Generalized Label Reduction for Merge-and-Shrink Heuristics

Silvan Sievers, Martin Wehrle and Malte Helmert

University of Basel, Switzerland

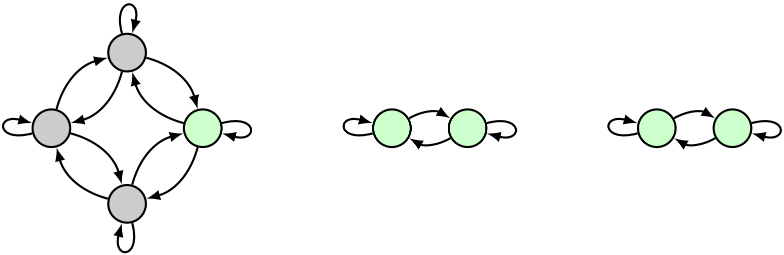
July 29, 2014

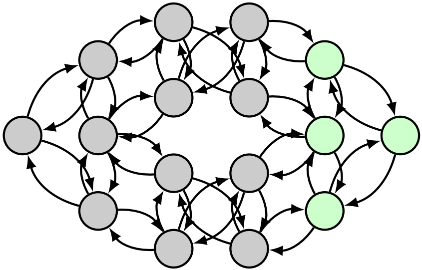
Outline

Merge-and-Shrink Heuristics

- Distance heuristics for state space search (Dräger et al. (2006), Helmert et al. (2007), Nissim et al. (2011), Helmert et al. (2014))
- Idea:
  - Represent state space as set of small finite automata
  - State space corresponds to product of automata
  - Transform automata to obtain distance heuristic for state space
- Applicable for classical planning and many other state space search problems

Example



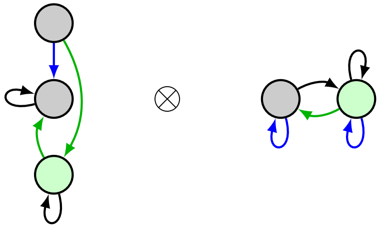


Merge-and-Shrink Transformations (1)

- Merge: replace two automata by their product automaton

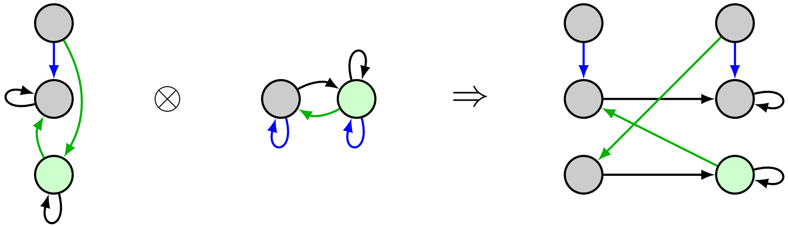
Merge-and-Shrink Transformations (1)

- Merge: replace two automata by their product automaton



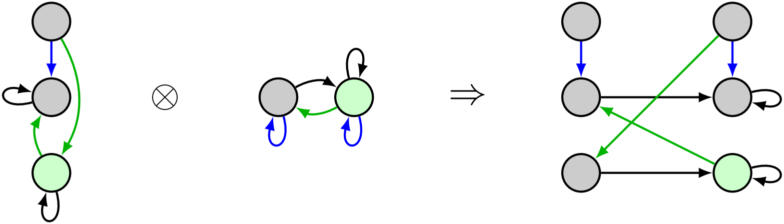
Merge-and-Shrink Transformations (1)

- Merge: replace two automata by their product automaton



Merge-and-Shrink Transformations (1)

- Merge: replace two automata by their product automaton



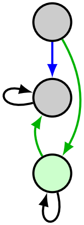
- Exact transformation: preserves distances in represented state space

Merge-and-Shrink Transformations (2)

- Shrink: abstract one automaton

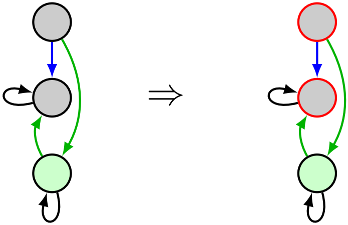
Merge-and-Shrink Transformations (2)

