Cost-Partitioned Merge-and-Shrink Heuristics for Optimal Classical Planning

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Setting

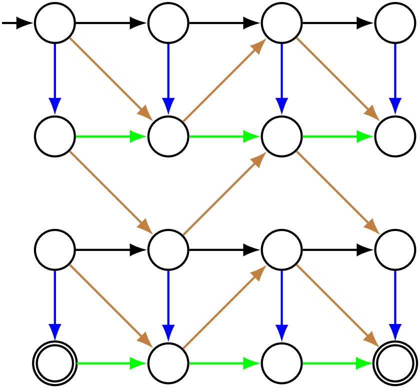
- optimal classical planning
- A^* search & admissible heuristic

Classical Planning

planning tasks $\Pi = \langle V, O, s_{\mathrm{I}}, S_{\mathrm{G}} \rangle$

- V: finite-domain state variables
- O: operators o with cost $cost(o)$
- s_{I}: initial state
- S_{G}: goal condition

Example Transition System

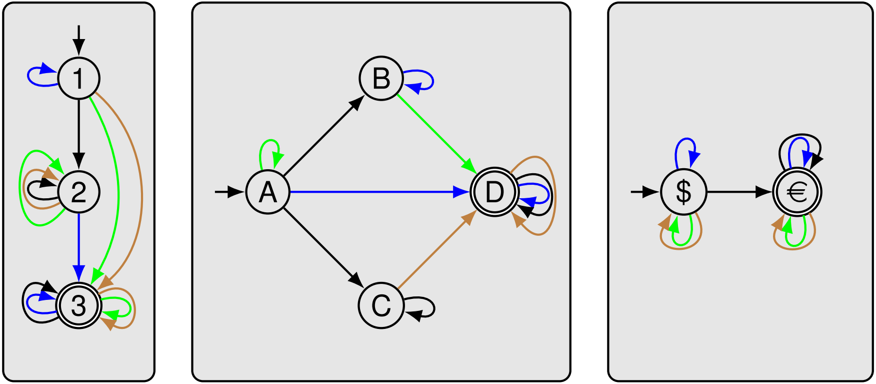


Merge-and-Shrink (M&S) Framework

procedure MERGEANDSHRINK(Planning Task Π)
  $F \leftarrow$ factored transition system of Π
  while not TERMINATE() **do**
    apply label reduction to F
    select two factors Θ_i, Θ_j from F
    optionally shrink Θ_i and/or Θ_j
    replace Θ_i and Θ_j by their product in F
  end while
  return $h^{\text{M\&S}} = \max_{\Theta \in F} h^*_{\Theta}$
end procedure

