Minimizing Necessary Observations for Nondeterministic Planning

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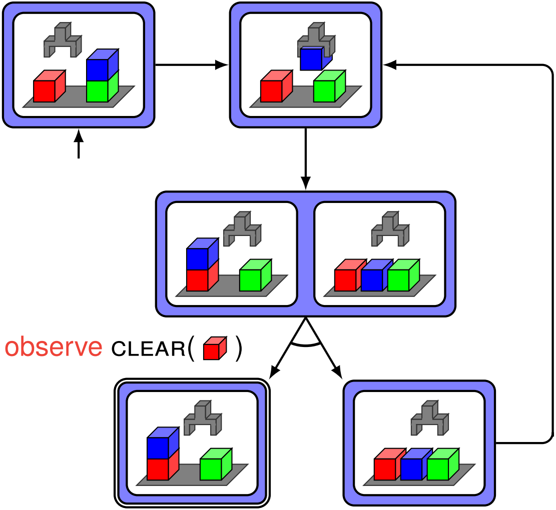
Motivation

Example: Partially Observable BLOCKSWORLD Domain with Nondeterministic PUT-DOWN Operator



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Motivation

Example: Partially Observable BLOCKSWORLD Domain with Nondeterministic PUT-DOWN Operator

Observing CLEAR predicate sufficient to find solutions.

Initial state known $\Rightarrow$ overhead camera sufficient as a sensor.

Question: How to find minimal sets of variables sufficient for solution existence in arbitrary POND planning tasks?

Remark: Here, “solution” means strong cyclic plan:

- closed: defined for all belief states it may reach, and
- proper: no dead ends

Preliminaries

Formalism

Motivation

Theory

Practical Algorithms

Empirical Evaluation

Conclusion

Problem OBSERVEINCLMIN:

- Input: POND planning task $\Pi = \langle \mathcal{V}, B_0, B_\star, \mathcal{A}, \mathcal{W} \rangle$ with
  - state variables $\mathcal{V}$
  - initial belief state B_0
  - goal description $B_\star$
  - nondeterministic actions $\mathcal{A}$
  - possibly observable variables $\mathcal{W} \subseteq \mathcal{V}$
- Output: Inclusion-minimal set of variables $\mathcal{O} \subseteq \mathcal{W}$ such that there exists a strong cyclic plan for Π observing only variables from $\mathcal{O}$, or NONE if no such set $\mathcal{O}$ exists.

Theorem (Rintanen, 2004)

The strong cyclic plan existence problem for POND planning, PLANEXPOND*, is* 2-EXPTIME*-complete.* □

Theorem

OBSERVEINCLMIN *is* 2-EXPTIME*-complete.*

Proof.

- Trivial reduction from PLANEXPOND
  $\Rightarrow$ OBSERVEINCLMIN 2-EXPTIME-hard.
- Naive algorithm iterating over all subsets of $\mathcal{W}$
  $\Rightarrow$ OBSERVEINCLMIN $\in$ 2-EXPTIME. □

Theory

Question: Can we improve over the naive algorithm from the proof?

Assumption: No obviously irrelevant variables in $\mathcal{W}$.
Ignore variables known in B_0 and never made unknown by any action.

Baseline Algorithm

Simple Greedy Algorithm

function SIMPLEGREEDYSEARCH(Π):
  if Π is unsolvable **then**
    return NONE
  Compute some plan π for Π
  Let $\mathcal{O}$ be the set of variables actually observed in π
  while Π still solvable with some o removed from $\mathcal{O}$ **do**
    Remove o from $\mathcal{O}$
  return $\mathcal{O}$

Theorem

Function SIMPLEGREEDYSEARCH

- *runs in* 2-EXPTIME,
- *correctly solves* OBSERVEINCLMIN. □

Plan Reuse

Motivation

- ✓ SIMPLEGREEDYSEARCH correct
- ✓ SIMPLEGREEDYSEARCH asymptotically optimal
- ✗ SIMPLEGREEDYSEARCH naive and inefficient
  - ➠ Look for ways to speed up SIMPLEGREEDYSEARCH!
  - ➠ Reuse portions of plan not affected by dropping a variable.

