Merge-and-Shrink Task Reformulation for Classical Planning

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HSDIP 2019

Classical Planning

Definition. *A planning task is a 4-tuple* $\Pi = (V, A, I, G)$ *where:*

- V *is a set of state variables, each* $v \in V$ *with a finite domain* D_v*.*
- A *is a set of actions; each* $a \in A$ *is a triple* (pre_a, eff_a, c_a)*, of precondition and effect (partial assignments), and the action's cost* $c_a \in \mathbb{R}_0^+$*.*
- *Initial state* I *(complete assignment), goal* G *(partial assignment).*

$\rightarrow$ Solution ("Plan"): Action sequence mapping I into s s.t. $s \models G$.

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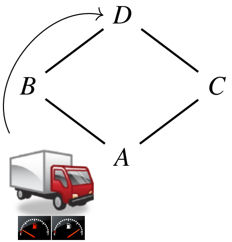
Running Example:

- $V = \{T, F\}$ with $D_t = \{A, B, C, D\}$, $D_F = \{0, 1, 2\}$.
- $A = \{drive(x, x', f, f')\}$
- $I = \{T = A, F = 2\}$
- $G = \{T = D\}$



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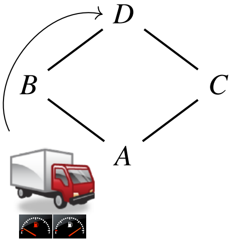

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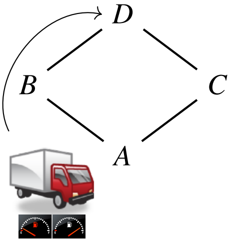

Accidental complexity: when solving the problem is harder due to how it is encoded

- $V = \{T, F, E\}$ with $D_t = \{A, B, C, D\}$, $D_F = \{0, 1, 2\}$, $D_E = \{on, off\}$.
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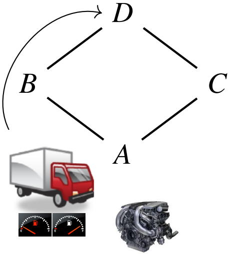

Reformulation

Transform the model to get rid of "accidental" complexity

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Task Π

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$$\text{Task } \Pi \xrightarrow{\text{reformulation } (\rho)} \text{Task } \rho(\Pi)$$

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\begin{tikzcd}
\text{Task } \Pi \arrow[r, "\text{reformulation } (\rho)"] & \text{Task } \rho(\Pi) \arrow[d, "\text{solve}"] \\
& \text{Plan } \pi^{\rho}
\end{tikzcd}
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- Polynomial: ρ and $\overleftarrow{\rho}$ run in polynomial time in the $|\Pi|$ and $|\overleftarrow{\rho}(\pi^\rho)|$.

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Properties:

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- Optimal: π^ρ is optimal for $\rho(\Pi) \Rightarrow \overleftarrow{\rho}(\pi^\rho)$

Abstraction Heuristics

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$\rightarrow$An abstraction is refinable if a solution for the abstract task can be transformed in polynomial time in a solution for the original

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Free DTG: The domain transition graph of a variable only considering actions without preconditions or effects on other variables.

Variable Abstraction (Helmert, 2006)

Any variable whose free DTG is strongly connected can be abstracted away

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$$\begin{aligned} \text{Abstract plan} &= \langle \mathrm{DR}_{\text{A-B},2\text{-}1}, \mathrm{DR}_{\text{B-D},1\text{-}0} \rangle \\ \text{Original plan} &= \langle \end{aligned}$$

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Extensions:

- Haslum (2007) gave a stronger criteria
- Tozicka et al. (2016) use this to merge values of a variable

Running Example with Accidental Complexity

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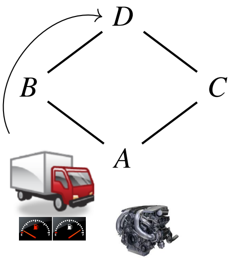

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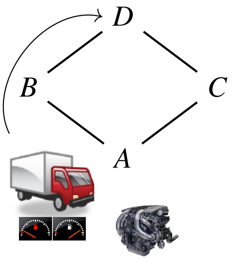

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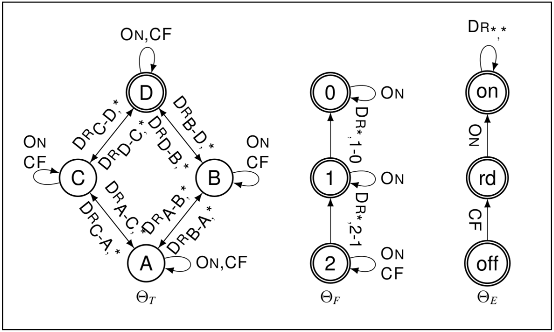
- check-fuel:
  pre: E=off, F=2
  eff: E=rd
- turn-on:
  pre: E=rd
  eff: E=on

