Merge-and-Shrink Abstractions for Classical Planning

Theory, Strategies, and Implementation

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PhD Defense

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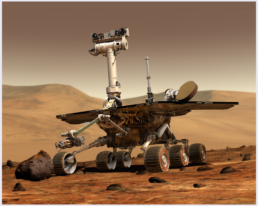
Classical Planning

Examples



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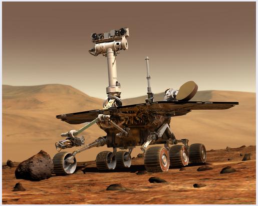
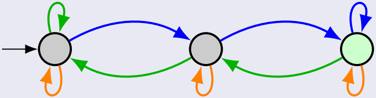


Representation: Transition Systems



Solving Planning Tasks Optimally

- Transition systems not given explicitly (too large)
- Compact description of planning tasks
- Use A^* with admissible heuristics

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Merge-and-shrink Heuristics
[Dräger, Finkbeiner & Podelski, 2006; Helmert, Haslum & Hoffmann, 2007]

- Compute abstraction of transition system
- Use optimal abstract solution as heuristic

Merge-and-shrink: Idea

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

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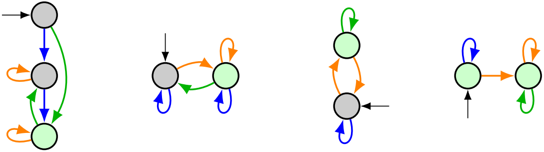

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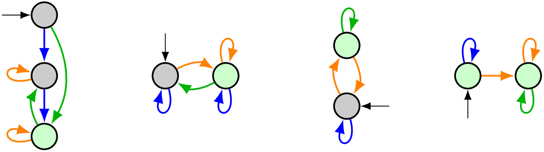

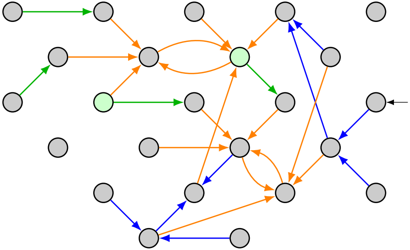

Merge-and-shrink Transformations: Merging

Replace two transition systems by their synchronized product

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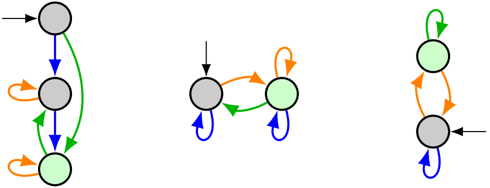

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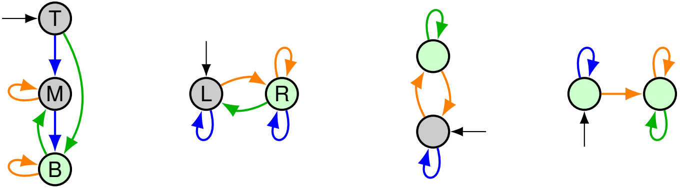

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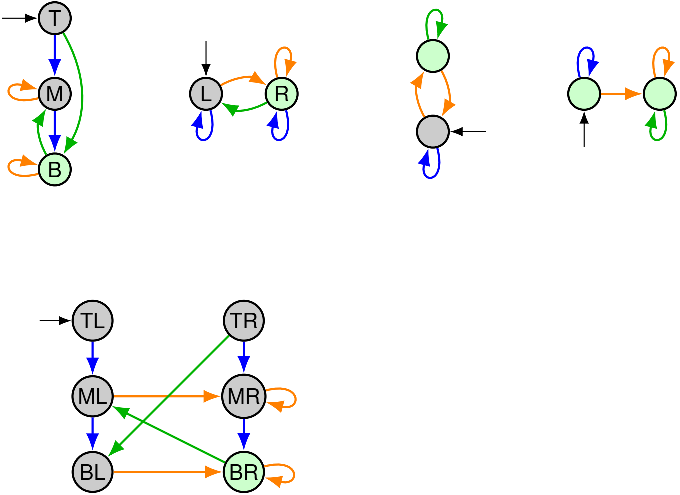

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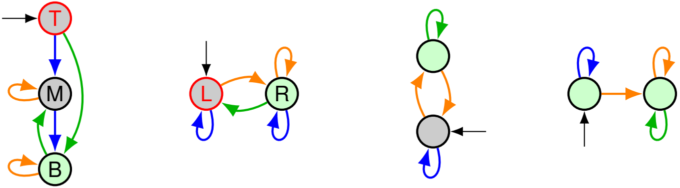