- Shrink: abstract one automaton



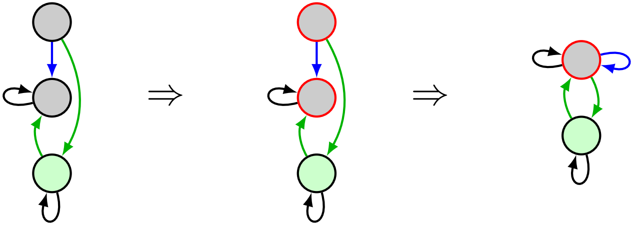
Merge-and-Shrink Transformations (2)

- Shrink: abstract one automaton



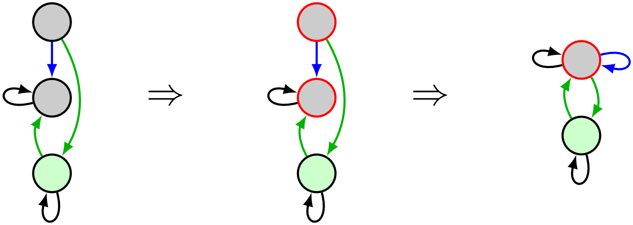
Merge-and-Shrink Transformations (2)

- Shrink: abstract one automaton



Merge-and-Shrink Transformations (2)

- Shrink: abstract one automaton



- Safe transformation: does not increase distances in represented state space
  (Exact with bisimulation, Nissim et al. (2011))

Previous Label Reduction and its Flaws

Proof Sketch for Theorem 5.11 of Helmert et al. (2014)

We prove by induction over the construction of T^α that, for any intermediate merge-and-shrink abstraction β over V': $\Theta^\tau_\beta = \Theta^\beta$ if $v^* \notin V'$, and $\Theta^\tau_\beta = \Theta^\beta|_{\tau^{\overline{V'}}}$ if $v^* \in V'$. The single tricky case in the induction is the case where $\beta = \alpha_1 \otimes \alpha_2$ and (WLOG) $v^* \in V_1$. Using the induction hypothesis, we then need to prove that $(\Theta^{\alpha_1}|_{\tau^{\overline{V_1}}} \otimes \Theta^{\alpha_2}|_{\tau^{\overline{V_1}}})|_{\tau^{\overline{V_1 \cup V_2}}} = \Theta^{\alpha_1 \otimes \alpha_2}|_{\tau^{\overline{V_1 \cup V_2}}}$. Since $\tau^{\overline{V_1}}$ is conservative for $\Theta^{\pi_{\overline{V_1}}}$, with $V_2 \subseteq \overline{V_1}$ and Proposition 5.4, it is conservative also for Θ^{α_2}. Hence, Lemma 5.6 reduces the left-hand side of our proof obligation to $((\Theta^{\alpha_1} \otimes \Theta^{\alpha_2})|_{\tau^{\overline{V_1}}})|_{\tau^{\overline{V_1 \cup V_2}}}$, which with $\tau^{\overline{V_1 \cup V_2}} \circ \tau^{\overline{V_1}} = \tau^{\overline{V_1 \cup V_2}}$ is equal to $(\Theta^{\alpha_1} \otimes \Theta^{\alpha_2})|_{\tau^{\overline{V_1 \cup V_2}}}$. The claim then follows with Theorem 4.5.

Previous Label Reduction and its Flaws

Proof Sketch for Theorem 5.11 of Helmert et al. (2014)

