Efficient Evaluation of Large Abstractions for Decoupled Search: Merge-and-Shrink and Symbolic Pattern Databases

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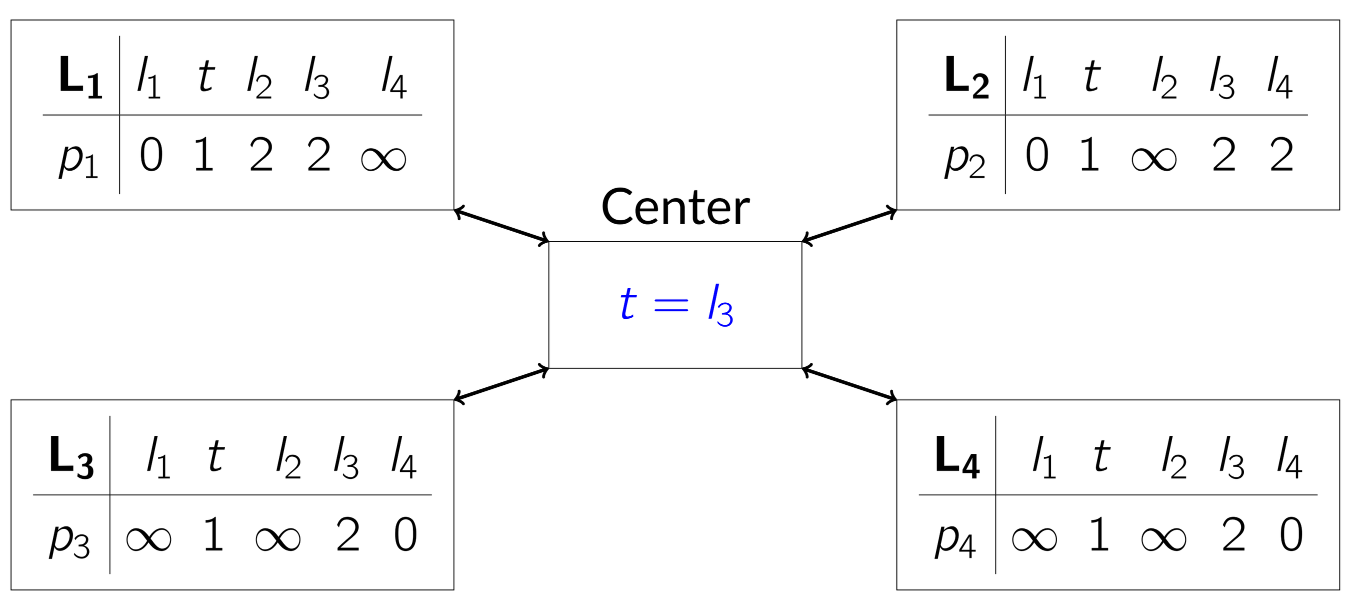
Context

- **Classical planning** with finite-domain variables.
- Decoupled search compactly represents sets of states by **partitioning the state variables into factors**.
- Large abstraction heuristics (Merge&Shrink, symbolic PDBs) represent heuristic values of state sets compactly using **factored mappings** or **ADDs**.

How to evaluate a decoupled state on a large abstraction heuristic?

Decoupled State Representation

Represented state set: cross-product of reached leaf states.