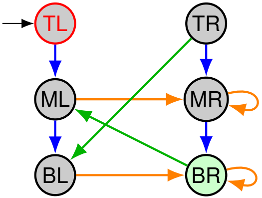

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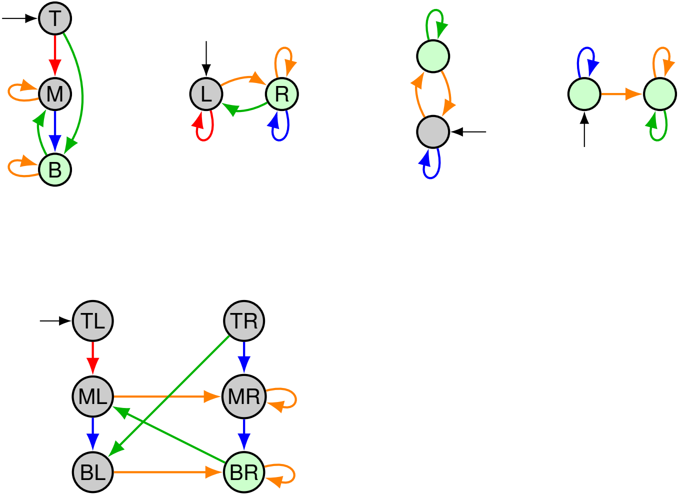

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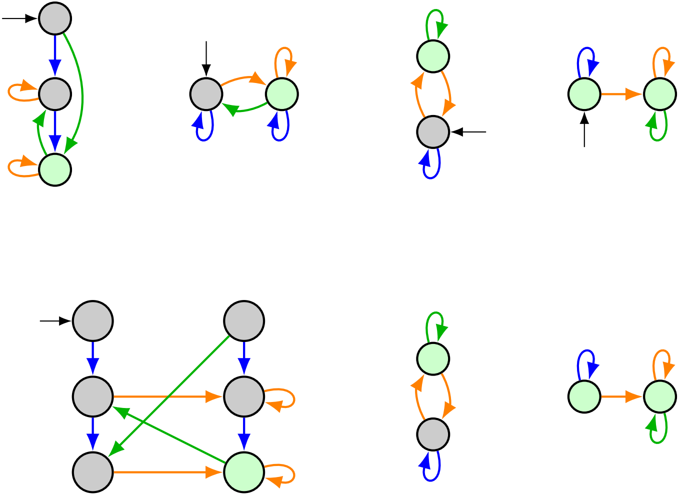

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Apply abstraction to some transition system

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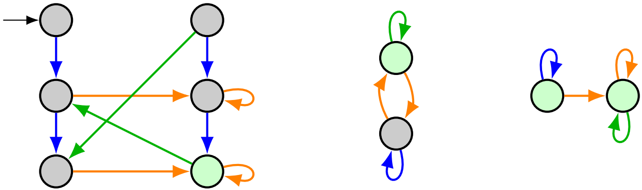

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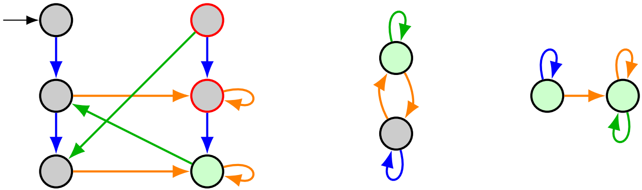

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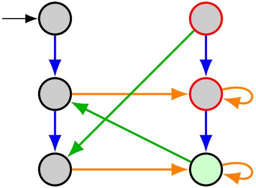