We prove by induction over the construction of T^α that, for any intermediate merge-and-shrink abstraction β over V': $\Theta^\tau_\beta = \Theta^\beta$ if $v^* \notin V'$, and $\Theta^\tau_\beta = \Theta^\beta|_{\tau^{\overline{V'}}}$ if $v^* \in V'$. The single tricky case in the induction is the case where $\beta = \alpha_1 \otimes \alpha_2$ and (WLOG) $v^* \in V_1$. Using the induction hypothesis, we then need to prove that $(\Theta^{\alpha_1}|_{\tau^{\overline{V_1}}} \otimes \Theta^{\alpha_2}|_{\tau^{\overline{V_1}}})|_{\tau^{\overline{V_1 \cup V_2}}} = \Theta^{\alpha_1 \otimes \alpha_2}|_{\tau^{\overline{V_1 \cup V_2}}}$. Since $\tau^{\overline{V_1}}$ is conservative for $\Theta^{\pi_{\overline{V_1}}}$, with $V_2 \subseteq \overline{V_1}$ and Proposition 5.4, it is conservative also for Θ^{α_2}. Hence, Lemma 5.6 reduces the left-hand side of our proof obligation to $((\Theta^{\alpha_1} \otimes \Theta^{\alpha_2})|_{\tau^{\overline{V_1}}})|_{\tau^{\overline{V_1 \cup V_2}}}$, which with $\tau^{\overline{V_1 \cup V_2}} \circ \tau^{\overline{V_1}} = \tau^{\overline{V_1 \cup V_2}}$ is equal to $(\Theta^{\alpha_1} \otimes \Theta^{\alpha_2})|_{\tau^{\overline{V_1 \cup V_2}}}$. The claim then follows with Theorem 4.5.

Previous Label Reduction and its Flaws

Proof Sketch for Theorem 5.11 of Helmert et al. (2014)

We prove by induction over the construction of T^α that, for any intermediate merge-and-shrink abstraction β over V': $\Theta^\tau_\beta = \Theta^\beta$ if $v^* \notin V'$, and $\Theta^\tau_\beta = \Theta^\beta|_{\tau_{\overline{V'}}}$ if $v^* \in V'$. The single tricky case in the induction is the case where $\beta = \alpha_1 \otimes \alpha_2$ and (WLOG) $v^* \in V_1$. Using the induction hypothesis, we then need to prove that $(\Theta^{\alpha_1}|_{\tau_{\overline{V_1}}} \otimes \Theta^{\alpha_2}|_{\tau_{\overline{V_1}}})|_{\tau_{\overline{V_1 \cup V_2}}} = \Theta^{\alpha_1 \otimes \alpha_2}|_{\tau_{\overline{V_1 \cup V_2}}}$. Since $\tau^{\overline{V_1}}$ is conservative for $\Theta^{\pi_{\overline{V_1}}}$, with $V_2 \subseteq \overline{V_1}$ and Proposition 5.4, it is conservative also for Θ^{α_2}. Hence, Lemma 5.6 reduces the left-hand side of our proof obligation to $((\Theta^{\alpha_1} \otimes \Theta^{\alpha_2})|_{\tau_{\overline{V_1}}})|_{\tau_{\overline{V_1 \cup V_2}}}$, which with $\tau^{\overline{V_1 \cup V_2}} \circ \tau^{\overline{V_1}} = \tau^{\overline{V_1 \cup V_2}}$ is equal to $(\Theta^{\alpha_1} \otimes \Theta^{\alpha_2})|_{\tau_{\overline{V_1 \cup V_2}}}$. The claim then follows with Theorem 4.5.

- Full potential restricted to linear merge strategies
- Based on syntax of underlying planning operators

Outline

1. Background
2. Generalized Label Reduction
3. Experiments

Contribution

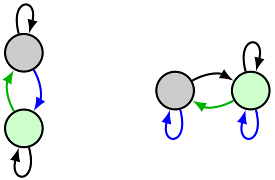
- Clear, easy and complete definition of label reduction
- Theoretic investigation: properties of label reduction (safeness and exactness)
- Empirical investigation for classical planning

Generalized Label Reduction

- Replace all labels of a chosen set by one chosen new label in all automata

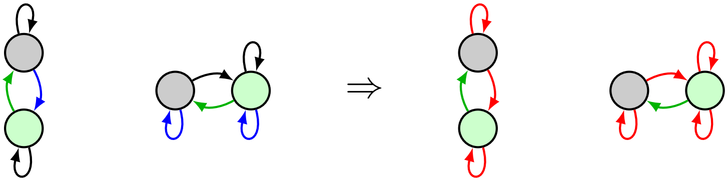
Generalized Label Reduction

- Replace all labels of a chosen set by one chosen new label in all automata



Generalized Label Reduction

- Replace all labels of a chosen set by one chosen new label in all automata



Theorem: Safeness

Theorem

Label reduction is safe, i. e. leaves the heuristic admissible.