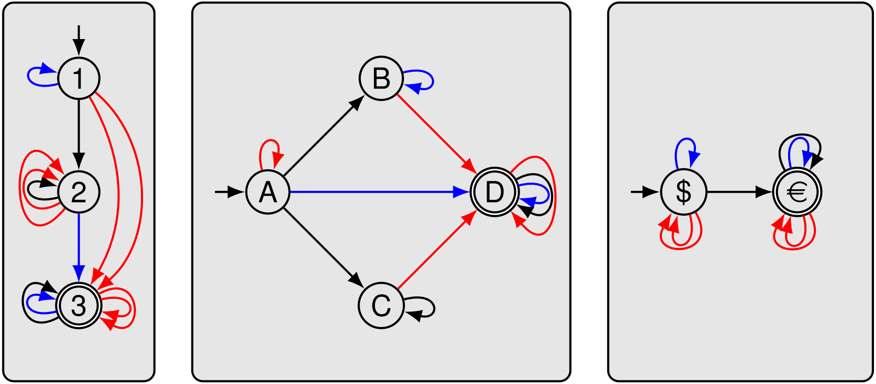
Example

Atomic Factored Transition System



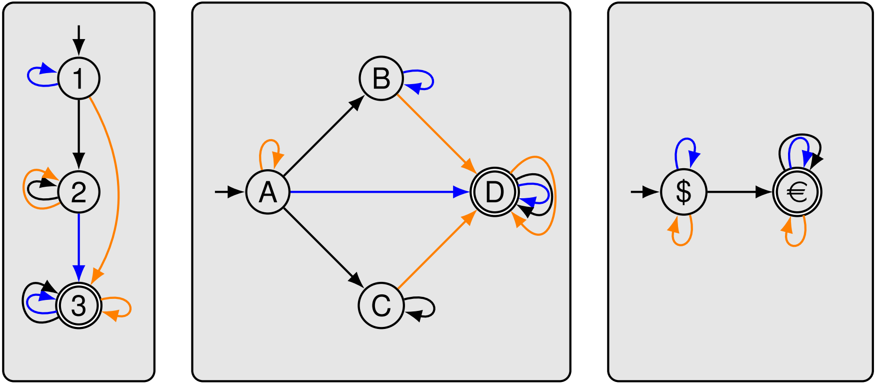
Example

Label Reduction



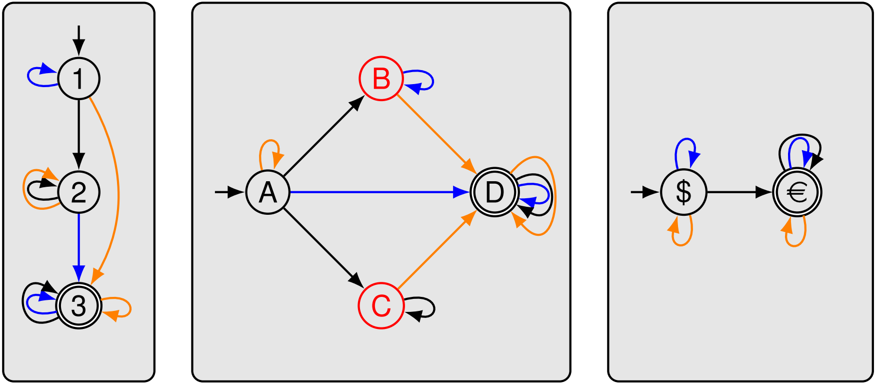
Example

Label Reduction



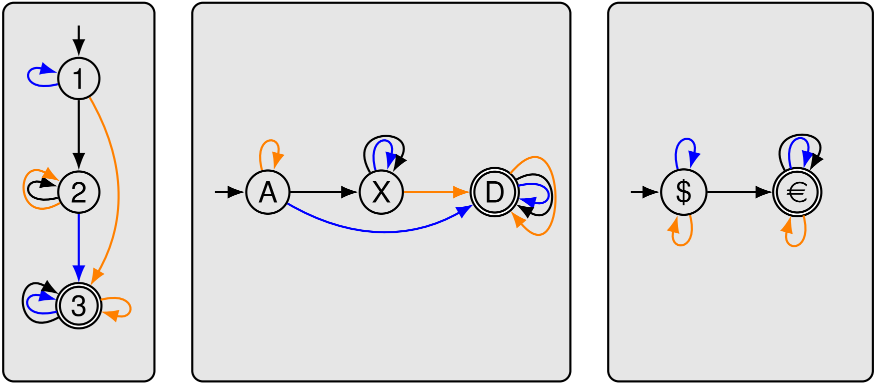
Example

Shrinking



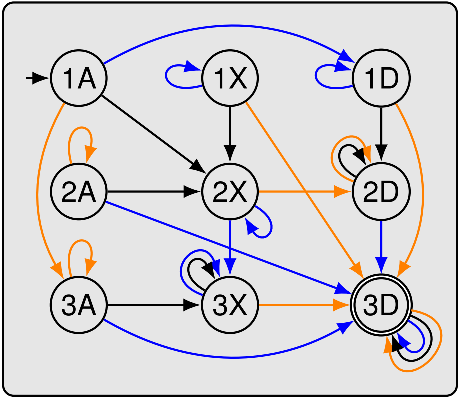
Example

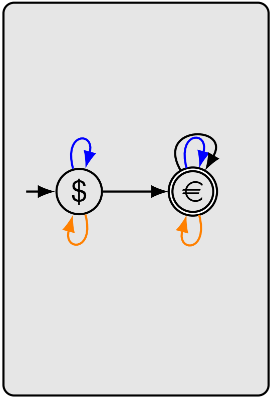
Shrinking



Example

Merging





Operator Cost Partitioning

- given: set of admissible heuristics $\mathcal{H} = \langle h_1, \dots, h_n \rangle$ for Π
- distribute the operator costs of Π among the heuristics: cost partition $\mathcal{C} = \langle cost_1, \dots, cost_n \rangle$ with $\sum_{i=1}^{n} cost_i(o) \leq cost(o)$ for all operators o
- summing the cost-partitioned heuristic values is admissible: $h_{\mathcal{H},\mathcal{C}}(s) = \sum_{i=1}^{n} h_i(s, cost_i)$
- here: consider optimal and saturated cost partitioning (OCP and SCP)

Contribution: (Extended) Label Cost Partitioning

- partition label costs rather than operator costs:
  $\sum_{i=1}^{n} \mathit{cost}_i(\ell) \leq \mathit{cost}(\ell)$ for all labels ℓ

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- partition label costs rather than operator costs:
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- extended label cost partitioning:
  - use factors from different factored transition systems
    $\rightarrow$ different labels
  - partition label costs of the original task and translate to labels of all factors:
    $\sum_{i=1}^{n} cost_i(\lambda_i(\ell)) \leq cost(\ell)$ for all labels ℓ

Contribution: Interaction of M&S and Cost Partitioning

transformation	OCP	SCP
