Who Needs These Operators Anyway: Top Quality Planning with Operator Subset Criteria

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Introduction: Classical Planning and Beyond

An FDR Planning task is 5-tuple $\Pi = \langle V, A, cost, I, G\rangle$:

- V: finite set of multi-valued (finite-domain) state variables
- A: finite set of actions of form $\langle pre, eff\rangle$ (preconditions/effects; partial variable assignments)
- $cost : A \mapsto \mathbb{R}^{0+}$ captures action cost
- I: initial state (variable assignment)
- G: goal description (partial variable assignment)

$\mathcal{P}_\Pi$ is the set of all plans for Π

Cost-optimal: find one single plan $\pi \in \mathcal{P}_\Pi$ minimizing summed action cost

Top-quality planning [Katz et al., AAAI 2020]:

Given: planning task Π, natural number q
Find: the set of plans $P = \{\pi \in \mathcal{P}_\Pi \mid cost(\pi) \leq q\}$.

Quotient top-quality planning [Katz et al., AAAI 2020]:

Given: planning task Π, equiv. relation N over its set of plans $\mathcal{P}_\Pi$, natural number q
Find: $P \subseteq \mathcal{P}_\Pi$ such that $\bigcup_{\pi\in P} N[\pi]$ is the solution to the top-quality planning.

Unordered Top-quality Planning:

$$\mathbf{U}_\Pi = \{(\pi, \pi') \mid \pi, \pi' \in \mathcal{P}_\Pi,\ \mathsf{MS}(\pi) = \mathsf{MS}(\pi')\}.$$

Challenges in Top-quality Planning

- Top-quality set of plans can be quite large, sometimes infinite
- Unordered top-quality does not help in cases of infinite solution sizes
- Even in unordered top-quality planning, plans can be unnecessarily long

Contributions

- Novel computational problem *subset top-quality planning*
- Solution (plan sets) are provably finite
- Planner based on task reformulation: extending ForbidIterative framework
- Theoretically stricter reformulation, forbidding more plans
  - Simpler and easier to solve: more tasks where solution is found
  - Solution set sizes are mostly the same

Subset Top-quality Planning

Subset Top-quality Planning Problem

Given: planning task Π and a natural number q
Find: a set of plans $P \subseteq \mathcal{P}_\Pi$ such that $\forall \pi \in P$, $cost(\pi) \leq q$, and $\forall \pi' \in \mathcal{P}_\Pi \setminus P$ with $cost(\pi') \leq q$, $\exists \pi \in P$ such that $\mathsf{MS}(\pi) \subset \mathsf{MS}(\pi')$

Theorem (Finite Solution Size)

Given a planning task Π and a natural number q, a smallest subset top-quality planning problem solution P is of finite size.

Proof hint: cycle-free plans

Subset Top-quality Planners

ForbidIterative Subset Top-quality Planning Algorithm

Input:
Planning task Π,
quality bound q

$P \leftarrow \emptyset$ ▷ Solution, initially empty
$\Pi' \leftarrow \Pi$ ▷ Current task
$\pi \leftarrow$ shortest cost-optimal plan of Π' ▷ Current plan
while $cost(\pi) \leq q$ **do**
  $\overline{\pi} \leftarrow$ MapPlanBack(π) ▷ Remove aux operators
  $P \leftarrow P \cup \{\overline{\pi}\} \cup \{\pi' \mid \pi' \sim \overline{\pi}, \mathsf{MS}(\pi') \neq \mathsf{MS}(\overline{\pi})\}$ ▷ Extend with symmetries
  $\Pi' \leftarrow \Pi^-_{\mathcal{M}^+}$, where $\mathcal{M} = \{\mathsf{MS}(\pi') \mid \pi' \in P\}$ ▷ Reformulate
  $\pi \leftarrow$ shortest cost-optimal plan to Π'
return P

Reformulation: MSQ

Variables

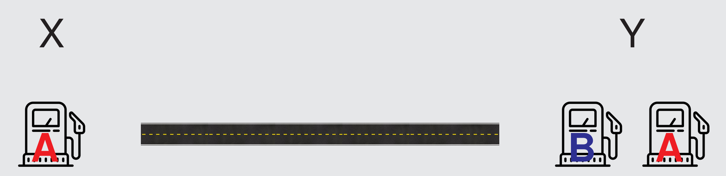
- additional variable $\overline{v}$ checking off multisets in $\mathcal{M}$
- additional counting variables $\overline{v}_o$ per operator in multisets

Init & Goal

- $\overline{v}$ variable: initially 0, in goal $|\mathcal{M}|$
- $\overline{v}_o$ variables: initially 0, not in goal

Operators

- per original operator: copies with additional pre and effects counting the number of appearances (up to max value in $\mathcal{M}$), while $\overline{v}$ is at its initial value
- additional operators: checking off multisets once original goal is reached



$\Pi' = \Pi$

✓ Fuel A, move X Y, Fuel A
$\mapsto$ $\Pi' = \Pi^-_{\mathcal{M}^+}$

✓ Fuel A, move X Y, Fuel B
✗ Fuel A, move X Y, Fuel A
✗ Fuel A, move X Y, Fuel A, Fuel B
✗ Fuel A, move X Y, Fuel B, Fuel A