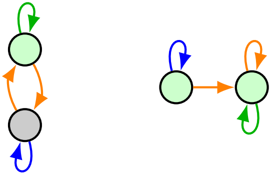

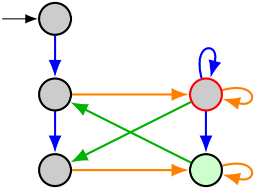

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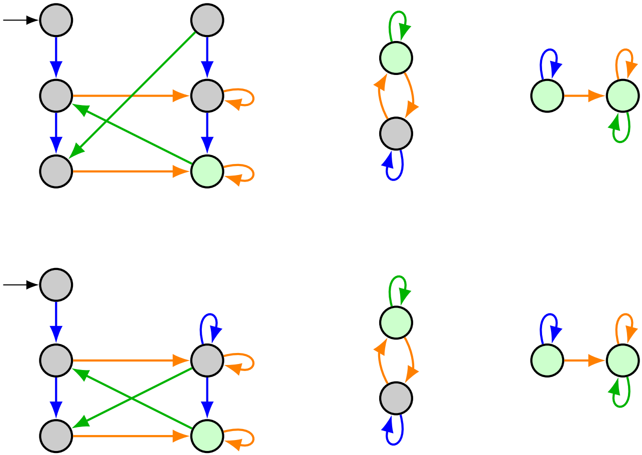
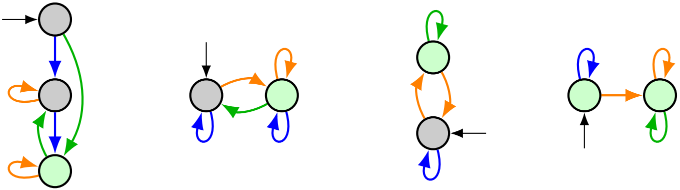


Merge-and-shrink: Ingredients

- Omitted: abstraction mapping, label mapping
- How to merge? $\rightarrow$ merge strategy

Representing Merge Strategies



Θ_1 Θ_2 Θ_3 Θ_4

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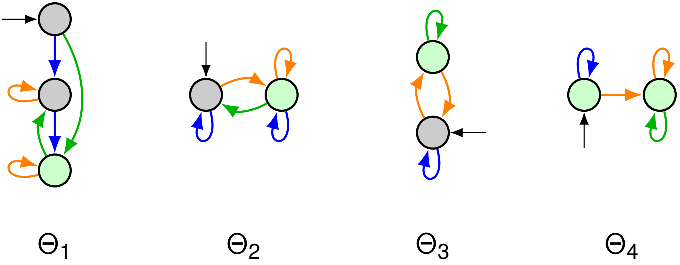

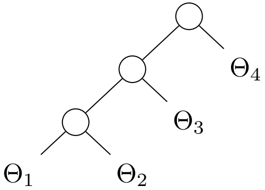

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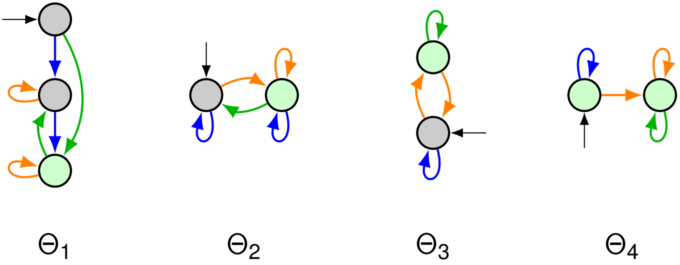

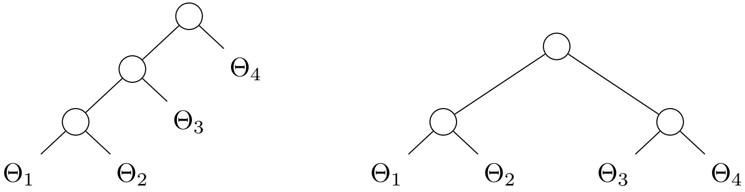

Contributions

Merge-and-shrink
Framework

Contributions

Theory:

- Generalized Label Reduction
- Expressiveness

Merge-and-shrink Framework

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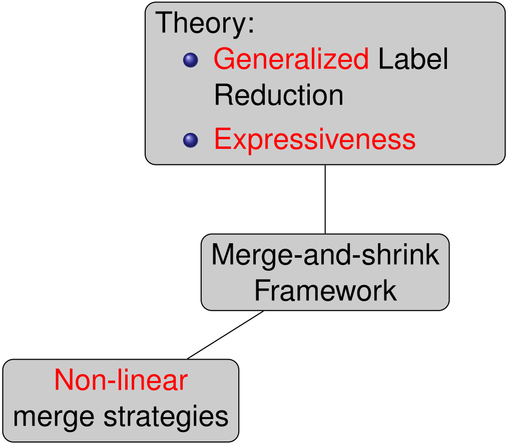

