# Merge-and-Shrink Task Reformulation for Classical Planning

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## Summary/TL;DR

### Motivation

- Different planning representations for classical planning (e.g., FDR, STRIPS)
- Computational complexity independent of chosen representation
- However: accidental complexity (of the chosen representation and model) can impact planner performance

### Contribution

- Merge-and-shrink (M&S) framework for task reformulation:
  - Task representation based on factored transition system (FTS)
  - Various transformations for satisficing and optimal planning
  - Plan reconstruction methods
- Theoretical result: M&S reformulations dominate previous FDR-based reformulation methods
- Adaptation of delete-relaxation and M&S heuristics to FTS representation

## Planning Task Representations

- Compact representation of transition systems (TS): $\Theta = \langle S, L, T, s^I, \mathcal{S}^\star \rangle$
- FDR task: $\Pi^\mathcal{V} = \langle \mathcal{V}, \mathcal{A}, s^\mathcal{I}, \mathcal{G} \rangle$
- FTS task: set of TSs $\{\Theta_1, \dots, \Theta_n\}$ with a common set $L$ of labels
  - Limited form of disjunctive preconditions, conditional effects, and non-deterministic effects

## FTS Task Reformulations with M&S

### Task Reformulation

Partial function $\rho$ on task $\Pi$ s.t. $\rho(\Pi)$ is solvable iff $\Pi$ is solvable and there exists a plan reconstruction function $\overleftarrow{\rho}$ that maps each solution $\pi$ of $\rho(\Pi)$ to a solution $\overleftarrow{\rho}(\pi)$ of $\Pi$.

Task $\Pi$ —— reformulation ($\rho$) ——→ Task $\rho(\Pi)$

Task $\rho(\Pi)$ —— solve ——→ Plan $\pi^\rho$

Plan $\pi^\rho$ —— plan reconstruction ($\overleftarrow{\rho}$) ——→ Plan $\pi = \overleftarrow{\rho}(\pi^\rho)$

### M&S Transformations on FTS Task $\Pi^\mathcal{T}$

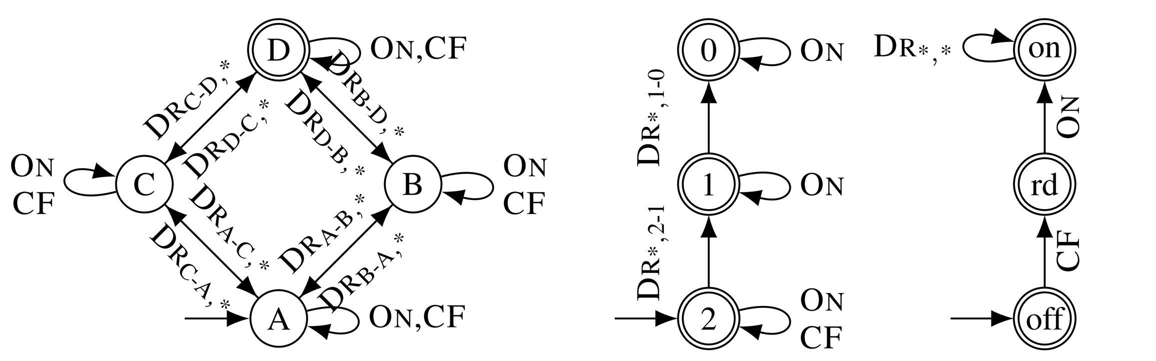
Exact transformations preserve the set of solutions (optimal planning):

- Label reduction: combine labels with the same transitions in all but one factor
- Bisimulation Shrinking: combine states in one factor if they are bisimilar (their outgoing transitions lead to equivalent states)
- Merging: replace two factors of $\Pi^\mathcal{T}$ by their product
- Pruning: throw away states not relevant for solutions

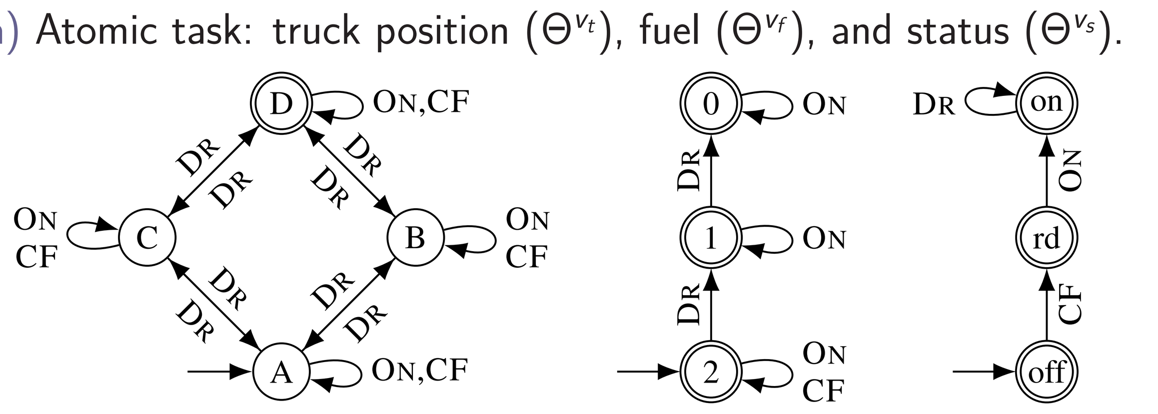
Transformations that preserve the existence of a solution (satisficing planning):

