X$ where $a_1, ..., a_m$ are all actions that could add p. To represent the inference from well-supports to dependencies, we add $\texttt{dep}(p, q) \leftarrow \texttt{ws}(a, p)$ for $\boldsymbol{a} \in A$, $q \in pre(\boldsymbol{a})$ and $p \in add(\boldsymbol{a})$. Finally, to establish the inference direction from dependencies to preconditions, we add $q \leftarrow \texttt{dep}(p, q)$. As in P_c, rules produced by vertex elimination process of the dependency graph of program P must be included to enforce acyclicity in the supported model. Moreover, we add $a \leftarrow \texttt{ws}(a, p)$ for $\boldsymbol{a} \in A$ and $p \in add(\boldsymbol{a})$, to enable an action atom a to represent its cost in the minimization constraint, and also $g \leftarrow \texttt{not } g$ for every $g \in G$ to guarantee the goal conditions. It can be shown that P_c and P_d capture the relaxed plans of Π as their supported models.

4 Empirical results

We have compared our methods based on the total time of encoding and solving with IP, the state-of-the-art integer programming encoding [5]. As benchmark problem sets, we use 2212 problem instances from 84 problem sets. The cumulative number of problems solved by all methods are presented in Figure 1.

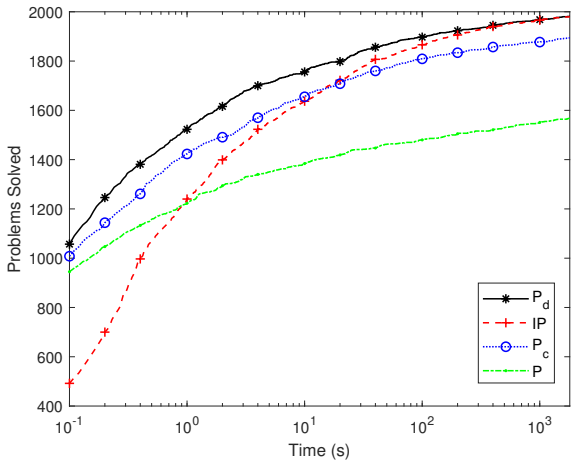

Fig. 1. Cumulative numbers of problems solved by the competing methods

5 Conclusion

In this work, we study the previously uninvestigated usage of ASP solvers for optimal relaxed planning. Three different encodings of relaxed planning problems into logic programs are provided, one based on the stable model semantics, and two based on the supported model semantics of logic programs. According to our empirical results, all our encodings enable Clasp to outperform the state-of-the-art methods.

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