Compiling Contingent Planning into Classical Planning: New Translations and Results

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Planning problems

- **Classical planning** assumes deterministic actions; solutions are action sequences
- **Conformant planning**: incomplete information and no sensing; solutions are action sequences
- **Contingent planning**: incomplete information and sensing; solutions are trees/policies
- Conformant and Contingent planning commonly addressed as search problems in belief space
- Challenging: # of belief states is **doubly exponential** in # of vars.

Translation-based approaches

- Family of translations $K_{T,M}$ from **conformant to classical** [Palacios & Geffner, 2007]
  - In the worst case, complete translation is exponential in # of vars
  - Translation instance K_i is poly and complete if $width(P) \leq i$
  - K_1 translation underlies T_0 conformant planner
- Similar family of translations $X_{T,M}$ from **contingent to FOND** [Albore et al., 2009]
  - In the worst case, complete translation is exponential in # of vars
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    - hence doubly exponential in # of vars
  - Used for selecting actions in **online** MSPR planner by considering relaxation where set of initial states replaced by **4 random samples**

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Aim of this work

- More effective translations from contingent to classical, that can be used to solve contingent problems **off-line**
  - Obtain the solution directly from a classical planner
- **Two translations**:
  - C_1: quadratic in number of initial states
  - C_2: linear in number of initial states
- Ongoing work: more compact translations that are linear or quadratic in **number of variables**
  - Like those underlying *CLG*, K-replanner, *LW*1

Syntax and semantics of contingent planning

Given a **Contingent problem** P:

Contingent problem $P = \langle F, O, A, I, G \rangle$

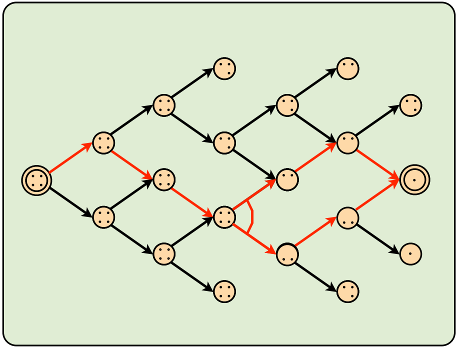
1. F fluents in P
2. O sensing actions
3. A actions, including conditional effects $C \rightarrow L$
4. I initial situation, CNF **clauses** over F-literals
5. G goal situation, **conjunction** of F-literals

P defines a **state model** $S(P)$:

Contingent state model $S(P) = \langle S, S_0, S_G, A, f, o \rangle$

1. S set of valuations s over fluents in F
2. S_0 set of initial states, S_G set of goal states
3. $A(s)$ actions applicable in s
4. $f(a, s)$ state transition function
5. $o(a, s)$ sensing function

Contingent State Model



- **Solution** marked in red, represented as a tree or a graph.
- Translation to classical
  - **Classical plan is sequence of actions representing tree solution.**

Idea of Brafman's & Shani's Translation [2012]

Classical state represents **all** current belief states.

- Use fluents:
  - L/s: L true **if** *s* was hidden initial state.
  - KW L/s: **knows value of L** if *s* was hidden initial state
  - KW $\neg s'/s$: s' **cannot** be the current state if *s* was hidden initial state
- For each action *a* in original problem *P* and subset *b* of S_0, create action $a(b)$
  - **Precondition**: *b* is a **belief distinguished** by obs; **know** and **verify precondition** *p* of *a*, for all states *s* in *b*
  - **Effect**: carry on effects L/s, for effect *L* of *a*, and all states *s* in *b*
  - **Observation** of p: **split** belief b; know p, for all states *s* in *b*
  - (also, keep track of KW L/s through actions and merge action)

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- Problem: **exponential in # of initial states**
- Planner MPSR uses heuristic based on multi-path translation using only a small subset *b* of S_0, s.t. $|b| \leq 4$

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Ideas in Translation C_1

Classical state represents **all** current belief states.