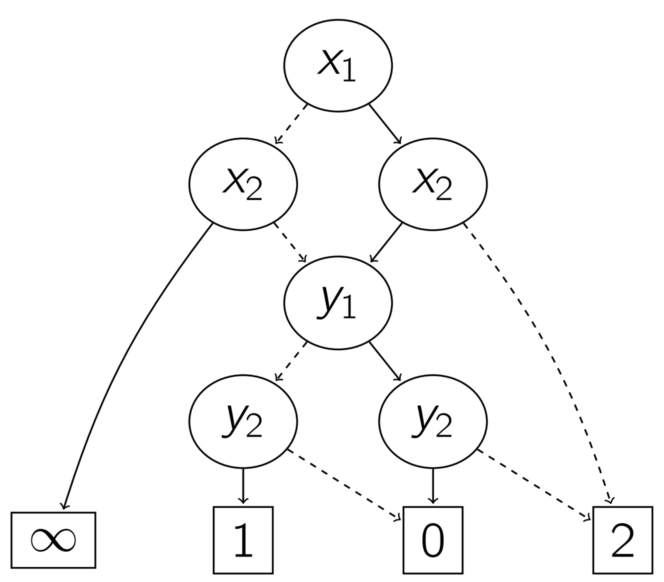


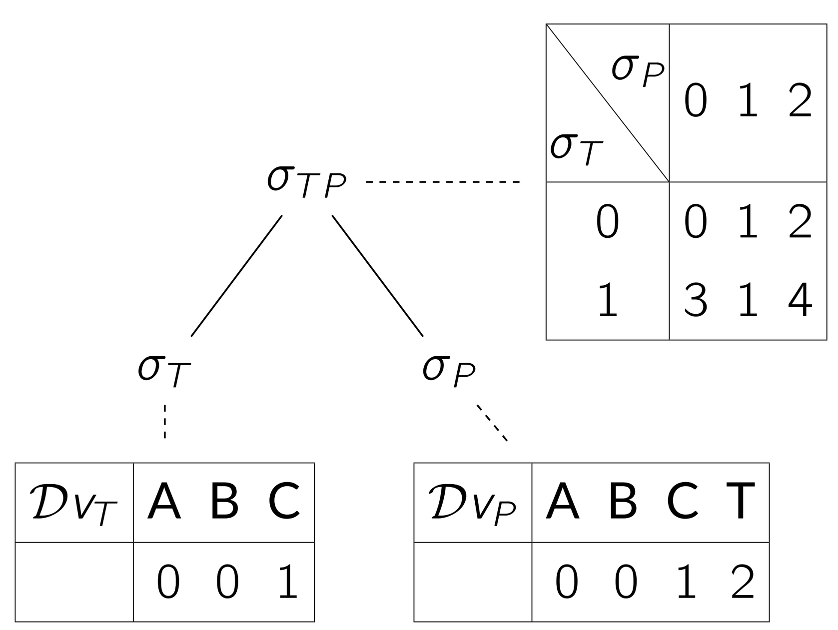
Symbolic PDBs (ADDs) vs. M&Ss Factored Mappings

Represented state sets:

All states that satisfy formula.

All states mapped to finite value set.





When are BDDs *compatible* with a decoupled state?

When is a decoupled state *compatible* with a Merge&Shrink tree?

Theoretical Results

Theorem 1. *Let A be an ADD of a PDB heuristic h, $s^{\mathcal{F}}$ a decoupled state, and $B \in \mathbb{R}^{+} \cup \{\infty\}$. It is* **NP**-*complete to decide if $h_{\mathcal{F}}(s^{\mathcal{F}}) < B$.*

Corollary 2. *Let σ be an FM that represents a M&S heuristic h and $s^{\mathcal{F}}$ a decoupled state. It is* **NP**-*complete to decide if $h_{\mathcal{F}}(s^{\mathcal{F}}) < B$.*

Compliance of Compact Data Structures

Definition 3 (Covered Leaves by FMs, Nestedness).

Leaves ***covered*** *by an FM:* $cov(\sigma) := \{L \in \mathcal{L} \mid L \cap vars(\sigma) \neq \emptyset\}$.

Leaves ***fully covered*** *by an FM:* $fc(\sigma) := \{L \in \mathcal{L} \mid L \subseteq vars(\sigma)\}$.

Leaves ***partially covered*** *by an FM:* $pc(\sigma) := cov(\sigma) \setminus fc(\sigma)$.

Leaves ***exactly covered*** *by an FM:* $ec(\sigma) := fc(\sigma) \setminus (fc(\sigma_L) \cup fc(\sigma_R))$ *if σ is a merge FM, and $ec(\sigma) := fc(\sigma)$ otherwise.*

Nestedness *of an FM:* $\mathcal{N}(\sigma) := 0$ *for atomic FMs, otherwise* $\mathcal{N}(\sigma) := max(\mathcal{N}(\sigma_L), \mathcal{N}(\sigma_R), |pc(\sigma_L) \cup pc(\sigma_R)|)$.

Definition 4 (Compliant FMs). *An FM is* ***compliant*** *with a factoring $\mathcal{F}$ if $\mathcal{N}(\sigma) \leq 1$; it is* ***strongly compliant*** *with $\mathcal{F}$ if for all $L \in \mathcal{L}$ there exists a descendant σ' of σ s.t. $cov(\sigma') = ec(\sigma') = \{L\}$.*

Definition 5 (Compliant ADDs). *A variable ordering is* ***compliant*** *with a factoring $\mathcal{F}$ if:*

$$\forall_{v<v'<v''}(\mathcal{F}(v) = \mathcal{F}(v'') \neq C) \implies \mathcal{F}(v') \in \{\mathcal{F}(v), C\}$$

Runtime – General vs. Compliant Heuristic