- Weak bisimulation: two states are weakly bisimilar if they have equivalent outgoing paths $\xrightarrow{\tau} \dots \xrightarrow{\tau}\xrightarrow{l}\xrightarrow{\tau} \dots \xrightarrow{\tau}$ leading to equivalent states, where $\tau$ are internal labels that can always be applied locally without side effects.

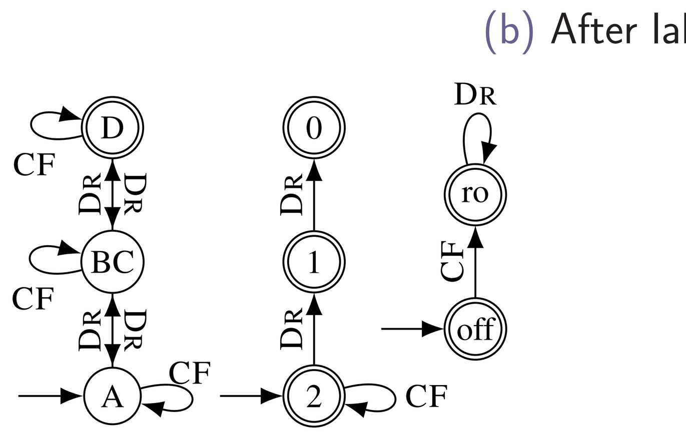
Example task: one truck, four locations, limited amount of fuel, turn on engine only with full tank → 3 FDR variables/atomic TSs



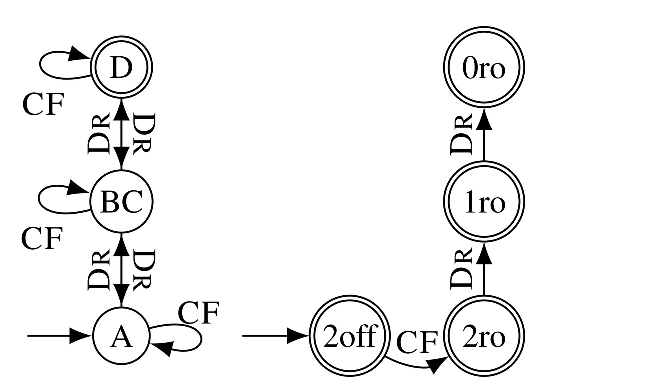
(a) Atomic task: truck position ($\Theta^{v_t}$), fuel ($\Theta^{v_f}$), and status ($\Theta^{v_s}$).



(b) After label reduction



(c) After shrinking and removing irrelevant ON.



(d) After merging and pruning unreachable states.

## Plan Reconstruction

- Given a sequence of planning tasks and reformulations and a plan of the final reformulated task, reconstruct plan of the original task.
- Treat exact transformations (merging, label reduction and bisimulation shrinking) as single transformation: only require label and state mapping
- Weak bisimulation: re-introduce $\tau$-label transitions whenever necessary

### Example

- Example plan for task of Figure c): (A, 2, off) $\xrightarrow{\text{CF}}$ (A, 2, ro) $\xrightarrow{\text{DR}}$ (BC, 1, ro) $\xrightarrow{\text{DR}}$ (D, 0, ro)
- Execution on task of Figure b): DR fails in rd; insert a $\tau$-transition with ON resulting in the plan: (A, 2, off) $\xrightarrow{\text{CF}}$ (A, 2, rd) $\xrightarrow{\text{ON}}$ (A, 2, on) $\xrightarrow{\text{DR}}$ (BC, 1, on) $\xrightarrow{\text{DR}}$ (D, 0, on).
- Reconstruct original plan by inverting label mapping: (A, 2, off) $\xrightarrow{\text{CF}}$ (A, 2, rd) $\xrightarrow{\text{ON}}$ (A, 2, on) $\xrightarrow{\text{DR}_{\text{A-B-2-1}}}$ (B, 1, on) $\xrightarrow{\text{DR}_{\text{B-D-1-0}}}$ (D, 0, on).

## Theoretical Comparison to FDR Reformulations

### Dominance

FTS reformulation $X$ dominates FDR reformulation $Y$ if, given an FDR task $\Pi^\mathcal{V}$ and an applicable reformulation $\rho^Y \in Y$, there exists a reformulation $\rho^X \in X$ such that it is applicable in the corresponding FTS task $atomic(\Pi^\mathcal{V})$ and $\rho^X(atomic(\Pi^\mathcal{V})) = atomic(\rho^Y(\Pi^\mathcal{V}))$.