- Fluents
  - L/s: L true **if** s was hidden initial state
  - XL/s: L known true in execution associated with the hidden state s.
    - *i.e.* L true in **belief** b **where** s **belongs to**.
    - s is a **witness** of b.
  - $D(s, s')$: s and s' in **different** belief states

- For each action a in original problem P, create action $a(s)$ for each s in S_0
  - Let b belief where s belongs to
  - **Precondition**: precondition p of a holds in all states s' in b
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  - **Quadratic** in # of initial states (vs exponential)
  - Contingent plans obtained **directly from classical planner**

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Outline

- Translation C_1 and C_2
  - Intuitions
  - Formal Translation
  - Properties
- Experimental Results and Challenges
- Conclusion and Future Work

Examples: States of C_1

Two states, One belief state

- Initial states: $s_1 = \{p, q\}$, $s_2 = \{q\}$,
- Initial belief state: $\{s_1, s_2\}$
- Initial classical state of C_1: $\{p/s_1, q/s_1, \quad q/s_2, \quad Xq/s_1, Xq/s_2\}$

Three states, Two belief states

- Initial states: $s_1 = \{p, q\}$, $s_2 = \{q\}$, $s_3 = \{p\}$
- Initial belief state: $\{s_1, s_2, s_3\}$
- Observe q
- Two belief states: $\{s_1, s_2\}$ and $\{s_3\}$
- Classical state: $\{p/s_1, q/s_1, \; q/s_2, \quad D(s_1, s_3), D(s_2, s_3), \quad p/s_3,$
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The translation C_1

Classical problem $C_1(P) = \langle F', I', G', A' \rangle$

1. $F' = \{L/s \mid L \in F, s \in S_0\} \cup \{D(s, s') \mid s, s' \in S_0\}$
2. $I' = \{L/s \mid L \in F, s \in S_0, s \models L\}$
3. $G' = G$
4. $A' = \{a(s) \mid a \in O \cup A, s \in S_0\}$ s.t.
   - XL/s in prec. for $L \in Pre(a)$
   - If a is **physical action** in A, with cond effect $a : C \rightarrow E$,
     - $a(s) : C/s', \neg D(s, s') \rightarrow E/s'$ for all states s' in S_0
   - If a is **sensing action** in O observing p,
     - $a(s) : \neg D(s, s'), \neg D(s, s''), p/s', \neg p/s'' \rightarrow D(s', s''), D(s'', s')$ for s', s'' in S_0
5. **Axioms**: $\bigwedge_{s' \in S_0} [L/s' \vee D(s, s')] \rightarrow XL/s$
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Properties of translation C_1

Theorem

Translations $C_1(P)$ is **sound** and **complete**.

- **Soundness**: classical plans for $C_1(P)$ are contingent plans for P.
- **Completeness**: all plans for P are classical plans for $C_1(P)$.
- **Translation size**
  - Number of actions **linear** in # of initial states (vs exponential)
  - Number of fluents remains **quadratic** in # of initial states
- Possible problems with C_1
  - Quadratic in # of initial states is still **big**
  - **Branching factor**: in any moment the classical planner can apply actions to any leaf.

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Ideas in Translation C_2

Translation $C_2(P, M)$

- Parameter M for the **maximum number of observations in a branch.**
- Use **stack** of size M for storing pending belief states
- Size: **linear** in # of initial states and M

Fluents of $C_2(P, M)$:

- L/s: L true **if** s was hidden initial state, as before.
- XL: L is known to be true in **current belief**
- $m(s)$: state s is part of the **current belief**
  - Instead of $D(s, s')$ used in C_1
- $stack(s, l)$: state s in belief state **stacked** at level l
- $lev(l)$: top of stack

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- Initial belief state: $\{s_1, s_2\}$
- Initial classical state of C_2:
  $\{m(s_1), p/s_1, q/s_1, \quad m(s_2), q/s_2, \quad Xq, \quad lev(0)\}$

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Given stack size M, Classical problem $C_2(P) = \langle F', I', G', A' \rangle$

1. $F' = \{L/s, m(s), lev(l), stack(l, s) \mid L \in F, s \in S_0, l \in [0, M]\}$
2. $G' = G$ $\quad I' = \{L/s, m(s), lev(0) \mid L \in F, s \in S_0, s \models L\}$
3. $A' = A \cup \{a(p, l), pop(l + 1) \mid a \in O, l \in [0, M]\}$ s.t.
   - If a is **physical action** in A, action a
     - Prec: XL for $L \in Pre(a)$, $\neg XG$
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     - $a(p, l) : m(s), \neg p/s \rightarrow stack(s, l+1), \neg m(s)$ for s in S_0
   - **Action** $pop(l)$:
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Properties of translation C_2

Theorem

Translation $C_2(P, M)$ is **sound** and **complete**, capturing all the contingent plans for P whose depth is bounded by M.

depth of contingent plan = max number of sensing actions in a branch

- **Soundness**: classical plans for $C_2(P)$ are contingent plans for P.
- **Completeness**: all plans for P are classical plans for $C_2(P)$, for some stack size M.
- Translation **size is linear** on number of initial states and stack size.

