Operator Mutexes and Symmetries for Simplifying Planning Tasks

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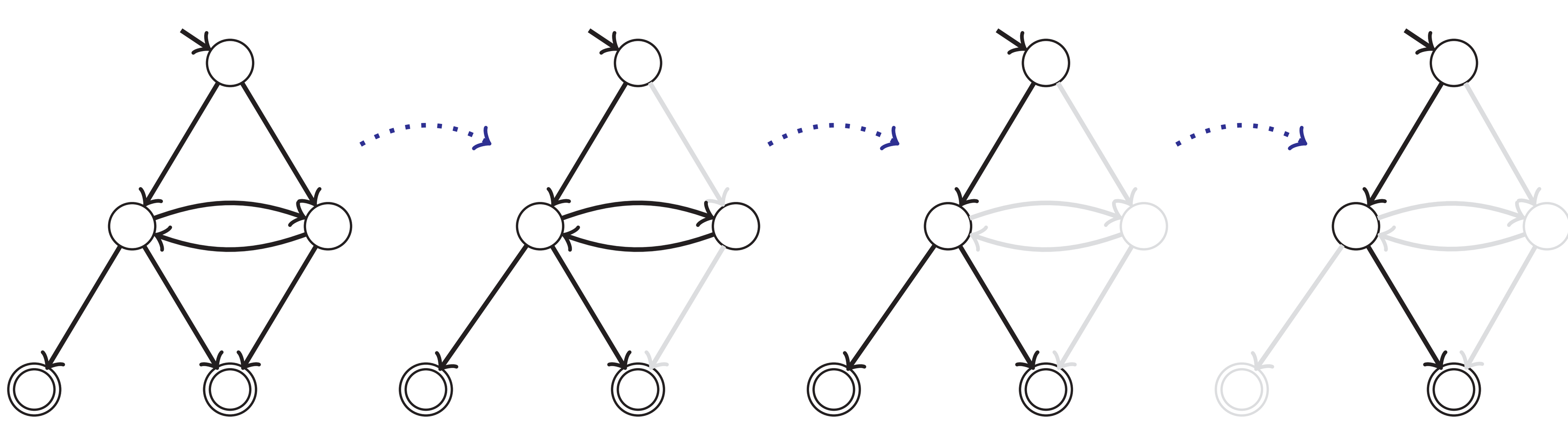
Background

A planning task in STRIPS: $\Pi = \langle \mathcal{F}, \mathcal{O}, I, G \rangle$; $\mathcal{F}$ is a finite set of **facts**; state $s \subseteq \mathcal{F}$; $I \subseteq \mathcal{F}$ is an **initial state**; $G \subseteq \mathcal{F}$ is a **goal specification**; $\mathcal{O}$ is a set of **operators** o specified by $\mathrm{pre}(o), \mathrm{del}(o), \mathrm{add}(o) \subseteq \mathcal{F}$ and cost $\mathrm{c}(o) \in \mathbb{R}_0^+$; $o \in \mathcal{O}$ is **applicable** in s iff $\mathrm{pre}(o) \subseteq s$; o applied on s yields $o[s] = (s \setminus \mathrm{del}(o)) \cup \mathrm{add}(o)$.
A **plan** π: $\pi[I] \supseteq G$; 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

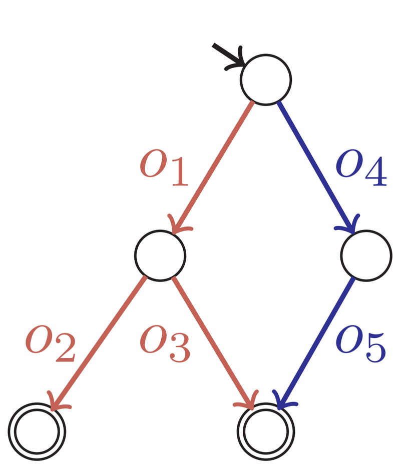
The goal is to remove as many operators as possible while preserving at least one strongly optimal plan.
We say that a set of operators is **redundant** if removing such a set preserves at least one strongly optimal plan.