Combinable Labels

Definitions

- Labels are locally equivalent in automaton Θ if they label the same set of transitions in Θ.
- Labels are Θ-combinable if they are locally equivalent in all automata but Θ.
- Label ℓ_1 globally subsumes label ℓ_2 if the set of transitions labeled by ℓ_2 is a subset of the transitions labeled by ℓ_1 in all automata.

Theorem: Exactness

Theorem

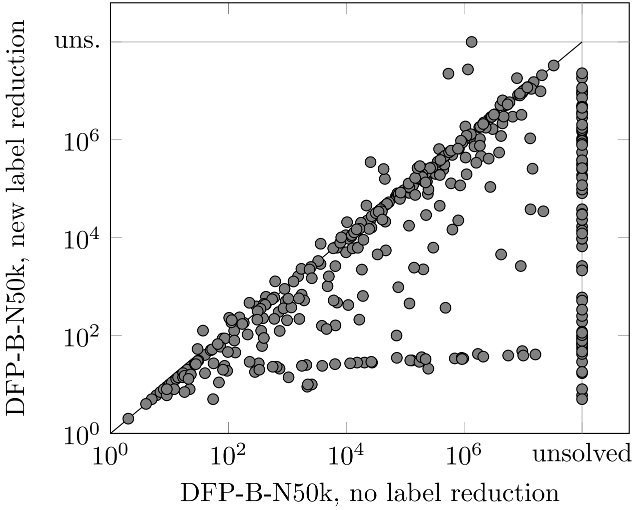
A label reduction which maps labels ℓ_1 and ℓ_2 onto a new label ℓ is exact, i. e. leaves the heuristic perfect, if and only if

1. *ℓ_1 globally subsumes ℓ_2, or*
2. *ℓ_2 globally subsumes ℓ_1, or*
3. *ℓ_1 and ℓ_2 are Θ-combinable for some automaton Θ of the set of automata.*

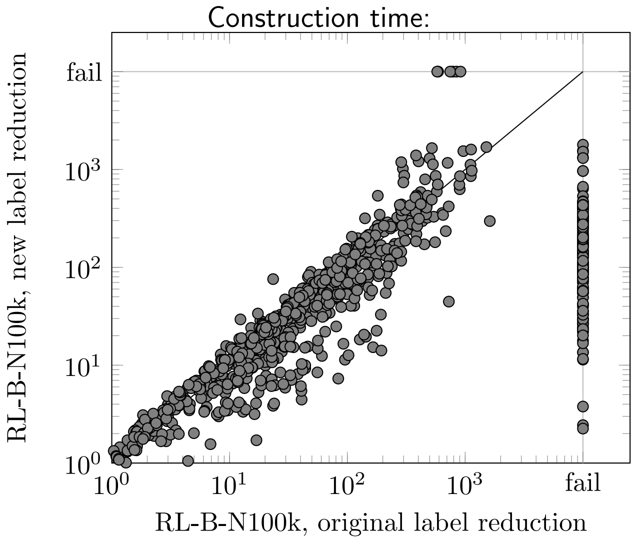
Outline

Results: Usefulness of Label Reduction

Expansions:



Results: Old vs. New Label Reduction Method



Conclusion

- Generalized label reduction for merge-and-shrink heuristics:
  - Cleaner and easier definition
  - Safe and unrestricted transformation
  - Exact transformation if based on Θ-combinability
- Empirical performance gain for merge-and-shrink heuristics in classical planning
- Opened possibilities to develop even better merge-and-shrink heuristics

The End

Thank you!

Results: Coverage

Coverage:

merge/shrink strategy	Label Reduction		
	none	old	new
RL-B-N50k	577	618	634
RL-B-N100k	560	599	639
RL-B-N200k	544	590	630
DFP-B-N50k	565	—	644
DFP-B-N100k	551	—	632
DFP-B-N200k	522	—	625