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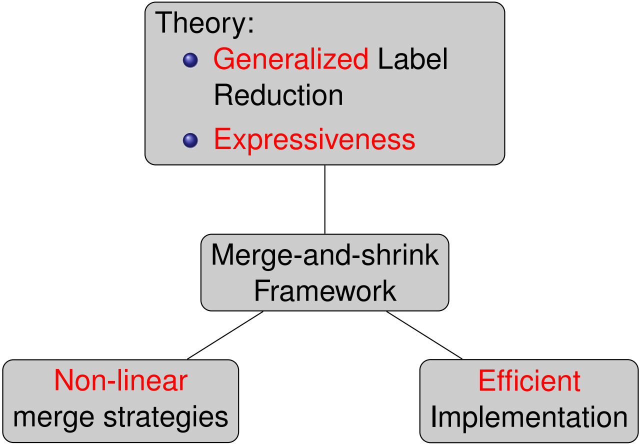

Outline

Merge-and-shrink Transformations: Label Reduction

Combine different labels to reduce number of transitions

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Previous Label Reduction

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

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Generalized Label Reduction [S, Wehrle & Helmert, 2014]

- Clear and easy definition
- Transformation like merging and shrinking

Generalized Label Reduction

Apply abstraction to the common label set of the factored transition system

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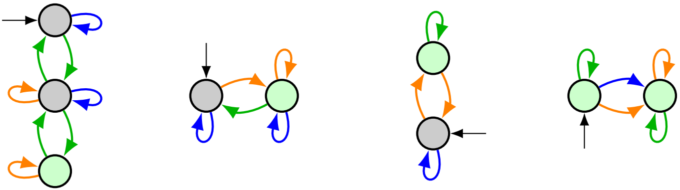

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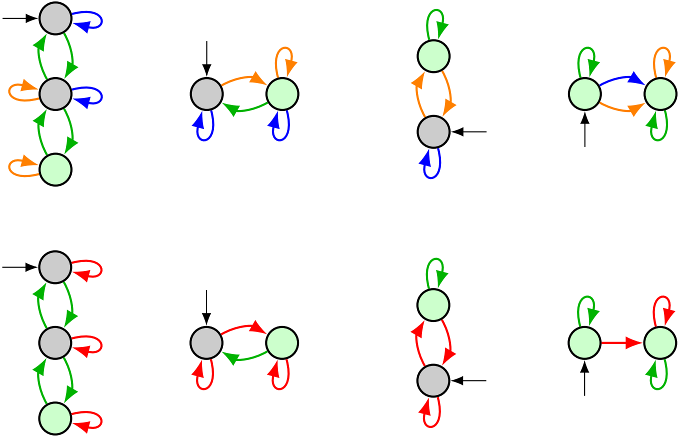

Exact Label Reductions

Locally equivalent labels: parallel transitions in a transition system

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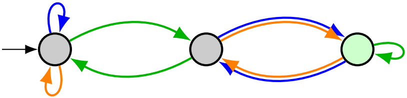

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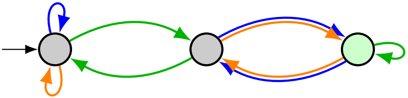

Combinable labels: locally equivalent in all but one transition systems

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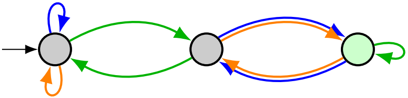

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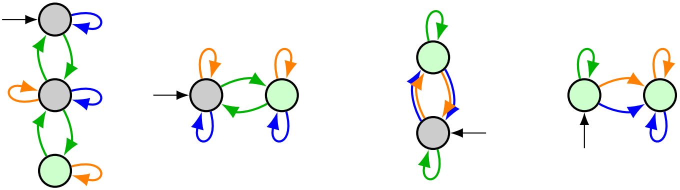

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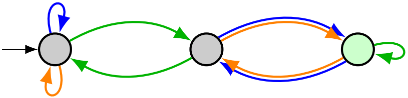

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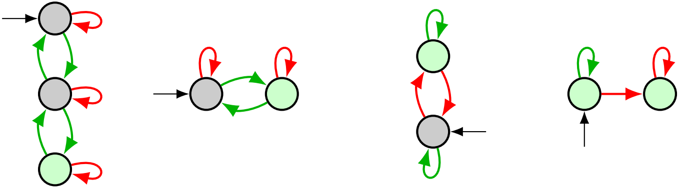

Expressive Power of Merge-and-Shrink
[Helmert, Röger & S, 2015]

What functions can be compactly represented
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by non-linear and linear merge-and-shrink?