Merge-and-Shrink



Atomic: One TS per variable such that $\Theta_1 \otimes \Theta_2 \otimes \Theta_3 = \Theta$

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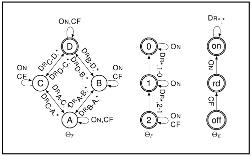

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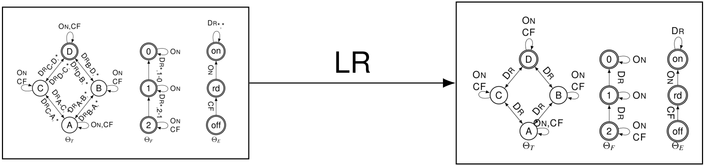

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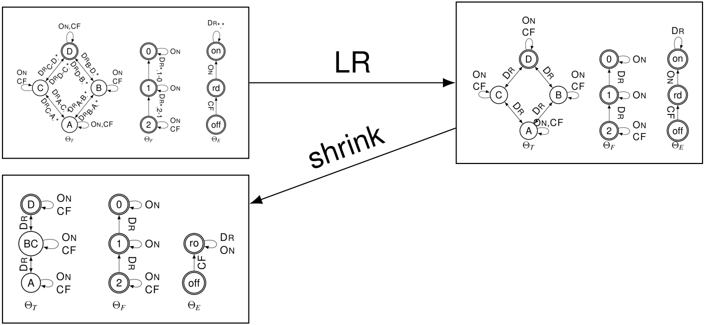

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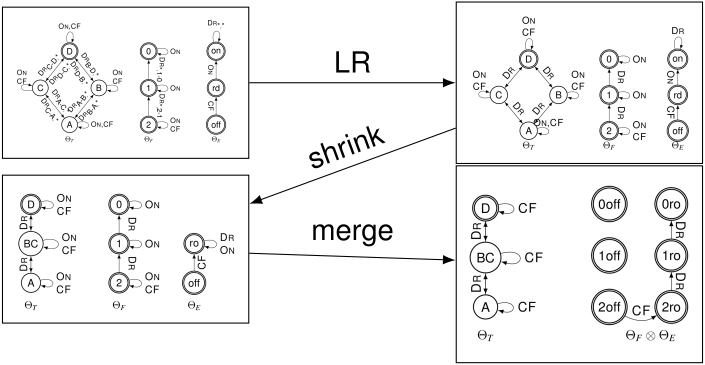

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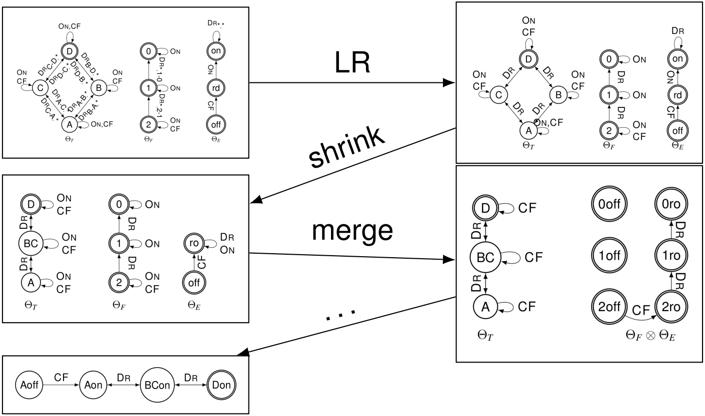

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M&S as Reformulation Framework

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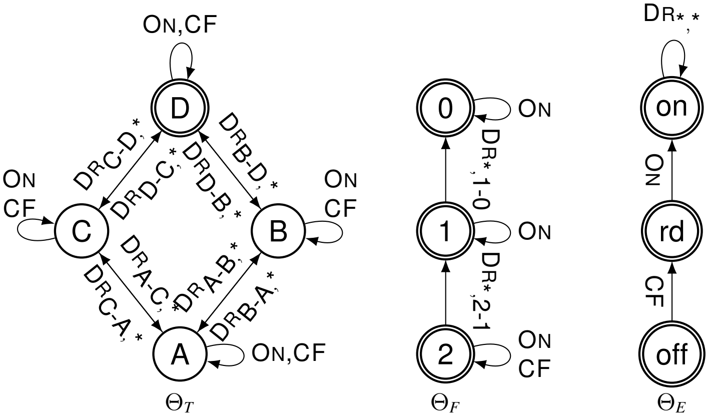
FTS Representation and Successor Generation



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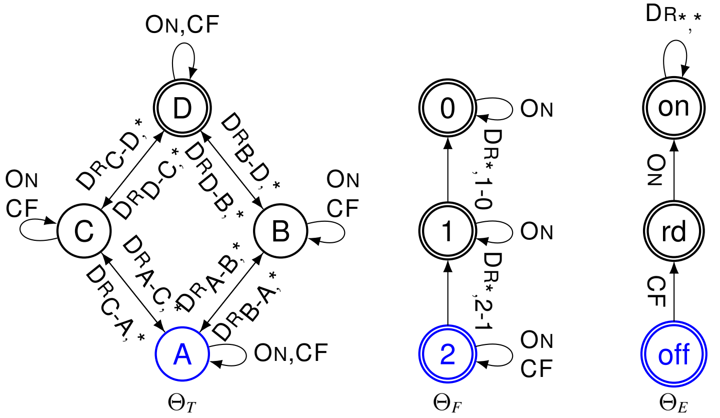

