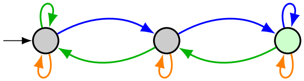
Merge-and-Shrink Heuristics for Classical Planning: Efficient Implementation and Partial Abstractions

Silvan Sievers

July 14, 2018

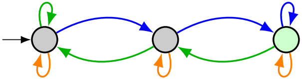
Motivation

- Given: large (labeled) transition system
  (your favorite search problem, classical planning task, . . .)



Motivation

- Given: large (labeled) transition system
  (your favorite search problem, classical planning task, . . .)



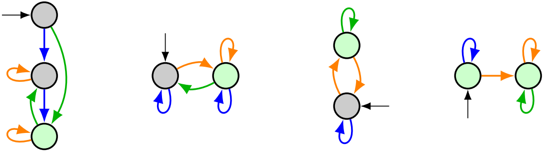
- Goal: compute admissible heuristic, then solve optimally using A*

Merge-and-shrink: Idea

Factored transition system: set of small transitions systems representing a large transition system (synchronized product)

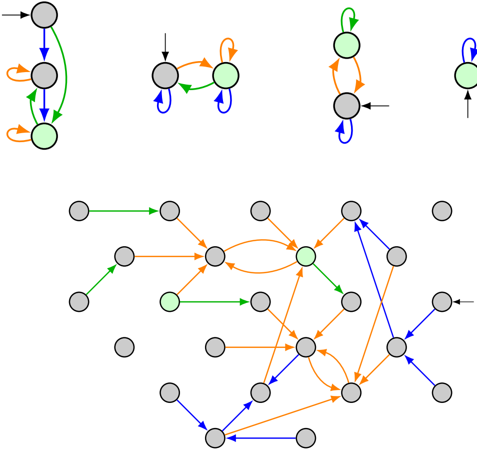
Merge-and-shrink: Idea

Factored transition system: set of small transitions systems representing a large transition system (synchronized product)



Merge-and-shrink: Idea

Factored transition system: set of small transitions systems representing a large transition system (synchronized product)



Merge-and-shrink: Framework

- Start with atomic factored transition system (one factor for each variable of the problem)
- Repeatedly apply transformation to factored transition system
- Keep factored mapping alongside to represent the abstraction (omitted in the following)

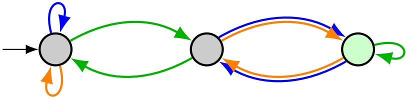
Outline

Representing Transition Systems

- Common approach: adjacency matrix
- Previous implementation: store transitions by labels
  $\rightarrow$ beneficial for all transformations

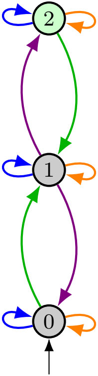
Representing Transition Systems

- Common approach: adjacency matrix
- Previous implementation: store transitions by labels
  → beneficial for all transformations
- New: store label groups of locally equivalent labels



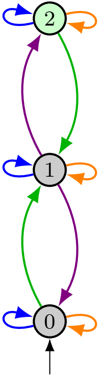
→ reduce memory pressure

Representing Transition Systems: Example



previous representation
blue arrow: $\{\langle 0,0\rangle, \langle 1,1\rangle, \langle 2,2\rangle\}$
orange arrow: $\{\langle 0,0\rangle, \langle 1,1\rangle, \langle 2,2\rangle\}$
green arrow: $\{\langle 0,1\rangle, \langle 2,1\rangle\}$
purple arrow: $\{\langle 1,0\rangle, \langle 1,2\rangle\}$

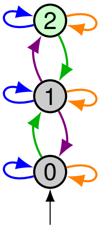
Representing Transition Systems: Example



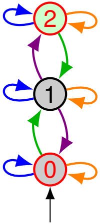
previous representation	
→:	$\{\langle 0,0\rangle, \langle 1,1\rangle, \langle 2,2\rangle\}$
→:	$\{\langle 0,0\rangle, \langle 1,1\rangle, \langle 2,2\rangle\}$
→:	$\{\langle 0,1\rangle, \langle 2,1\rangle\}$
→:	$\{\langle 1,0\rangle, \langle 1,2\rangle\}$

optimized representation	
{→, →}:	$\{\langle 0,0\rangle, \langle 1,1\rangle, \langle 2,2\rangle\}$
{→}:	$\{\langle 0,1\rangle, \langle 2,1\rangle\}$
{→}:	$\{\langle 1,0\rangle, \langle 1,2\rangle\}$