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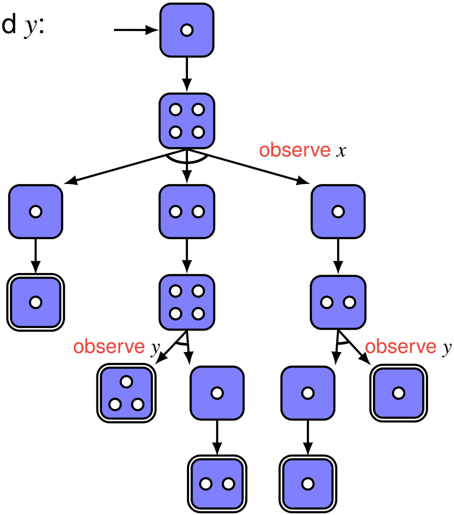
Plan Reuse

Example, $\mathcal{W} = \{x, y\}$

Plan observing x and y:

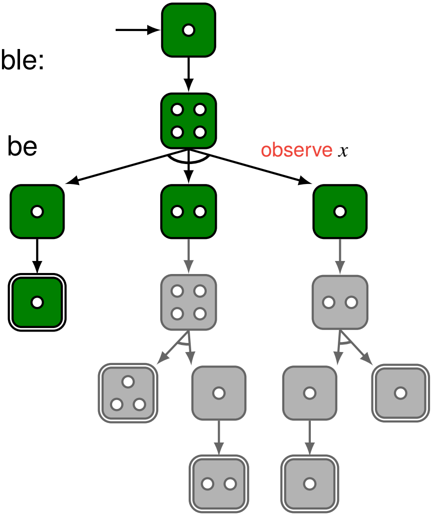


Plan Reuse

Example, $\mathcal{W} = \{x, y\}$

Reusable plan fragment if y unobservable:

- y known or
- never needs to be observed before goal



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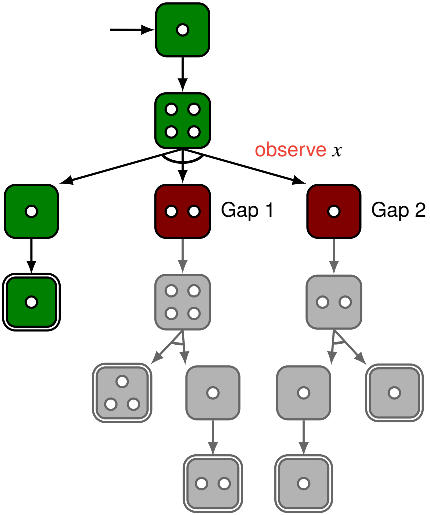
Plan Reuse

Example, $\mathcal{W} = \{x, y\}$

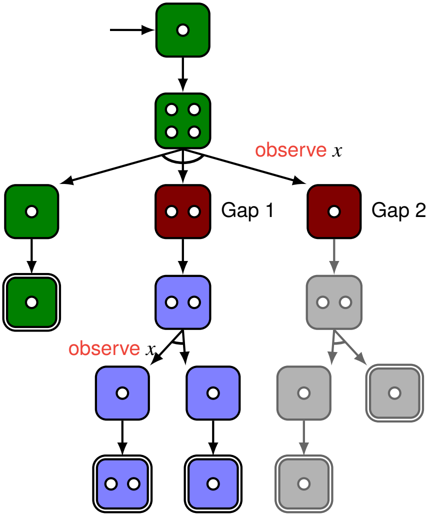
Gap states that need replanning



Plan Reuse

Example, $\mathcal{W} = \{x, y\}$

Plan to fill gap 1



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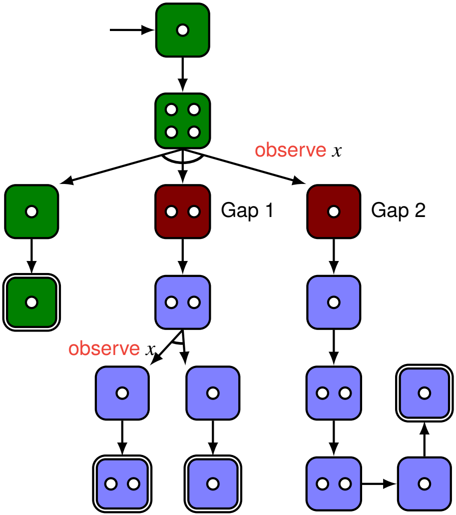
Plan Reuse

Example, $\mathcal{W} = \{x, y\}$

Plan to fill gap 2



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Plan Reuse

Soundness

To eliminate variable y:

- Let π be the old plan still observing y.
- Identify gaps $1, \dots, n$ in π.
- Let π_y be the reusable fragment of π.
- Let π_j, $j = 1, \dots, n$, be the new sub-plans filling the gaps.
- Let $\pi' = \pi_y \oplus \pi_1 \oplus \cdots \oplus \pi_n$ ($\oplus =$ function overriding).