exact label reduction	preserved	preserved
h-preserving shrinking	not increased	preserved
merging	not decreased	incomparable

Contribution: Merge-and-Shrink with SCP added

procedure MERGEANDSHRINK(Planning Task Π)
  $F \leftarrow$ factored transition system of Π
  $\mathcal{H} \leftarrow \emptyset$
  while not TERMINATE() **do**
    apply label reduction to F
    $\mathcal{H} \leftarrow \mathcal{H} \cup \{\text{COMPUTESCP}(F)\}$
    select two factors Θ_i, Θ_j from F
    optionally shrink Θ_i and/or Θ_j
    replace Θ_i and Θ_j by their product in F
  end while
  $\mathcal{H} \leftarrow \mathcal{H} \cup \{\text{COMPUTESCP}(F)\}$
  return $h^{\text{M\&S}} = \max_{\Theta \in F} h^*_\Theta$ ▷ original M&S
  return $h^{\text{M\&S+SCP}} = \max_{h \in \mathcal{H}}$ ▷ M&S + SCP
end procedure

Results

evaluate impact of how many SCPs to compute:

	$i = 1$	$i = 2$	$i = 5$	$i = 10$
coverage	933	930	926	917

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evaluate alternatives of when to compute SCP in an iteration:

	$i = 1$
after label redution	933
after shrinking	933
after merging	925

Results

evaluate different orders for computing SCPs:

	rnd	otn	nto	mhsc	mh	msc
h_{int}^{SCP}	933	932	928	928	927	930

Results

evaluate different orders for computing SCPs:

	rnd	otn	nto	mhsc	mh	msc
h^{SCP}_{int}	933	932	928	928	927	930

evaluate an offline alternative to compute SCPs after M&S instead of interleaved as before:

	rnd	otn	nto	mhsc	mh	msc
$h^{SCP}_{off\text{-}div}$	915	841	904	887	907	838

Summary

- label cost partitioning for M&S
- impact of M&S transformations on cost-partitioned heuristics
- practical combination of M&S and SCP