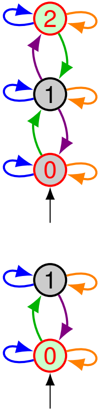
Transformations: Shrinking



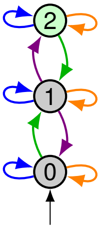
Transformations: Shrinking

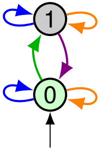


Transformations: Shrinking

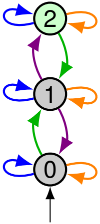


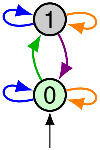
Transformations: Shrinking





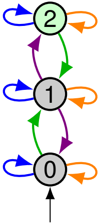
Transformations: Shrinking



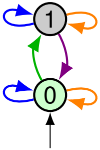


representation	
{→, →}:	$\{\langle 0,0\rangle, \langle 1,1\rangle, \langle 2,2\rangle\}$
{→}:	$\{\langle 0,1\rangle, \langle 2,1\rangle\}$
{→}:	$\{\langle 1,0\rangle, \langle 1,2\rangle\}$

Transformations: Shrinking

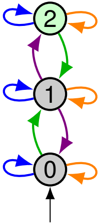


representation	
{→, →}:	$\{\langle 0,0\rangle, \langle 1,1\rangle, \langle 2,2\rangle\}$
{→}:	$\{\langle 0,1\rangle, \langle 2,1\rangle\}$
{→}:	$\{\langle 1,0\rangle, \langle 1,2\rangle\}$

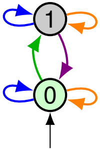


representation

Transformations: Shrinking

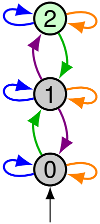


representation	
{→, →}:	$\{\langle 0,0\rangle, \langle 1,1\rangle, \langle 2,2\rangle\}$
{→}:	$\{\langle 0,1\rangle, \langle 2,1\rangle\}$
{→}:	$\{\langle 1,0\rangle, \langle 1,2\rangle\}$

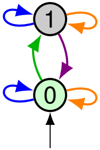


representation
{→, →}:

Transformations: Shrinking

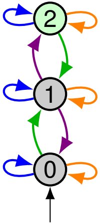


representation	
{→, →}:	$\{\langle 0,0\rangle, \langle 1,1\rangle, \langle 2,2\rangle\}$
{→}:	$\{\langle 0,1\rangle, \langle 2,1\rangle\}$
{→}:	$\{\langle 1,0\rangle, \langle 1,2\rangle\}$

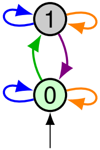


representation	
{→, →}:	$\{\langle 0,0\rangle, \quad \}$

Transformations: Shrinking

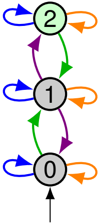


representation	
{→, →}:	$\{\langle 0, 0\rangle, \langle 1, 1\rangle, \langle 2, 2\rangle\}$
{→}:	$\{\langle 0, 1\rangle, \langle 2, 1\rangle\}$
{→}:	$\{\langle 1, 0\rangle, \langle 1, 2\rangle\}$

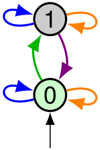


representation	
{→, →}:	$\{\langle 0, 0\rangle, \langle 1, 1\rangle\}$

Transformations: Shrinking

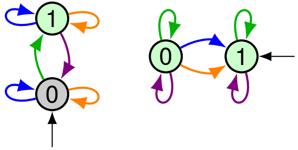


representation	
{→, →}:	$\{\langle 0,0\rangle, \langle 1,1\rangle, \langle 2,2\rangle\}$
{→}:	$\{\langle 0,1\rangle, \langle 2,1\rangle\}$
{→}:	$\{\langle 1,0\rangle, \langle 1,2\rangle\}$