Generalize actions: substitute two FDR actions by a single one if they are equal except for a precondition on a binary variable.
**Theorem:** Exact label reduction strictly dominates generalize actions.

Safe variable abstraction: remove any root variable in the causal graph whose free domain transition graph is strongly connected.
**Theorem:** Removing transition systems with core states after applying weak bisimulation shrinking strictly dominates safe variable abstraction.

Merge values: reduce the domain of an FDR variable by merging several values whenever they can be switched via actions without any side effects.
**Theorem:** Weak bisimulation shrinking strictly dominates merge values.

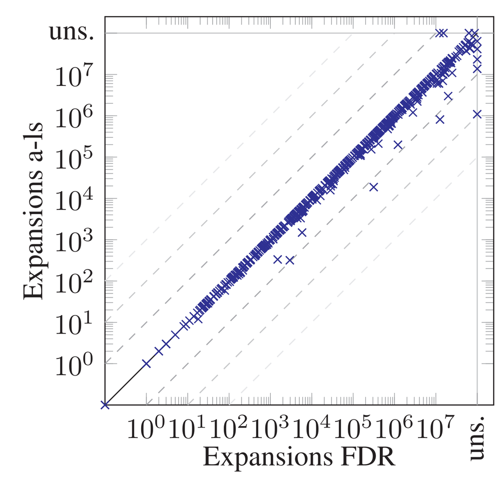
## Planning on the FTS Representation

- Applicable actions: multiple transitions with same label for single state ⇒ for each abstract state, store set of outgoing labels
- Successor generation: enumerate all successors for single state and label
- Delete relaxation heuristics: factors can be in multiple states simultaneously

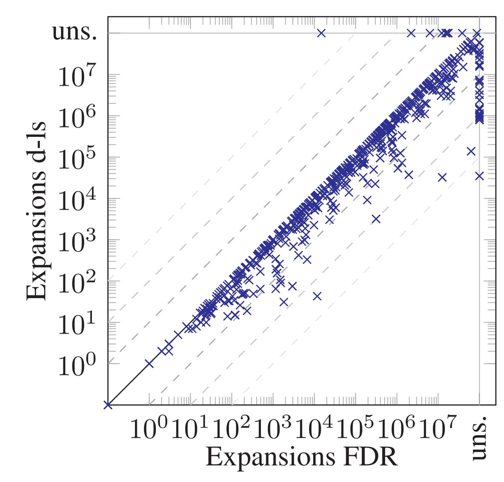
## Experiments

| | 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 | $h^{\text{M\&S}}$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 | |

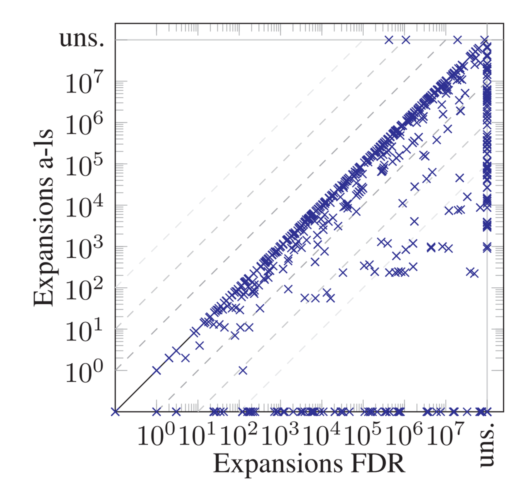
| | FDR | a | a-ls | d-ls | m-ls | tot | orcl |
|---|---|---|---|---|---|---|---|
| FDR | – | **18** | 15 | **27** | **22** | 1326 | $h^{\text{FF}}$: 1413 |
| a | 6 | – | 13 | **28** | **22** | 1272 | |
| a-ls | **18** | **15** | – | **31** | **24** | 1368 | |
| d-ls | 10 | 10 | 4 | – | 11 | 1208 | |
| m-ls | 13 | 15 | 7 | **21** | – | 1224 | |
| FDR | – | **17** | **15** | **24** | **23** | 1502 | $h^{\text{FF}}$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 | |



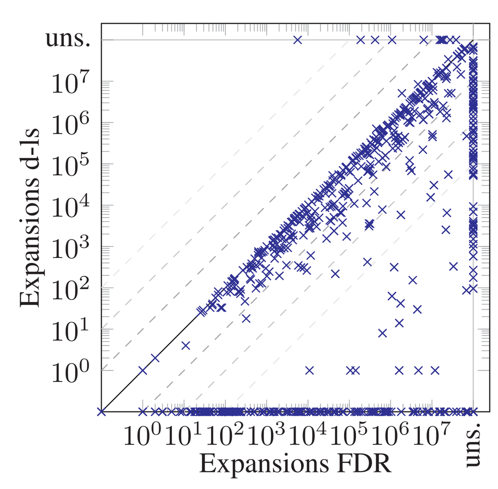

Bisimulation + LR




Merge (DFP) + LR + Bisimulation




Weak Bisimulation + LR




Merge (DFP) + LR + Weak Bisimulation