Lemma

If π and all π_j are strong cyclic plans, then so is π'.

Proof sketch.

In π', "last" subplan "wins". Thus, closedness and properness of π and all π_j carry over to π'. □

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Plan Reuse

Soundness

To minimize set of observation variables:

- Eliminate variables one by one, if possible.

Theorem

Plan π resulting from successive elimination of variables is strong cyclic plan.

Proof sketch.

Base case + inductive application of previous lemma. □

Remarks:

- In induction, skip gaps filled/circumvented by chance when filling earlier gap.
- In elimination step, existence of π_j not guaranteed. Resulting π' not necessarily with inclusion minimal set $\mathcal{O}$.

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Plan Reuse

Suboptimality

Remark:

Observation sets found with plan reuse can be suboptimal.

Example: Let Π with

- Propositional variables $\mathcal{V} = \{a, b, c\}$,
- Initial belief state $B_0 = \overline{a}\overline{b}\overline{c}$,
- Goal belief state $B_\star = c$,
- Observable variables $\mathcal{W} = \{b\}$,
- Actions $\mathcal{A} = \{a_1, a_2, a_3, a_4\}$, where
  - $a_1 = \langle \overline{a} \longrightarrow a \rangle$,
  - $a_2 = \langle \overline{b} \longrightarrow (b \text{ or } \top) \rangle$,
  - $a_3 = \langle b \longrightarrow c \rangle$,
  - $a_4 = \langle \overline{a}\overline{b}\overline{c} \longrightarrow c \rangle$.

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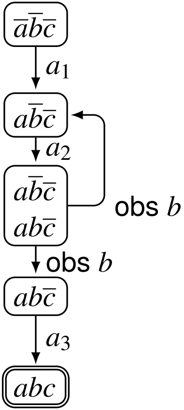
Plan Reuse

Suboptimality

Example (ctd.): Possible plan for Π:

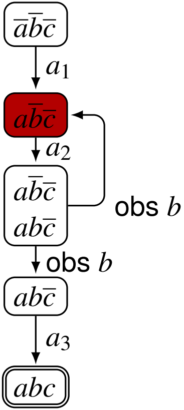


With observation of b.

Plan Reuse

Suboptimality

Example (ctd.): Possible plan for Π:



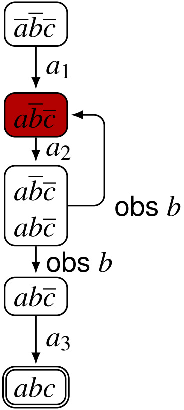
With observation of b.

Only gap state.

Plan Reuse

Suboptimality

Example (ctd.): Possible plan for Π:



With observation of b.

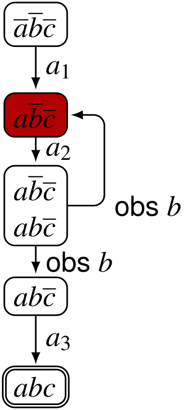
No plan for $a\bar{b}\bar{c}$ without observing b:

- only applicable action a_2 makes b unknown
- then all actions inapplicable

Plan Reuse

Suboptimality

Example (ctd.): Possible plan for Π:



With observation of b.

No plan for $a\bar{b}\bar{c}$ without observing b:

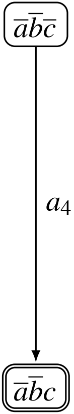
- only applicable action a_2 makes b unknown
- then all actions inapplicable

Variable b cannot be removed
$\Rightarrow$ solution $\mathcal{O} = \{b\}$

Plan Reuse

Suboptimality

Example (ctd.): Possible plan for Π:

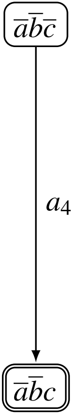


Plan for $\overline{a}\overline{b}\overline{c}$ without observation of b exists.

Plan Reuse

Suboptimality

Example (ctd.): Possible plan for Π:



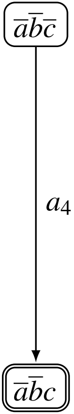
Plan for $\overline{a}\overline{b}\overline{c}$ without observation of b exists.

$\Rightarrow$ optimal solution $\mathcal{O}^* = \emptyset$

Plan Reuse

Suboptimality

Example (ctd.): Possible plan for Π:



Plan for $\overline{a}\overline{b}\overline{c}$ without observation of b exists.

