Operator Mutexes and Symmetries for Simplifying Planning Tasks

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BACKGROUND

A planning task in STRIPS: $\Pi = (F, O, I, G)$; $F$ is a finite set of facts; state $s \subseteq F$; $I \subseteq F$ is an initial state; $G \subseteq F$ is a goal specification; $O$ is a set of operators $o$ specified by $\text{pre}(o), \text{del}(o), \text{add}(o) \subseteq F$ and cost $c(o) \in \mathbb{R}_+^+$; $o \in O$ is applicable in $s$ iff $\text{pre}(o) \subseteq s$; $o$ applied on $s$ yields $o[s] = (s \setminus \text{del}(o)) \cup \text{add}(o)$. A plan $\pi$: $\pi[I] \supseteq G$; an optimal plan is a plan with the minimal cost; a strongly optimal plan is an optimal plan with the minimum number of operators.

SIMPLIFICATION OF PLANNING TASKS

The goal is to remove as many operators as possible while preserving at least one strongly optimal plan. We say that a set of operators is redundant if removing such a set preserves at least one strongly optimal plan.

OPERATOR Mutex

A strong operator mutex (op-mutex) $O$ is a nonempty set of operators s.t. $O \not\subseteq \pi$ for every strongly optimal plan $\pi$. Every op-mutex contains at least one redundant operator.

If op-mutexes between two sets of operators $O_1$ and $O_2$ form a complete bipartite graph, then $O_1$ or $O_2$ is redundant.

INFERENCE FROM ABSTRACTIONS

Given an abstract state space $\Theta_{\Pi}$ and operators $o_1, o_2, o_1 \neq o_2$, if $o_2$ is not reachable after $o_1$ and $o_1$ is not reachable after $o_2$, then $(o_1, o_2)$ is an op-mutex.

Works with any abstraction method, e.g., Pattern Databases, Merge-and-Shrink, Cartesian Abstractions.

OPERATORS-AS-FACTS Compilation

Given the planning task $\Pi = (F, O, I, G)$, the op-fact compilation is $\Pi_{op} = (F \cup F_{op}, O_{op}, I, G)$, where $F_{op} = \{f \mid o \in O\}$ and $O_{op} = \{\{o \mid o \in O\}$ where $o$ equals to $o$ except for $\text{add}(o') = \text{add}(o) \cup \{f\}$.

If $F = \{f_1, \ldots, f_n\}$ is a mutex in $\Pi_{op}$, then $\{o_1, \ldots, o_n\}$ is an op-mutex in $\Pi$.

Pruning with Symmetries

A plan preserving symmetry of the transition system $\Theta = \langle S, I, T, s_1, S_2 \rangle$ is a permutation $\sigma$ of $S \cup L$ mapping states to states and labels to labels s.t. $s \sim s' \in T$ iff $\sigma(s) \sim \sigma(s') \in T$, $c(\sigma(s)) = c(\sigma(s'))$, $s \in S$, iff $\sigma(s) \in S$, and $\sigma(s) = s_1$. For every plan $\pi$ it holds that $\sigma(\pi)$ is also a plan, moreover $\pi = \sigma(\pi)$ and $c(\pi) = c(\sigma(\pi))$.

If $(o_1, o_2)$ is an op-mutex and there exists a symmetry $\sigma(o_1) = o_2$, then both $\{o_1\}$ and $\{o_2\}$ are redundant.

Similarly for two sets of operators $O_1$ and $O_2$: If $(o_1, o_2)$ is an op-mutex for every $o_1 \in O_1$ and every $o_2 \in O_2$, and there exists a symmetry $\sigma(O_1) = O_2$, then both $O_1$ and $O_2$ are redundant.

EXPERIMENTAL RESULTS

Average percentage of removed operators (15 min. time limit):