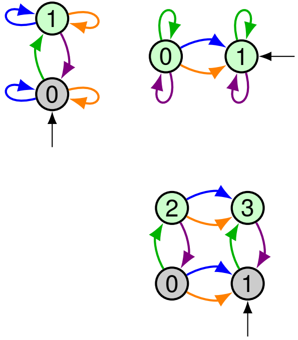


representation	
{→, →}:	$\{\langle 0,0\rangle, \langle 1,1\rangle\}$
{→}:	$\{\langle 0,1\rangle\}$
{→}:	$\{\langle 1,0\rangle\}$

Transformations: Merging

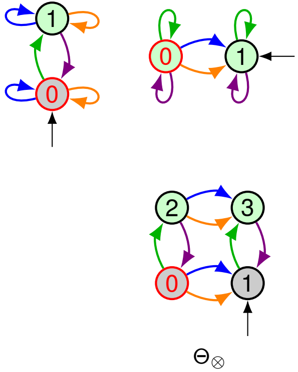


Transformations: Merging

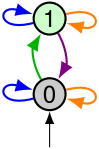


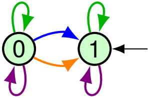
$\Theta_{\otimes}$

Transformations: Merging



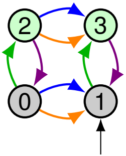
Transformations: Merging





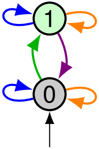
representation	
{→, →}:	$\{\langle 0,0\rangle, \langle 1,1\rangle\}$
{→}:	$\{\langle 0,1\rangle\}$
{→}:	$\{\langle 1,0\rangle\}$

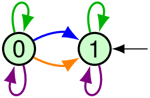
representation	
{→, →}:	$\{\langle 0,1\rangle\}$
{→, →}:	$\{\langle 0,0\rangle, \langle 1,1\rangle\}$



$\Theta_{\otimes}$

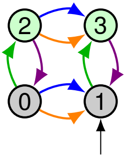
Transformations: Merging





representation	
{→, →}:	$\{\langle 0,0\rangle, \langle 1,1\rangle\}$
{→}:	$\{\langle 0,1\rangle\}$
{→}:	$\{\langle 1,0\rangle\}$

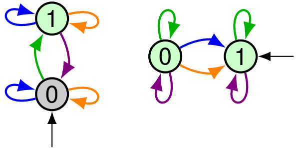
representation	
{→, →}:	$\{\langle 0,1\rangle\}$
{→, →}:	$\{\langle 0,0\rangle, \langle 1,1\rangle\}$



$\Theta_\otimes$

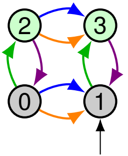
representation

Transformations: Merging



representation	
{→, →}:	$\{\langle 0,0\rangle, \langle 1,1\rangle\}$
{→}:	$\{\langle 0,1\rangle\}$
{→}:	$\{\langle 1,0\rangle\}$

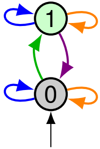
representation	
{→, →}:	$\{\langle 0,1\rangle\}$
{→, →}:	$\{\langle 0,0\rangle, \langle 1,1\rangle\}$

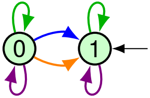


$\Theta_\otimes$

representation
{→, →}:

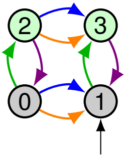
Transformations: Merging





representation	
{→, →}:	{⟨0, 0⟩, ⟨1, 1⟩}
{→}:	{⟨0, 1⟩}
{→}:	{⟨1, 0⟩}

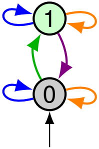
representation	
{→, →}:	{⟨0, 1⟩}
{→, →}:	{⟨0, 0⟩, ⟨1, 1⟩}

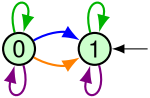


$\Theta_\otimes$

representation	
{→, →}:	{⟨0, 1⟩, }

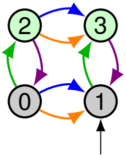
Transformations: Merging





representation	
$\{{\color{blue}\rightarrow}, {\color{orange}\rightarrow}\}$:	$\{\langle 0,0\rangle, {\color{red}\langle 1,1\rangle}\}$
$\{{\color{green}\rightarrow}\}$:	$\{\langle 0,1\rangle\}$
$\{{\color{purple}\rightarrow}\}$:	$\{\langle 1,0\rangle\}$