State: ⟨T=A, F=2, E=off⟩

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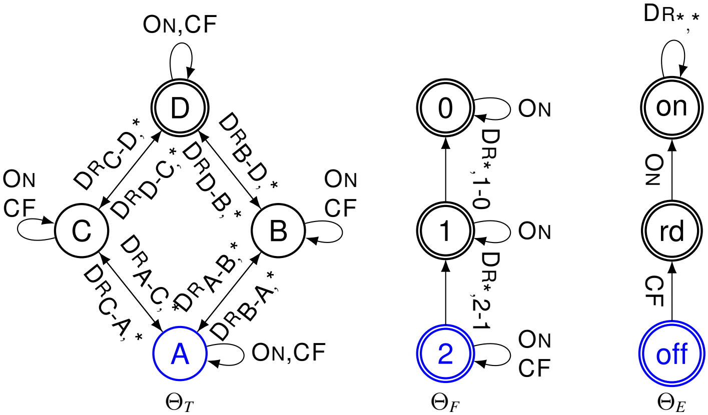

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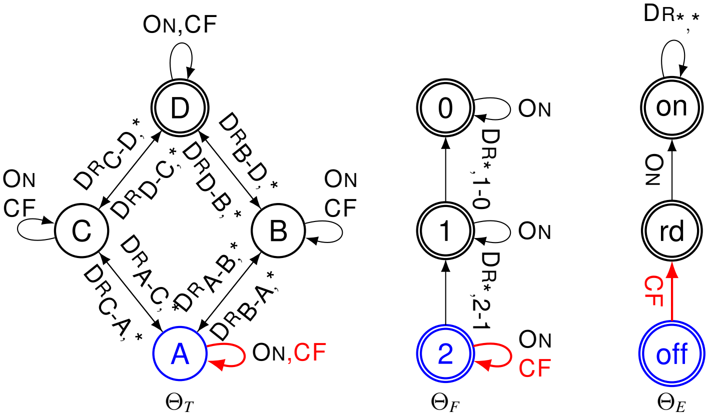

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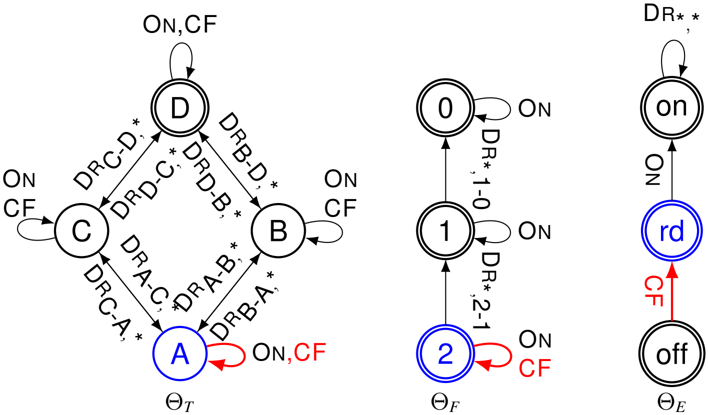

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Applicable labels: $\{CF\}$
Successor: ⟨T=A, F=2, E=rd⟩

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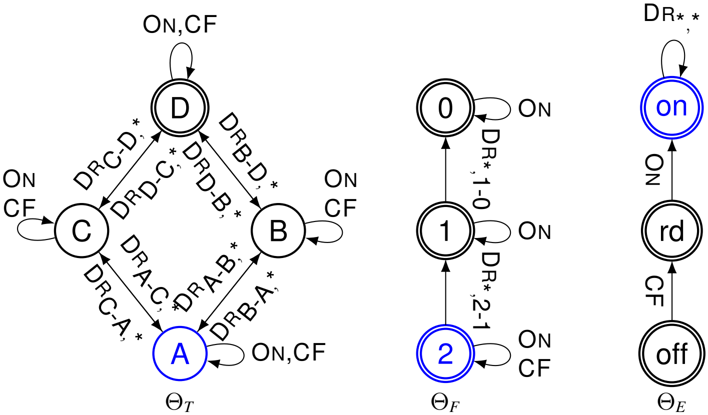