Theorem

- Non-linear merge-and-shrink strictly more powerful than linear merge-and-shrink

Outline

First Non-linear Merge Strategy for Planning
[S, Wehrle & Helmert, 2014]

Adapted from model checking [Dräger, Finkbeiner & Podelski, 2006]

DFP Merge Strategy

- Score-based: assign each merge candidate a value
- Prefer products fine-grained in goal region

Factored Symmetries

[S, Wehrle, Helmert, Shleyfman & Katz, 2015]

Factored Symmetries

Goal-stable automorphisms of a factored transition system

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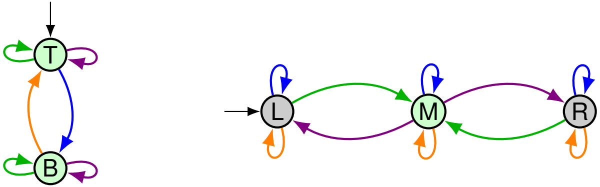

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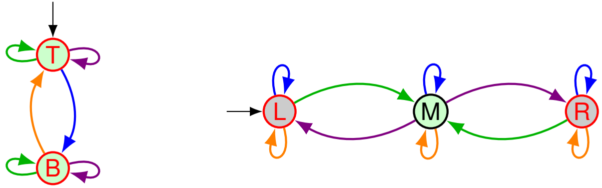

- T ⇔ B, L ⇔ R
- → ⇔ →

Symmetry-enhanced Merge Strategies

What to do with symmetries?

- Shrinking by combining symmetric states

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Framework to Enhance Merge Strategies with Symmetries

- Compute symmetries and select one
- In the next iterations, merge all affected transition systems
- Otherwise, use fallback merge strategy

Another Score-based Merge Strategy

MIASM: maximum intermediate abstraction size minimizing

[Fan, Müller & Holte, 2014]

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Taxonomy of Merge Strategies

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Capture causal dependencies

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Precomputed merge strategies		Score-based merge strategies
Capture causal dependencies		Interaction with other strategies

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Precomputed merge strategies

Capture **causal dependencies**

Score-based merge strategies

Interaction with other strategies

Hybrid Merge Strategies

Precompute only **some part** of the merge tree

SCC Framework for Merge Strategies

[S, Wehrle & Helmert, 2016]

- Precomputation: partition transition systems according to the SCCs of the causal graph
- Secondary score-based merge strategy:
  - First merge transition systems within partitions
  - Then merge resulting products

Outline

Experimental Study

- Integration into Fast Downward

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- Evaluation on planning benchmarks: 1667 tasks
- Typical IPC limits: 30m, 2GB

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- Reporting coverage

Evolution of Merge-and-Shrink Heuristics

Old Lab. Red.

$$\frac{\text{RL}}{702}$$

Evolution of Merge-and-Shrink Heuristics

Old Lab. Red.

RL
702

Gen. Lab. Red.

RL
728

Evolution of Merge-and-Shrink Heuristics

Old Lab. Red.

RL
702

Gen. Lab. Red.

RL	DFP	MIASM
728	746	773

Evolution of Merge-and-Shrink Heuristics

Old Lab. Red.

RL
702

Gen. Lab. Red.

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Factored Symmetries

RL	DFP
743	752

Evolution of Merge-and-Shrink Heuristics

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RL
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State-of-the-art Merge Strategies

sbMIASM
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Factored Symmetries

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State-of-the-art Merge Strategies

sbMIASM	DFP (TB)
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State-of-the-art Merge Strategies

sbMIASM	DFP (TB)	SCC-sbMIASM	SCC-DFP
755	760	770	780

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State-of-the-art Merge Strategies

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- Algebraic view
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Non-linear strategies:

- DFP, sbMIASM
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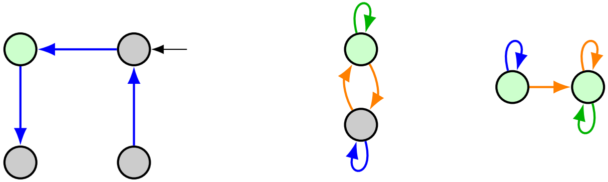
Efficient Implementation

Selected Publications

- Efficient Implementation of PDBs [S, Ortlieb & Helmert, 2012]
- Generalized Label Reduction [S, Wehrle & Helmert, 2014]
- Structural Symmetries [Shelyfman, Katz, S, Wehrle & Helmert, 2015]
- Factored Symmetries [S, Wehrle, Helmert, Shleyfman & Katz, 2015]
- Expressiveness of M&S [Helmert, Röger & S, 2015]
- Symmetries for Abs. Heuristics [S, Wehrle, Helmert & Katz 2015]
- Merge Strategies [S, Wehrle & Helmert, 2016]
- PDBs with Symmetries [S, Wehrle, Helmert & Katz, 2017]