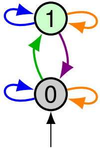
representation	
$\{{\color{blue}\rightarrow}, {\color{orange}\rightarrow}\}$:	$\{{\color{red}\langle 0,1\rangle}\}$
$\{{\color{green}\rightarrow}, {\color{purple}\rightarrow}\}$:	$\{\langle 0,0\rangle, \langle 1,1\rangle\}$

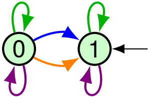


$\Theta_\otimes$

representation	
$\{{\color{blue}\rightarrow}, {\color{orange}\rightarrow}\}$:	$\{\langle 0,1\rangle, {\color{red}\langle 2,3\rangle}\}$

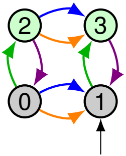
Transformations: Merging





representation	
{→, →}:	$\{\langle 0,0\rangle,\langle 1,1\rangle\}$
{→}:	$\{\langle 0,1\rangle\}$
{→}:	$\{\langle 1,0\rangle\}$

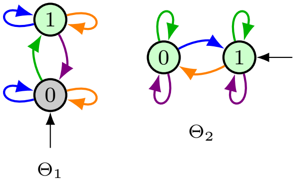
representation	
{→, →}:	$\{\langle 0,1\rangle\}$
{→, →}:	$\{\langle 0,0\rangle,\langle 1,1\rangle\}$



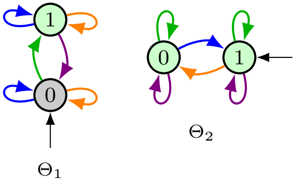
$\Theta_\otimes$

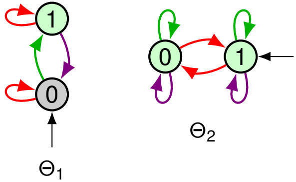
representation	
{→, →}:	$\{\langle 0,1\rangle,\langle 2,3\rangle\}$
{→}:	$\{\langle 0,2\rangle,\langle 1,3\rangle\}$
{→}:	$\{\langle 2,0\rangle,\langle 3,1\rangle\}$

Transformations: Generalized Label Reduction

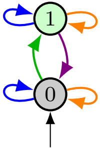


Transformations: Generalized Label Reduction

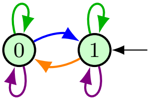




Transformations: Generalized Label Reduction



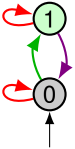
Θ_1



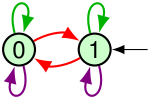
Θ_2

	representation
{blue →, orange →}:	{⟨0, 0⟩, ⟨1, 1⟩}
{green →}:	{⟨0, 1⟩}
{purple →}:	{⟨1, 0⟩}

	representation
{blue →}:	{⟨0, 1⟩}
{orange →}:	{⟨1, 0⟩}
{green →, purple →}:	{⟨0, 0⟩, ⟨1, 1⟩}

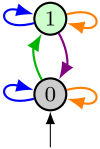


Θ_1

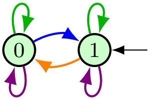


Θ_2

Transformations: Generalized Label Reduction



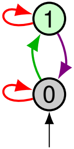
Θ_1



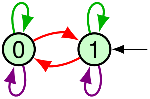
Θ_2

	representation
{→, →}:	$\{\langle 0,0\rangle, \langle 1,1\rangle\}$
{→}:	$\{\langle 0,1\rangle\}$
{→}:	$\{\langle 1,0\rangle\}$

	representation
{→}:	$\{\langle 0,1\rangle\}$
{→}:	$\{\langle 1,0\rangle\}$
{→, →}:	$\{\langle 0,0\rangle, \langle 1,1\rangle\}$