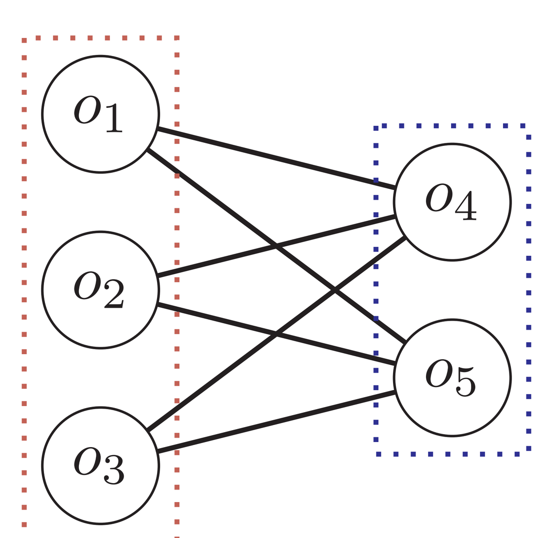


Operator Mutex

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

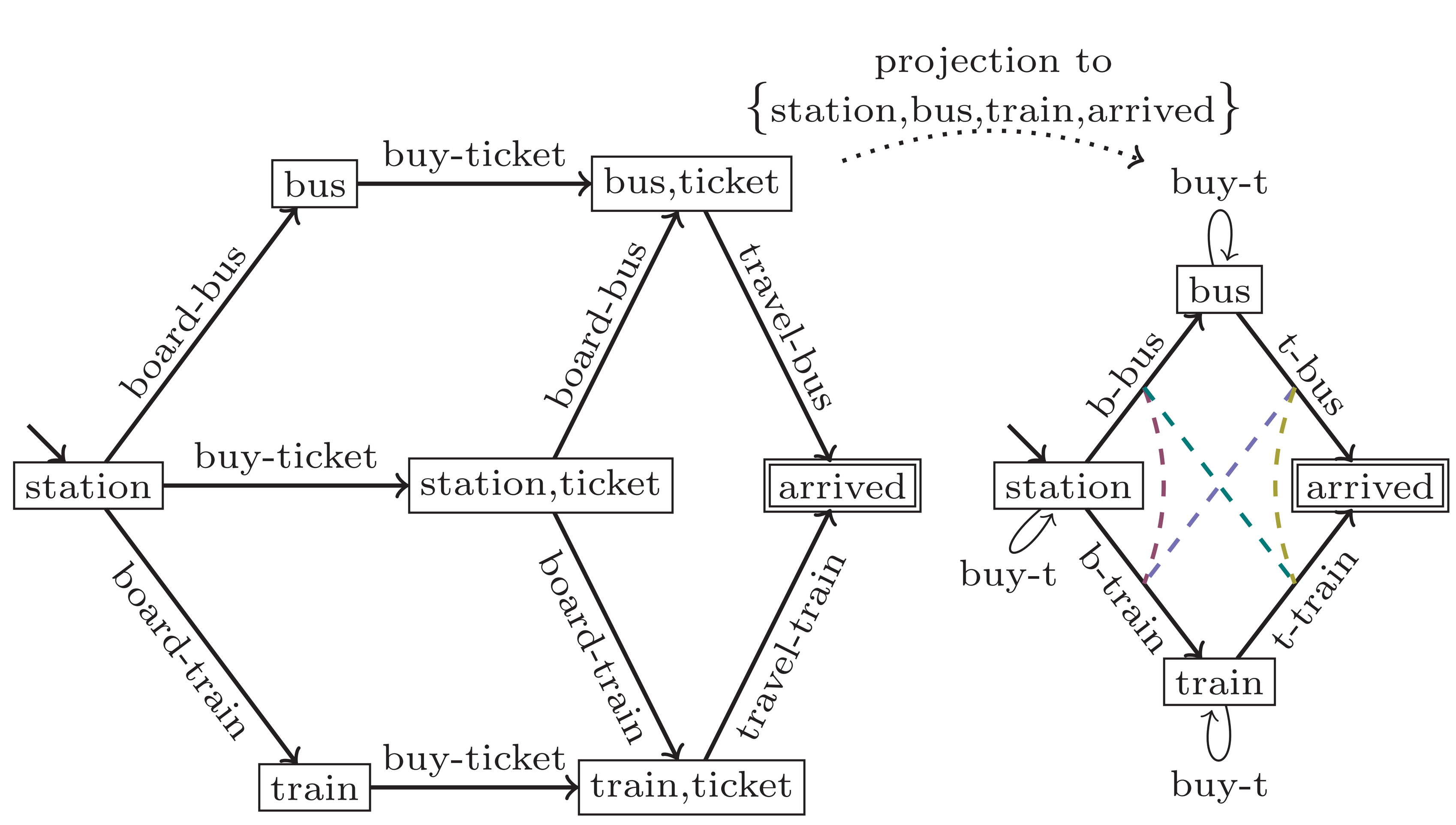
If op-mutexes between two sets of operators O_1 and O_2 form a **complete bipartite graph**, then O_1 or O_2 is **redundant**.