$\Rightarrow$ optimal solution $\mathcal{O}^* = \emptyset$

$\Rightarrow$ solution $\mathcal{O} = \{b\}$ found with plan reuse was suboptimal

Functional Dependencies

Further enhancement: functional dependencies

- Idea: If value of variable o can be inferred from values of observed variables $o^1, \dots, o^n$, need not observe o.
- Identify such functional dependencies in plan π.
- Replace observations of o in π by observation of $o^1, \dots, o^n$.
- Remark: functional dependencies only have to hold in states reachable following π, not necessarily in all reachable states.
- Implemented: only exactly-one mutexes between propositional variables.

Empirical Evaluation

Runtimes

Motivation
Theory
Practical Algorithms
Empirical Evaluation
Conclusion

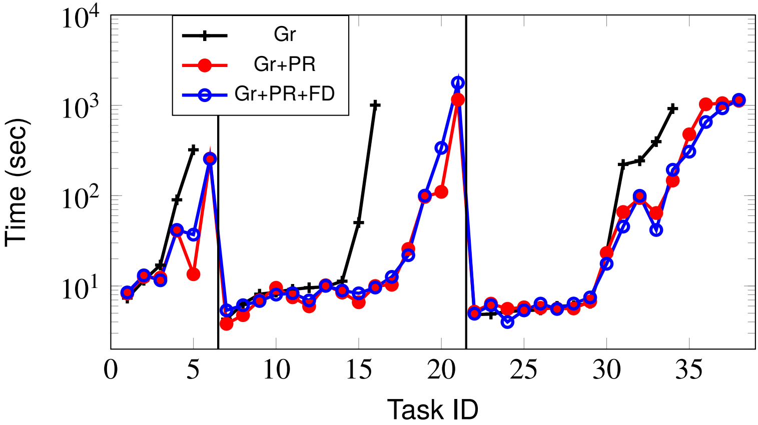
- Implementation on top of MYND planner[1].
- LAO* search [Hansen & Zilberstein, 2001] guided by FF heuristic [Hoffmann & Nebel, 2001].
- Domains:
  - BLOCKSWORLD
  - FIRSTRESPONDERS
  - TIDYUP
- Legend:
  - Gr = greedy
  - PR = plan reuse
  - FD = functional dependencies

[1] https://bitbucket.org/robertmattmueller/mynd

Empirical Evaluation

Runtimes

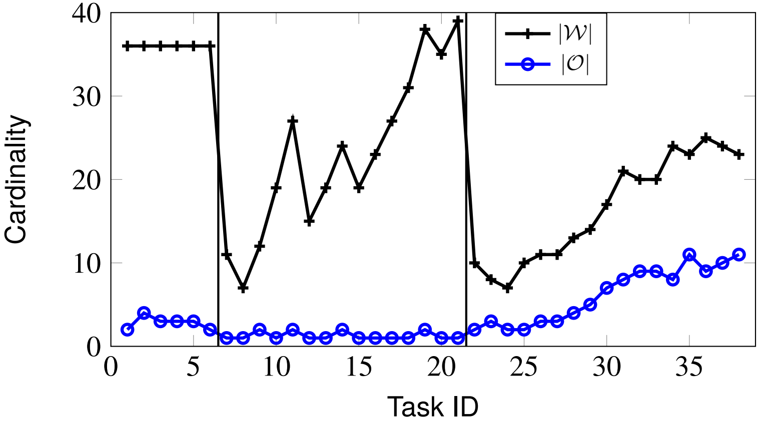
Overall runtime needed for finding final observation set.



Empirical Evaluation

Observation Set Cardinalities

Cardinalities of the observation sets before/after minimization.



Empirical Evaluation

Domain-specific Observations

Variables in resulting observation sets:

- BLOCKSWORLD: mostly
  - ONTABLE
  - CLEAR

  (either of them alone is sufficient.)
- FIRSTRESPONDERS:
  - FIRE (in all tasks, for relevant locations)
  - In one instance without road to hospital: VICTIMSTATUS – needs to be observed for applicability of TREATVICTIMONSCENE.
- TIDYUP: relevant instances of
  - GRIPPERSTATUS
  - TABLECLEAN
  - DOORSTATE
  - ROBOTLOCATION
  - CUPLOCATION

Conclusion and Future Work

Conclusion:

- Theory: OBSERVEINCLMIN is 2-EXPTIME-complete.
- Presented asymptotically optimal baseline greedy top-down algorithm for OBSERVEINCLMIN.
- Extended it with
  - plan reuse (pays off) and
  - functional dependencies (do not really pay off).

Future work:

- Complement top-down with bottom-up procedure.
- Investigate variable ordering heuristics for the iteration over candidate variables for removal.
- Study problem on domain instead of planning task level.