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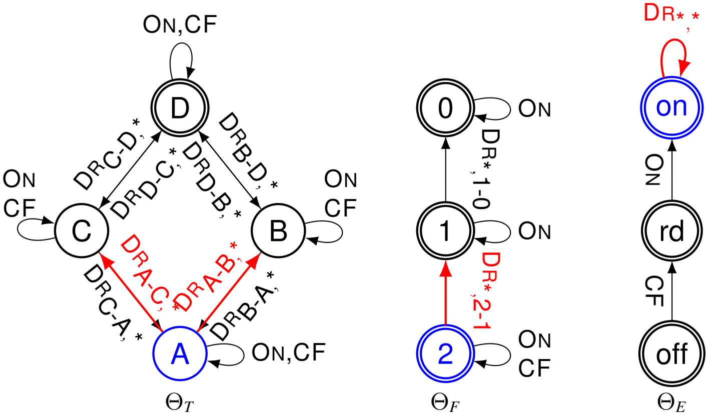

State: $\langle$T=A, F=2, E=on$\rangle$
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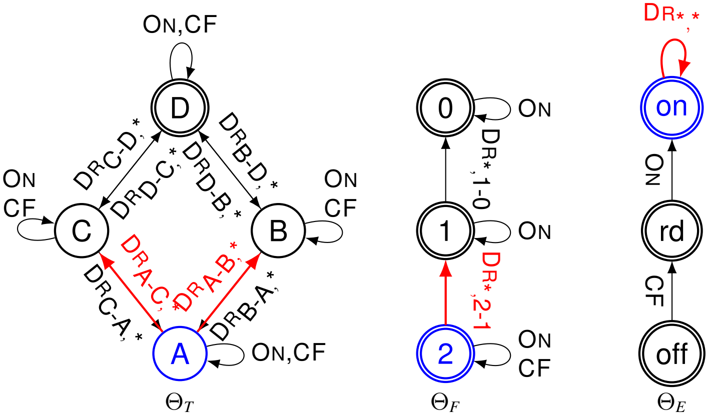

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Successor ($\text{DR}_{\text{A-B},2\text{-}1}$): ⟨T=B, F=1, E=on⟩

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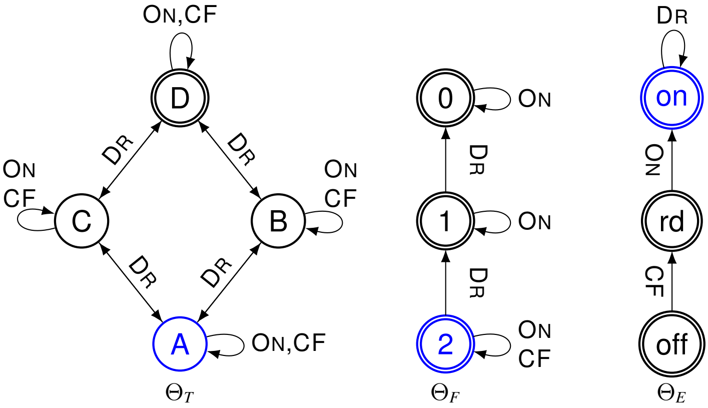

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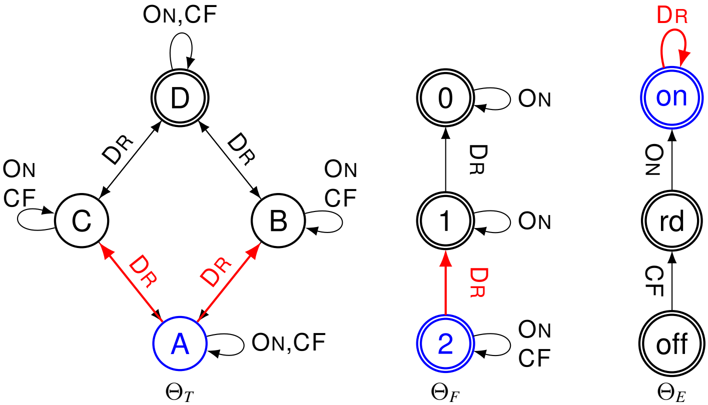

State: ⟨T=A, F=2, E=on⟩
Applicable labels: {DR}

Successor (DR): ⟨T=B, F=1, E=on⟩

Successor (DR): ⟨T=C, F=1, E=on⟩

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Advantage of FTS over FDR:

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- Limited form of conditional effects
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Replaces a TS Θ_i by an abstraction thereof ($\alpha(\Theta_i)$)
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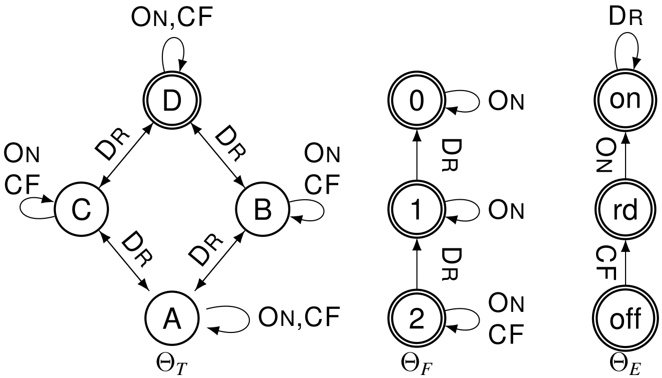