Empirical comparison with contingent planners

- **Compiled away axioms** into new actions + bookkeeping.
- **Solved** output of **translations** C_1 and C_2 with many state-of-the-art Classical Planners.
- SIW, LAMA, and FF were retained as providing the **best** performances.
- C_2 shows slightly better **coverage**
  - Usually smaller but more complicated classical problems than C_1.
- Performances of **translations outperform** Contingent-FF, MBP, and Pond contingent planners.
- **"New generation"** of offline contingent planners perform better than these C_1/C_2 + classical planner, e.g. CLG, DNFct.

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Performance of Classical Planners on C_1

C_1		SIW			LAMA		
problem	pddl	plan	#exp/#act	nodes/s	size	#exp/#act	node/s
dispose 4 1	522	576	33.35	40	375	1310	7688
ebtcs 30	913.4	180	4.67	6	180	32.37	24459
ebtcs 50	4043	300	4.56	1	300	169.5	2338
elog 5	1081	450	25.97	3	330	2085	15812
elog 7	3621	TO			TO		
grid 3	1113	1239	57.04	26	78	326.73	564
grid 5	6432	TO			210	333.1	106
localize 5	3431	558	35.68	2	243	90.17	948
unix 2	3169	453	35.62	4	216	1.45	1116
unix 3	81058	MO			591	3.26	35

- PDDL size in kb; plan length; #exp/#act = expanded / plan length; nodes / second. TO = $>$ 2h. MO = $>$ 2gb.
- Expanding more costly in bigger problems.
- SIW slower as uses strong inference.

Performance of Classical Planners on C_2

C_2		SIW			LAMA		
problem	pddl	plan	#exp/#act	node/s	size	#exp/#act	node/s
dispose 4 1	450	395	4.38	89	259	16	122
ebtcs 30	1317	243	2.61	28	177	4.2	83
ebtcs 50	5405	363	6.42	5	297	4.4	27
elog 5	362	301	5.99	52	287	148.4	1758
elog 7	553	481	7.23	42	401	554.5	778
grid 3	535	407	6.72	44	257	62.77	187
grid 5	1367	IW$>$ 2			97	163.15	39
localize5	295.7	305	5.93	78	183	5.27	732
unix 2	718	137	8.39	36	117	4.21	147
unix 3	5918	MO			TO		

- In comparison with C_1
  - Faster node expansion for SIW
  - Slower node expansion for LAMA

Experimental challenges

- Translated problems are a **new family of problems** for classical planning, with peculiar characteristics.
- Classical planners shown **very different behaviors**, yet no one dominated the others on the C_1 and C_2 translations.
- **Axioms** are badly treated by classical planners in general: we had to compile them away, producing heavier PDDLs.
  - E.g. MSPR would be simpler and faster with axioms
- Results shown some limits of the **heuristics**, as it is difficult here to have a good heuristic evaluation
  - Many actions with zero cost/axioms/auxiliary actions
  - In Contingent Planning reasoning about gathered knowledge is needed but heuristics may not detect such need

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Conclusion and Future Work

- **Translations** C_1 and C_2 from **contingent** planning P into **classical** planning
  - $C_1(P)$ is **sound and complete**
  - $C_2(P, M)$ is **sound and complete**,
    - for at most M sensing in a branch.
- Experimental results **comparable with previous generation** of contingent planners, but **outperformed by recent** ones.
- New **challenge** for classical planners

Future work

- **Compact translation** based on C_2, polynomial in num of variables.
- Use **axiom support** of classical planners.
- Most informed **online** contingent planning
  - This approach could help to deal with dead-ends

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All good things come to an End

Thank you!

End of Presentation