Inference from Abstractions

Given an abstract state space Θ_Π^α 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

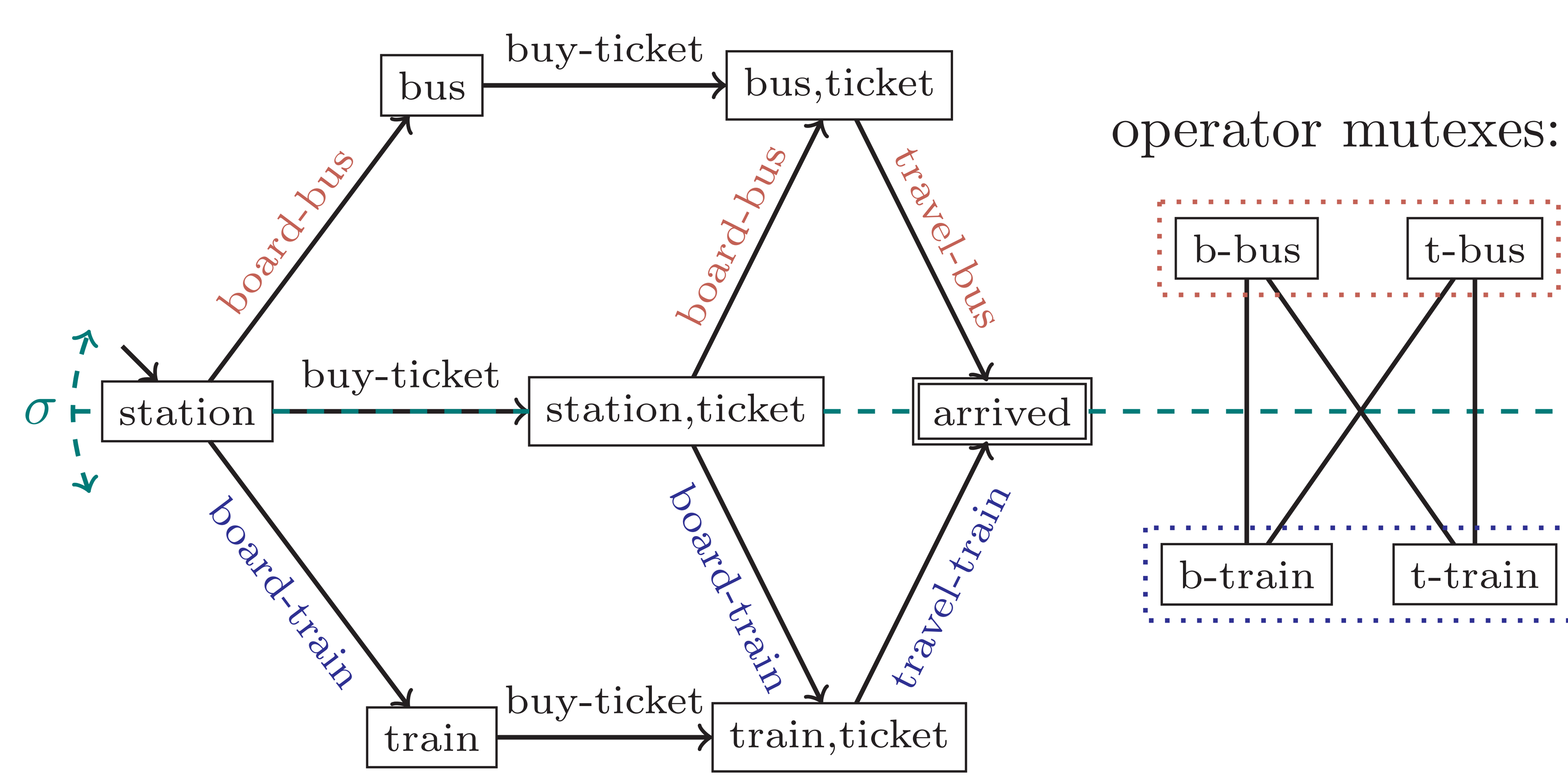
Given the planning task $\Pi = \langle \mathcal{F}, \mathcal{O}, I, G \rangle$, the op-fact compilation is $\Pi_{\mathrm{op}} = \langle \mathcal{F} \cup \mathcal{F}_{\mathrm{op}}, \mathcal{O}_{\mathrm{op}}, I, G \rangle$, where $\mathcal{F}_{\mathrm{op}} = \{ f_o \mid o \in \mathcal{O} \}$ and $\mathcal{O}_{\mathrm{op}} = \{ o' \mid o \in \mathcal{O} \}$ where o' equals to o except for $\mathrm{add}(o') = \mathrm{add}(o) \cup \{ f_o \}$.

