Generalized Label Reduction for Merge-and-Shrink Heuristics

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Outline

1. Merge-and-Shrink Heuristics
2. Previous Label Reduction
3. Generalized Label Reduction
4. Experiments
5. Conclusion
Computation of merge-and-shrink heuristics:

- Start with the set of **atomic** transition systems
- Repeatedly apply one of the following:
  - **Merge**: replace two transition systems by their **synchronized product**
  - **Shrink**: replace a transition system by an **abstract transition system**
- Stop when one transition system is left, use as heuristic

**State-of-the-art** abstraction heuristic for planning
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Concept

Label Reduction:

- Identify and eliminate *semantically equivalent labels* in transition systems
- Always useful:
  - Reduction of *memory* and time consumption
  - Heuristic quality *preserved*
  - Fast to compute
- **Crucial** for efficiently computing merge-and-shrink heuristics
Previous Label Reduction in the Merge-and-Shrink Computation

Previous theory:
- Choose one pivot variable
- Label reduction only allowed for transition systems containing pivot variable
Drawbacks

Main drawback of previous label reduction:

- Label reduction **limited** to one branch of the merge tree

Consequences:

- Usage of linear merge strategies to **circumvent** drawbacks
- **Large part** of the space of possible merge strategies not yet explored
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A label reduction for a set of transition systems with label set $L$ is defined as follows:

- For a set of labels $L' \subseteq L$, choose a new label $\ell \not\in L$ and set $\text{cost}(\ell) := \min_{\ell' \in L'} \text{cost}(\ell')$.
- Replace each label $\ell' \in L'$ by the new label $\ell$ in all transition systems.

Formally: a label reduction $\tau$ is a label mapping, i.e. a function defined on $L$. 

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\text{Definition}
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\[
\Theta_1: \begin{align*}
\ell_1 &\quad \ell_2 \\
\ell_2 &\quad \ell_2
\end{align*}
\]

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\Theta_2: \begin{align*}
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Generalized Label Reduction

Definition

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\[ \tau(\Theta_1): \ell \]
\[ \tau(\Theta_2): \ell \leftrightarrow \ell \]
Theorem: Safeness

Theorem

Label reduction is always safe, i.e. leaves the heuristic admissible. (Formal proof in the paper)

Intuition:

- Transitions are preserved: transitions not lost in synchronized product
- (Goal) states of transition systems not modified
- Transition costs not increased
Combinable Labels

**Definition**

Let \( X \) be a set of transition systems with label set \( L \), let \( \ell_1, \ell_2 \in L \) and let \( \Theta \in X \).

\[ \Theta_1: \ell_1 \]

\[ \ell_2 \]

\[ \Theta_2: \ell_1 \quad \ell_2 \]
Combinable Labels

Definition

Let $X$ be a set of transition systems with label set $L$, let $\ell_1, \ell_2 \in L$ and let $\Theta \in X$.

- $\ell_1$ and $\ell_2$ are **locally equivalent in $\Theta$** if they label the same set of transitions in $\Theta$.

**Diagram:**

$$\Theta_1: \ell_1$$

$$\Theta_2: \ell_1 \leftarrow \ell_2$$
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- $\ell_1$ and $\ell_2$ are $\Theta$-combinable in $X$ if they are locally equivalent in all $\Theta' \in X \setminus \{\Theta\}$.
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- $\ell_1$ and $\ell_2$ are $\Theta$-combinable in $X$ if they are locally equivalent in all $\Theta' \in X \setminus \{\Theta\}$.
- $\ell_1$ globally subsumes $\ell_2$ if the set of transitions labeled by $\ell_2$ is a subset of the set of transitions labeled by $\ell_1$ in all transition systems.
Theorem: Exactness

Let $\tau$ be a label reduction which maps labels $\ell_1$ and $\ell_2$ onto a new label $\ell$. $\tau$ is exact, i.e. leaves the heuristic perfect, iff $\text{cost}(\ell_1) = \text{cost}(\ell_2)$ and

1. $\ell_1$ globally subsumes $\ell_2$, or
2. $\ell_2$ globally subsumes $\ell_1$, or
3. $\ell_1$ and $\ell_2$ are $\Theta$-combinable for some $\Theta \in X$. 
Theorem: Exactness

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\[ \Theta_1 : \ell_1 \quad \Theta_2 : \ell_1 \rightarrow \ell_2 \quad \Theta_1 \otimes \Theta_2 : \]

\[ \ell_2 \rightleftharpoons 1 \quad 4 \quad 3 \quad 14 \quad 24 \]

\[ 13 \quad 23 \]
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\[
\begin{align*}
\Theta_1 &: \quad \ell_1 \\
\ell_2 &\searrow \quad 1 \\
\Theta_2 &: \quad \ell_1 \quad \ell_2 \\
3 &\searrow \quad 4 \\
\Theta_1 \otimes \Theta_2 &: \quad \ell_2 \\
\ell_1 &\searrow \quad 13 \\
\end{align*}
\]
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Experimental Setup

General:

- Fast Downward planning system

Merge-and-shrink heuristic:

- Linear merge strategy reverse-level (RL)
- Non-linear merge strategy proposed by Dräger et al. (DFP)
- Shrinking based on bisimulation (B)
Coverage Results

Observations:

- Label reduction always useful
- New **better** than old:
  - larger computational effort
  - compensated by reduced
  - memory/time consumption
- Non-linear merge strategy DFP: **best performer**

<table>
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<tr>
<th>merge/shrink strategy</th>
<th>Label Reduction</th>
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<td>RL-B-N50k</td>
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<td>RL-B-N100k</td>
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<td>DFP-B-N200k</td>
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</tbody>
</table>
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Conclusion

Summary:

- **Generalized** label reduction for merge-and-shrink heuristics:
  - Safe transformation: *always* allowed on all transition systems
  - Exact transformation: if based on $\Theta$-combinability (among others)

- Prepared the ground for **non-linear merge strategies** in practice:
  - Implemented non-linear merge strategy DFP
  - Experimental performance gain
The End

Thank you!
## Results: Usefulness of Label Reduction (1)

<table>
<thead>
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<th>DFP-B-50K</th>
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</tr>
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<td>+1</td>
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<td>driverlog (20)</td>
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<td>−1</td>
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<tr>
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<tr>
<td>Remaining domains (605)</td>
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</tr>
<tr>
<td>Sum (1396)</td>
<td>560</td>
<td>599</td>
</tr>
</tbody>
</table>
Remarks:

- Label reduction of crucial importance for efficiency
- Bisimulation based shrinking profits from label reduction
Results: Old vs. New Label Reduction Method

Remarks:
- Resulting heuristics similarly informative
- Failures almost always due to memory limit
Weaknesses of previous label reduction:

- **Local** transformation of one transition system
  (problematic for synchronization behavior)
- **Syntax**-based comparison of labels
  (requires access to underlying planning operators)
- **Independence** of shrink strategy
  (no label reduction opportunities from shrinking)
Notes on the implementation:

- Label reduction through $\Theta$-combinability may enable other $\Theta'$-combinability opportunities
  - $\rightarrow$ Label reduction performed as fixpoint computation
- Order of considered transition systems matters
  - $\rightarrow$ Randomized order