Reformulation: SQ

Variables

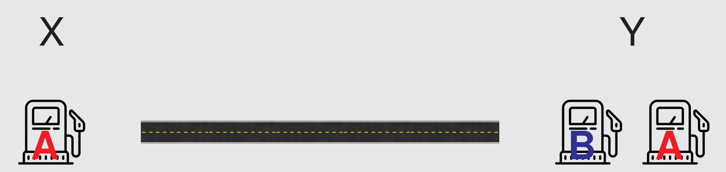
- additional variable $\overline{v}$ checking off sets in $\mathcal{M}$ ($|\mathcal{M}|+1$ values)
- additional binary variables $\overline{v}_o$ per operator in sets

Init & Goal

- $\overline{v}$ variable: initially 0, in goal $|\mathcal{M}|$
- $\overline{v}_o$ variables: initially 0, not in goal

Operators

- per original operator: additional pre and effects, setting $\overline{v}_o = 1$ if in $\mathcal{M}$, while $\overline{v}$ is at its initial value
- additional operators: checking off sets once original goal is reached



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Evaluation

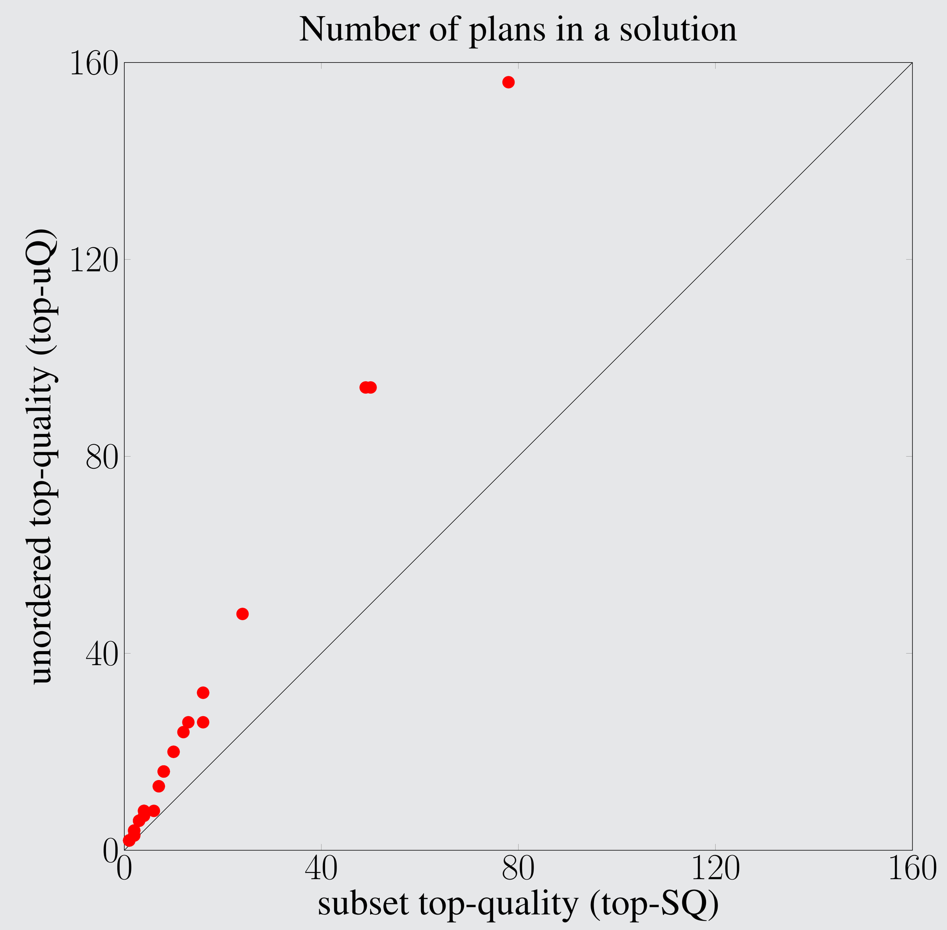
Experimental Setting

- Comparing unordered top-quality planner to the suggested reformulations
- While they solve different problems, we compare in how many cases a solution could be found
- Compare solution size

Coverage on IPC domains

Domain	top-uQ	top-MSQ	top-SQ
childsnack14	0	**6**	**6**
data-network18	0	**4**	**4**
elevators08	0	**2**	**2**
gripper	5	**16**	**16**
miconic	15	**17**	16
movie	**1**	0	0
openstacks08	**2**	1	1
parcprinter08	**25**	24	24
parcprinter11	**18**	17	17
pipesworld-notankage	**8**	7	7
psr-small	45	45	**47**
satellite	2	**4**	**4**
scanalyzer08	4	**6**	**6**
scanalyzer11	1	**3**	**3**
sokoban08	0	0	**1**
storage	**11**	9	10
Sum	337	361	**364**

Solution Size



Summary and Future Work

- Introduced a new computational problem in top-quality planning
- Introduced planners based on planning task reformulation
- Shown the new planners to be more practical than existing (unordered) top-quality planners
- Future: improve the coverage of existing top-quality planners, for all computational problems