Θ_1

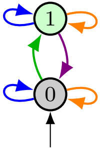


Θ_2

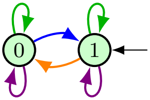
representation

representation

Transformations: Generalized Label Reduction



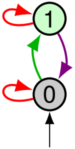
Θ_1



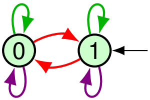
Θ_2

representation	
{→, →}:	$\{\langle 0,0\rangle, \langle 1,1\rangle\}$
{→}:	$\{\langle 0,1\rangle\}$
{→}:	$\{\langle 1,0\rangle\}$

representation	
{→}:	$\{\langle 0,1\rangle\}$
{→}:	$\{\langle 1,0\rangle\}$
{→, →}:	$\{\langle 0,0\rangle, \langle 1,1\rangle\}$



Θ_1

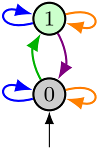


Θ_2

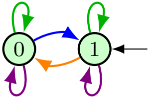
representation
{→}:

representation
{→}:

Transformations: Generalized Label Reduction



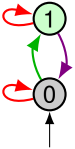
Θ_1



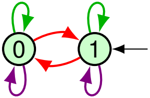
Θ_2

representation	
{→, →}:	{⟨0, 0⟩, ⟨1, 1⟩}
{→}:	{⟨0, 1⟩}
{→}:	{⟨1, 0⟩}

representation	
{→}:	{⟨0, 1⟩}
{→}:	{⟨1, 0⟩}
{→, →}:	{⟨0, 0⟩, ⟨1, 1⟩}



Θ_1

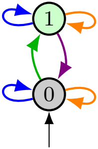


Θ_2

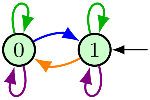
representation	
{→}:	{⟨0, 0⟩, ⟨1, 1⟩}

representation	
{→}:	{⟨0, 1⟩, ⟨1, 0⟩}

Transformations: Generalized Label Reduction



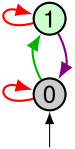
Θ_1



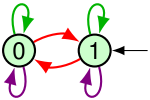
Θ_2

representation	
$\{\color{blue}\rightarrow, \color{orange}\rightarrow\}$:	$\{\langle 0,0\rangle, \langle 1,1\rangle\}$
$\{\color{lime}\rightarrow\}$:	$\{\langle 0,1\rangle\}$
$\{\color{purple}\rightarrow\}$:	$\{\langle 1,0\rangle\}$

representation	
$\{\color{blue}\rightarrow\}$:	$\{\langle 0,1\rangle\}$
$\{\color{orange}\rightarrow\}$:	$\{\langle 1,0\rangle\}$
$\{\color{lime}\rightarrow, \color{purple}\rightarrow\}$:	$\{\langle 0,0\rangle, \langle 1,1\rangle\}$



Θ_1



Θ_2

representation	
$\{\color{red}\rightarrow\}$:	$\{\langle 0,0\rangle, \langle 1,1\rangle\}$
$\{\color{lime}\rightarrow\}$:	$\{\langle 0,1\rangle\}$
$\{\color{purple}\rightarrow\}$:	$\{\langle 1,0\rangle\}$

representation	
$\{\color{red}\rightarrow\}$:	$\{\langle 0,1\rangle, \langle 1,0\rangle\}$
$\{\color{lime}\rightarrow, \color{purple}\rightarrow\}$:	$\{\langle 0,0\rangle, \langle 1,1\rangle\}$

Algorithm Framework

Merge-and-Shrink in Fast Downward

$F \leftarrow F(\Pi)$ // factored transition system
While $|F| > 1$:
  $\Theta_1, \Theta_2, \leftarrow \textsc{Select}(F)$
  $\textsc{LabelReduction}(\text{F})$
  $F \leftarrow \textsc{Shrink}(F, \Theta_1, \Theta_2)$
  $F \leftarrow \textsc{Merge}(F, \Theta_1, \Theta_2)$
Return $h_\Pi^{\text{M\&S}} \leftarrow h_\Theta^*$ // Θ: single factor in F

Parameters: transformation strategies, size limits

Remarks

Considering label groups also benefits:

- Computing bisimulation-based shrinking
- Computing symmetry-based merging

Experiments – Previous vs. Optimized Implementation

- Integrate old version into recent Fast Downward
- All results with bisimulation-based shrinking, 50000 states