Merge-and-shrink Transformations: Pruning



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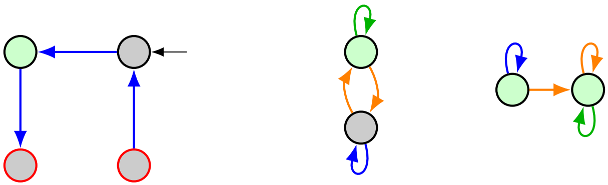

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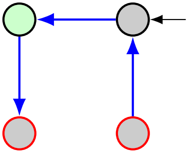

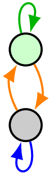

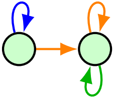

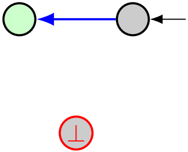

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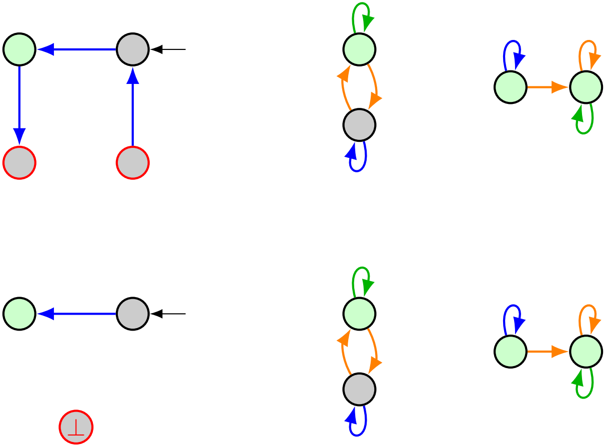


Factored Mappings

$\mathcal{M}_{\Theta_1}$ \ $\mathcal{M}_{\Theta_2}$	0	1
0	0	1
1	2	2

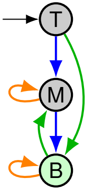
$\mathcal{M}_{\Theta_1 \otimes \Theta_2}$

$\mathcal{M}_{\Theta_1}$

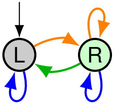
$\mathcal{M}_{\Theta_2}$

dom(Θ_1)	T	M	B
	0	0	1

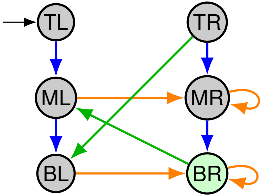
dom(Θ_2)	L	R
	0	1



Θ_1



Θ_2



$\Theta_1 \otimes \Theta_2$

Factored Mappings

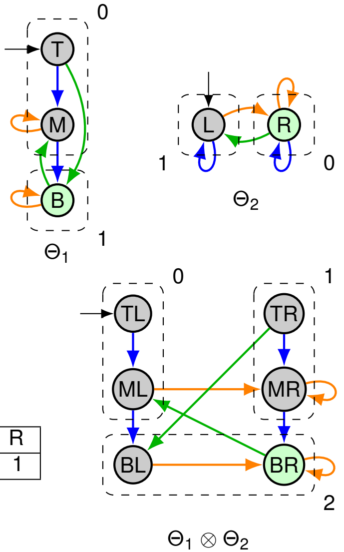
$\mathcal{M}_{\Theta_1}$ \ $\mathcal{M}_{\Theta_2}$	0	1
0	0	1
1	2	2

$\mathcal{M}_{\Theta_1 \otimes \Theta_2}$

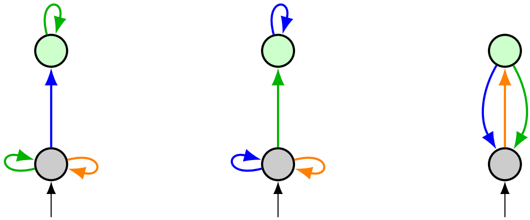
$\mathcal{M}_{\Theta_1}$ $\mathcal{M}_{\Theta_2}$

$dom(\Theta_1)$	T	M	B
	0	0	1

$dom(\Theta_2)$	L	R
	0	1



DFP: Example Computation



DFP: Example Computation