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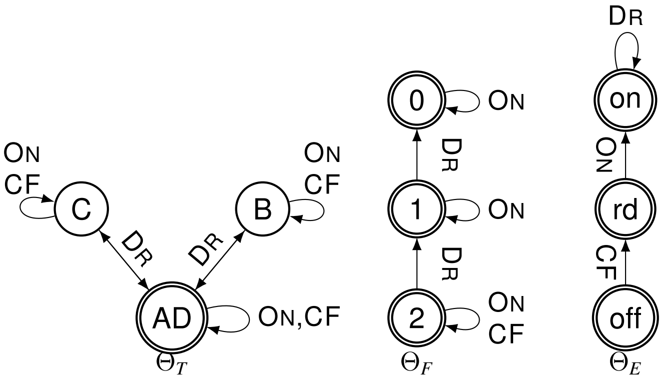

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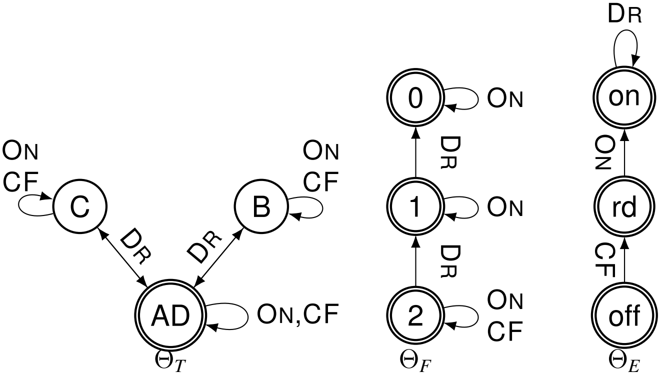

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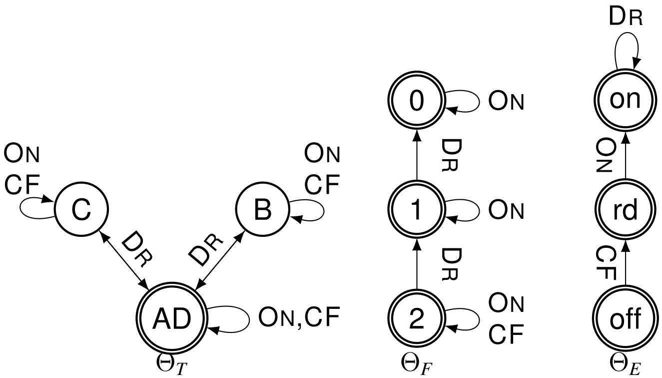

Plan = $\langle\rangle \Rightarrow$ Only "refinable" abstractions are suitable for reformulation

(Strong) Bisimulation Shrinking

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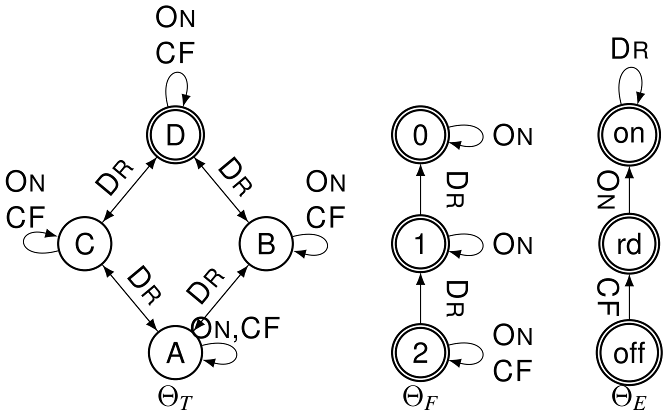

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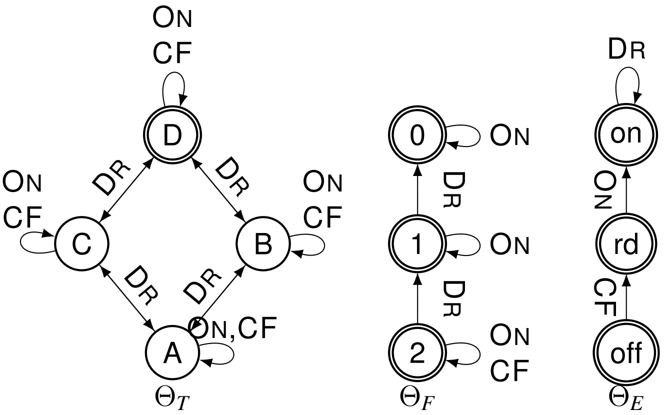