Experiments – Previous vs. Optimized Implementation

- Integrate old version into recent Fast Downward
- All results with bisimulation-based shrinking, 50000 states

	previous	optimized	difference	
Coverage	733	754	**21**	CGGL
# constr	1387	1467	**80**	
Coverage	768	774	**6**	DFP
# constr	1419	1504	**85**	
Coverage	778	804	**26**	MIASMdfp
# constr	1382	1480	**98**	
Coverage	756	773	**17**	RL
# constr	1433	1515	**82**	

Outline

Motivation

- Efficient implementation increased performance
- But: heuristic computation fails in 151–267 out of 1667 tasks for state-of-the-art configurations

Algorithm – Early Termination

Merge-and-Shrink in Fast Downward

$F \leftarrow F(\Pi)$ // factored transition system

While $|F| > 1$ **and not** $\textsc{ReachedLimit}()$:

$\Theta_1, \Theta_2, \leftarrow \textsc{Select}(F)$

$\textsc{LabelReduction}(F)$

$F \leftarrow \textsc{Shrink}(F, \Theta_1, \Theta_2)$

$F \leftarrow \textsc{Merge}(F, \Theta_1, \Theta_2)$

Return $h_{\Pi}^{\text{M\&S}} \leftarrow \textsc{ComputeHeuristic}(F)$

Algorithm – Early Termination

Merge-and-Shrink in Fast Downward

$F \leftarrow F(\Pi)$ // factored transition system
While $|F| > 1$ **and not** $\textsc{ReachedLimit}()$:
  $\Theta_1, \Theta_2, \leftarrow \textsc{Select}(F)$
  $\textsc{LabelReduction}(\mathrm{F})$
  $F \leftarrow \textsc{Shrink}(F, \Theta_1, \Theta_2)$
  $F \leftarrow \textsc{Merge}(F, \Theta_1, \Theta_2)$
Return $h_{\Pi}^{\mathrm{M\&S}} \leftarrow \textsc{ComputeHeuristic}(F)$

Termination criteria ($\textsc{ReachedLimit}$):

- Growing too many transitions in a factor
- Reaching a time limit

Computing the Heuristic from Partial Abstractions

- Given: set of remaining factors and corresponding factored mappings
  $\rightarrow$ set of partial abstractions
- Wanted: merge-and-shrink heuristic

Computing the Heuristic from Partial Abstractions

- Given: set of remaining factors and corresponding factored mappings
  $\rightarrow$ set of partial abstractions
- Wanted: merge-and-shrink heuristic
- Two simple variants:
  - Compute $h^{\text{M\&S}}$ as maximum over heuristics induced by partial abstractions
  - Choose a single “good” heuristic, preferring high initial state heuristic values, breaking ties by favoring larger factors

Experiments – Limiting Transitions

		single heuristic			maximum heuristic			
	base	t2m	t5m	t10m	t2m	t5m	t10m	
Coverage	**804**	775	791	801	775	791	801	MIASMdfp
# constr	1482	**1515**	1493	1490	**1515**	1493	1490	
Coverage	**802**	787	797	**802**	792	798	**802**	sbMIASM
# constr	1400	**1453**	1422	1414	1452	1424	1417	
Coverage	**813**	778	801	811	778	801	811	SCCdfp
# constr	1506	**1532**	1515	1514	**1532**	1515	1512	

Experiments – Limiting Time

		single heuristic			maximum heuristic			
	base	450s	900s	1350s	450s	900s	1350s	
Coverage	804	**835**	832	827	**835**	833	826	MIASMdfp
# constr	1482	**1595**	1591	1568	1592	1590	1566	
Coverage	802	835	835	835	**836**	**836**	835	sbMIASM
# constr	1400	**1637**	1628	1616	1636	1628	1615	
Coverage	813	844	844	840	844	**845**	840	SCCdfp
# constr	1506	**1622**	1620	1608	**1622**	1620	1610	

Conclusions

- Algorithmic view on merge-and-shrink for classical planning
- Efficient implementation in Fast Downward
- Partial abstractions further push efficiency