If $F = \{ f_{o_1}, \dots, f_{o_n} \}$ is a **mutex** in Π_{op}, then $\{o_1, \dots, o_n\}$ is an **op-mutex** in Π.
Therefore we can use any method for inference of mutexes, including h^m family of heuristics.

Pruning with Symmetries

A **plan preserving symmetry** of the transition system $\Theta = \langle \mathcal{S}, L, T, s_I, S_\star \rangle$ is a permutation σ of $\mathcal{S} \cup L$ mapping states to states and labels to labels s. t. $s \xrightarrow{o} s' \in T$ iff $\sigma(s) \xrightarrow{\sigma(o)} \sigma(s') \in T$, $\mathrm{c}(o) = \mathrm{c}(\sigma(o))$, $s \in S_\star$ iff $\sigma(s) \in S_\star$, and $\sigma(s_I) = s_I$.
For every plan π it holds that $\sigma(\pi)$ is also a plan, moreover $|\pi| = |\sigma(\pi)|$ and $\mathrm{c}(\pi) = \mathrm{c}(\sigma(\pi))$.

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):

domain	baseline h^2+de	fam	Π^2_{op}	h^2+de with fam	h^2+de with Π^2_{op}
barman11	**52.11**	4.71	24.48	**+3.60**	**+3.60**
barman14	**53.43**	4.94	25.28	**+4.01**	**+4.01**
caldera18	**39.34**	0.73	13.25	0.00	**+1.45**
cavediving14	0.66	**1.15**	**1.44**	**+1.15**	**+1.15**
childsnack14	0.00	**39.58**	**39.58**	**+39.58**	**+39.58**
hiking14	0.00	**0.07**	**0.07**	**+0.07**	**+0.07**
parcprinter08	**70.68**	28.61	28.61	0.00	0.00
parcprinter11	**70.15**	25.75	25.75	0.00	0.00
pathways06	**3.94**	2.22	2.26	**+3.73**	**+3.73**
pegsol08	**13.57**	0.00	1.92	**+0.36**	**+0.36**
pegsol11	**9.53**	1.08	3.51	**+0.20**	**+0.20**
pipesworld06	**11.46**	0.04	4.04	**+0.04**	**+0.04**
scanalyzer08	**3.19**	0.00	2.10	0.00	0.00
scanalyzer11	**3.17**	0.00	2.12	0.00	0.00
sokoban08	0.24	1.54	**1.71**	+1.54	**+1.60**
sokoban11	0.35	1.86	**2.12**	+1.86	**+1.95**
tpp06	**37.96**	1.49	19.97	**+1.79**	**+1.79**
trucks06	**75.02**	0.00	0.71	**+7.87**	**+7.87**
woodworking08	**53.47**	2.83	10.79	**+1.60**	**+1.60**
woodworking11	**53.72**	2.73	10.17	**+1.83**	**+1.83**
overall	**53.72**	7.99	13.73	+4.29	**+4.39**

Fišer, D.; Torralba, Á.; and Shleyfman, A. 2019. Operator Mutexes and Symmetries for Simplifying Planning Tasks. In *Proc. AAAI'19*.