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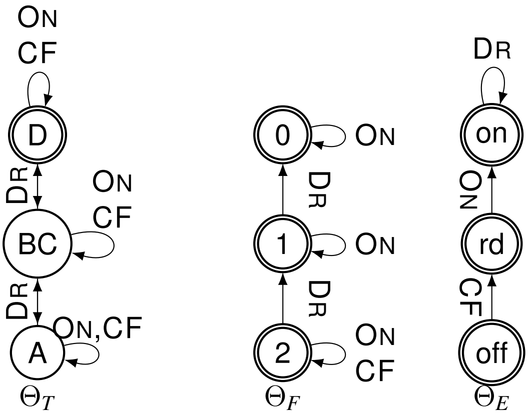

Plan = $\langle$CF, ON, DR(BC), DR(D)$\rangle \rightarrow$

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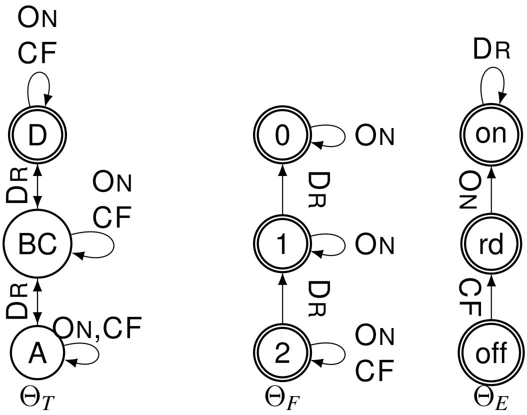
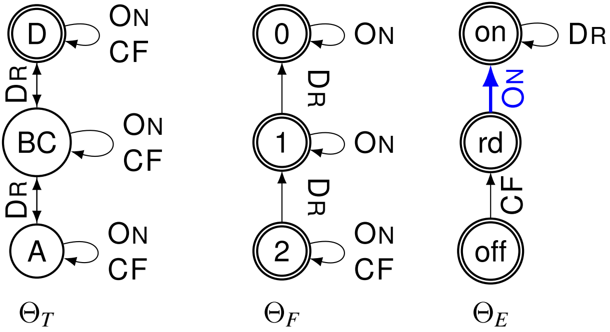


Plan = $\langle$CF, ON, DR(BC), DR$(D)\rangle \rightarrow \langle$CF, ON, DR$(B)$, DR$(D)\rangle$

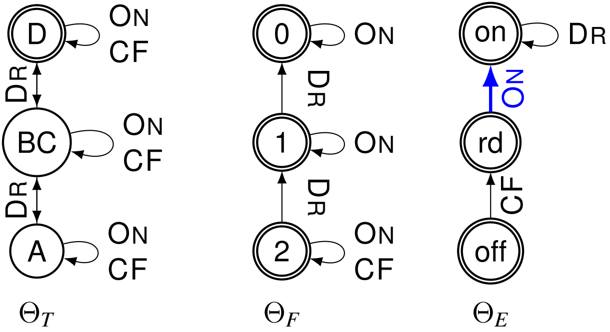
Weak Bisimulation Shrinking

1. Identify τ labels that are internal to a TS (self-loop everywhere)



Weak Bisimulation Shrinking

1. Identify τ labels that are internal to a TS (self-loop everywhere)
2. Bisimulation allowing free-use of τ labels



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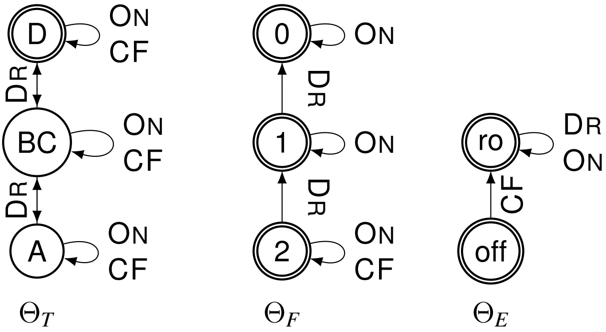

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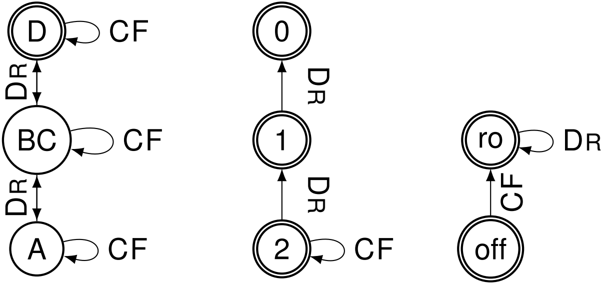

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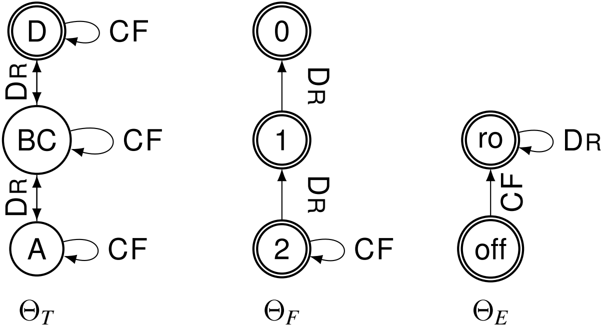

