A Stubborn Set Algorithm for Optimal Planning

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Introduction

Heuristic search
- Popular technique to facilitate planning.
- Drawback: number of state explorations scales exponentially even under generous assumptions [Helmer and Röger 2008].

Partial order reduction
- Observation: unnecessary interleavings of transitions
- Idea: Enforce a particular ordering among operators.
- Problem: Original techniques in model checking are sound [Chen and Yao 2009, Godefroid 1996], but adaptations for planning are not [Chen and Yao 2009, Xu et al. 2011, Chen et al. 2009].
- Objective: Adapt original techniques with as little modification as possible.

Preliminaries

SAS’ planning tasks
- An SAS’ planning task is a 4-tuple \((V, I, O, G)\), where:
  - \(V\) is the set of state.
  - \(I\) is the initial state.
  - \(O\) is a finite set of operators.
  - \(G\) is the goal.
- A fact is a pair \((v, d)\) with \(v \in V\) and \(d \in \text{Dom}(v)\).

Dependency of operators
- Operator \(o_1\) disables \(o_2\) if \(o_2\) requires a variable to have a particular value and \(o_1\) assigns another value to the variable.
- Operators \(o_1\) and \(o_2\) conflict if both of them affect a common variable differently.
- Operators \(o_1\) and \(o_2\) are dependent if \(o_1\) disables \(o_2\), or \(o_2\) disables \(o_1\), or \(o_1\) and \(o_2\) conflict.

Disjunctive action landmarks
A disjunctive action landmark for a set of facts \(F\) in state \(s\) is a set of operators \(L\) such that every applicable operator sequence that starts in \(s\) and ends in \(s' \supseteq F\) contains at least one operator \(o \in L\).

Necessary enabling sets
A necessary enabling set for operator \(o \notin \text{app}(s)\) in state \(s\) is a disjunctive action landmark for \(\text{pre}(o)\) in \(s\).

Strong stubborn sets

Definition
Let \(T\) be a planning task and let \(s\) be a state. A strong stubborn set in \(s\) is a set of operators \(T_s \subseteq O\) such that:
1. \(T_s\) contains all the operators that interfere with some applicable operator in \(T_s\).
2. \(T_s\) contains a necessary enabling set in \(s\) for each inapplicable operator in \(T_s\).
3. \(T_s\) contains a disjunctive action landmark for the goal in \(s\).

Strong stubborn set computation (conceptually)

Algorithm 1 Strong stubborn set computation for state \(s\)

Input: State \(s\)

Output: Strong stubborn set \(T_s\) for \(s\)

1. \(T_s \leftarrow L_s^G\) for some disjunctive action landmark \(L_s^G\) for \(G\) in \(s\)
2. repeat
3. for all \(o \in T_s\) do
4. if \(o \notin \text{app}(s)\) then
5. \(T_s \leftarrow T_s \cup \text{dep}(o)\)
6. else
7. \(T_s \leftarrow T_s \cup N_o^G\) for some nec. enabling set \(N_o^G\) for \(o \in T_s\)
8. until \(T_s\) reaches a fixed-point
9. return \(T_s\)

Experiments

Node generations and coverage
- Plain \(A^*\)
- \(A^*\) with Expansion Core (EC) [Chen and Yao 2009, Xu et al. 2011], and
- \(A^*\) with strong stubborn sets (SSS), all guided by the LM-cut heuristic.

Future work
- Investigation of other partial order reduction methods and their combination with our POR framework.

References

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