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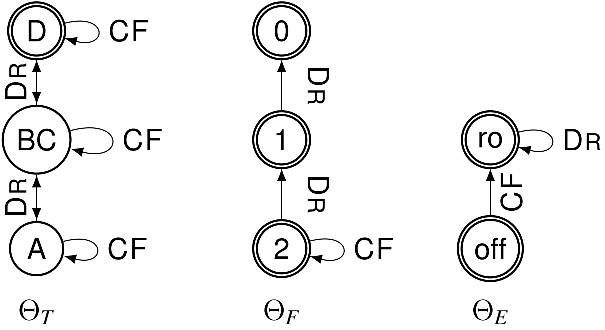
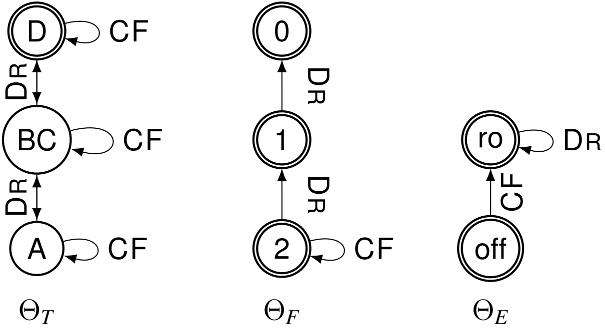


Plan = $\langle$CF, DR(BC), DR$(D)\rangle \rightarrow \langle$CF, ON, DR$(BC)$, DR$(D)\rangle$

Merge

Replace Θ_i and Θ_j by their product: $\Theta_i \otimes \Theta_j$



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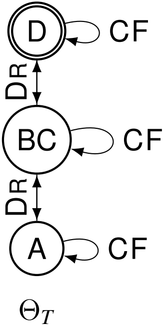

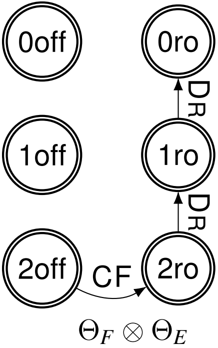

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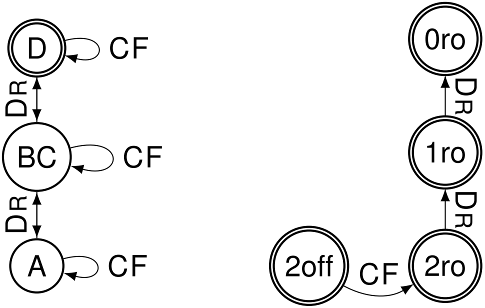

Θ_T $\Theta_F \otimes \Theta_E$

Merge

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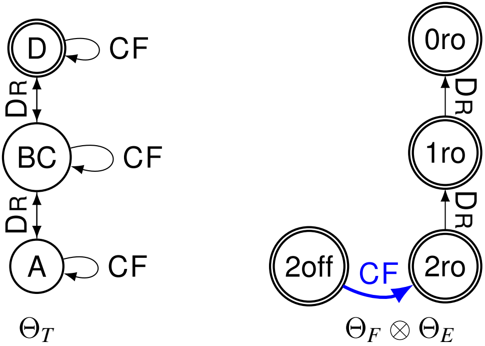

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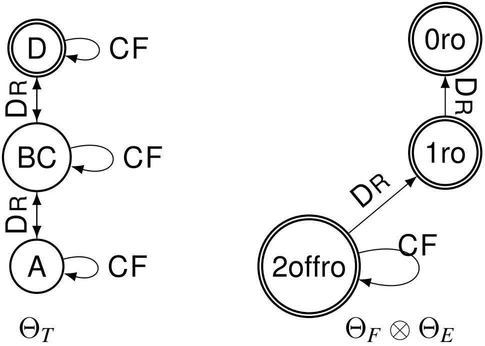

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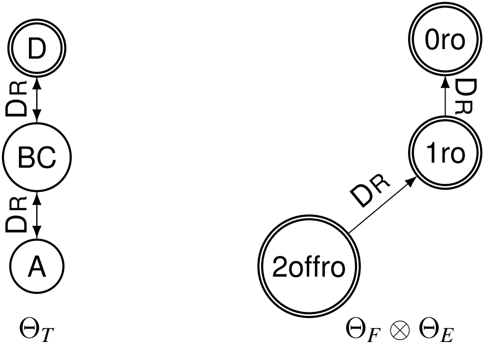

Relation to FDR Reformulation Methods

An FTS reformulation method dominates an FDR reformulation method if it can do the same reformulations:

$$\begin{tikzcd}
\Pi \arrow[rr, "\rho^{FDR}"] \arrow[d, "\text{atomic}"] & & \rho^{FDR}(\Pi) \arrow[d, "\text{atomic}"] \\
\{\Theta_1, \ldots, \Theta_n\}, L & & \{\Theta'_1, \ldots, \Theta'_m\}, L'
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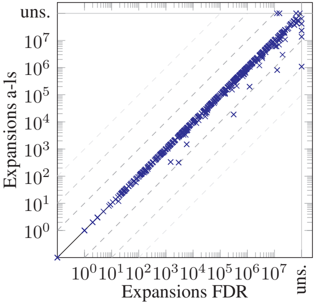
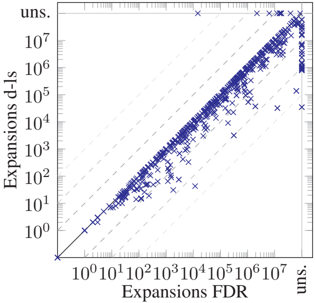
\end{tikzcd}$$

- Variable abstraction and merge values are dominated by weak bisimulation shrinking (plus removing TSs with a core state)
- Generalize actions is dominated by label reduction

Search Space Reduction: Optimal

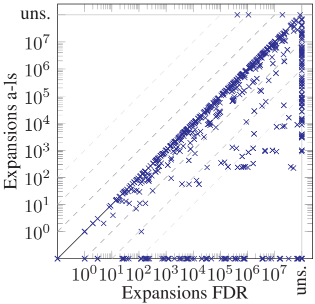


Bisimulation + LR

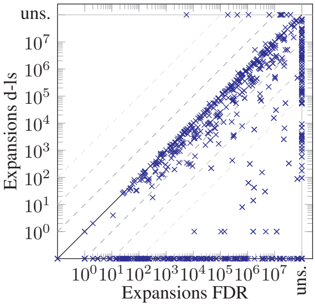


Merge (DFP) + LR + Bisimulation

Search Space Reduction: Satisficing



Weak Bisimulation + LR



Merge (DFP) + LR + Weak Bisimulation

Optimal Planning

	FDR	a	a-ls	d-ls	m-ls	tot	orcl
FDR						797	$h^{\max}$: 801
a						770	
a-ls						780	
d-ls					600		
m-ls					632		
FDR						822	$h^{\text{M\&S}_d}$: 910
a						826	
a-ls						831	
d-ls					815		
m-ls					849		

Optimal Planning

	FDR	a	a-ls	d-ls	m-ls	tot	orcl
FDR						797	$h^{\max}$: 801
a						770	
a-ls		**4**				780	
d-ls		2	1			600	
m-ls		4	4			632	
FDR						822	$h^{\mathrm{M\&S_d}}$: 910
a						826	
a-ls		**4**				831	
d-ls		11	10			815	
m-ls		15	15			849	

Optimal Planning

	FDR	a	a-ls	d-ls	m-ls	tot	orcl
FDR	–	**12**	**13**	**37**	**36**	797	$h^{\max}$: 801
a	1	–	1	**36**	**36**	770	
a-ls	3	**4**	–	**36**	**35**	780	
d-ls	2	2	1	–	7	600	
m-ls	4	4	4	**19**	–	632	
FDR	–	2	3	12	14	822	$h^{\mathrm{M\&S}_d}$: 910
a	**4**	–	1	**13**	**16**	826	
a-ls	**7**	**4**	–	**13**	**16**	831	
d-ls	**13**	11	10	–	11	815	
m-ls	**16**	15	15	**16**	–	849	

Satisficing Planning

	FDR	a	a-ls	d-ls	m-ls	tot	orcl
FDR						1326	h^{FF}: 1413
a						1272	
a-ls						1368	
d-ls					1208		
m-ls					1224		
FDR						1502	$h^{\mathrm{FF}}_{\mathrm{p.}}$: 1589
a						1461	
a-ls						1471	
d-ls					1357		
m-ls					1322		

Satisficing Planning

	FDR	a	a-ls	d-ls	m-ls	tot	orcl
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m-ls		7	3			1322	

Satisficing Planning

	FDR	a	a-ls	d-ls	m-ls	tot	orcl
FDR	–	**18**	15	**27**	**22**	1326	h^{FF}: 1413
a	6	–	13	**28**	**22**	1272	
a-ls	**18**	**15**	–	**31**	**24**	1368	
d-ls	10	10	4	–	11	1208	
m-ls	13	15	7	**21**	–	1224	
FDR	–	**17**	**15**	**24**	**23**	1502	$h^{FF}_{p.}$: 1589
a	8	–	**11**	**25**	**24**	1461	
a-ls	13	8	–	**26**	**26**	1471	
d-ls	9	6	2	–	15	1357	
m-ls	9	7	3	**16**	–	1322	

Conclusion

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  - $\rightarrow$ More abstraction heuristics for cost-optimal planning
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  - $\rightarrow$ Landmarks and Novelty for satisficing planning
- Provide a plan reconstruction for M&S transformations
  - Merge, LR, Pruning, Bisimulation $\rightarrow$ optimal reformulation
  - Weak bisimulation $\rightarrow$ satisficing reformulation
  - $\rightarrow$ Dominance-based pruning
  - $\rightarrow$ Tunnel macros