Compiling Probabilistic Conformant Planning into Mixed Dynamic Bayesian Network

June 5th

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Overview

• Goal
  – Solve Probabilistic Conformant Planning by the marginal MAP inference

• Contribution
Contents

• Introduction

• Compiling PCP into Mixed DBN

• Empirical Evaluation

• Conclusion
Introduction

• What is Planning?

• What is Probabilistic Conformant Planning?

• How to formulate PCP as the Marginal MAP inference?

• Review the definition of Mixed Network
Planning

• Planning
  – a process of selecting and organizing actions to achieve desired goal

  – \(<S, T, A>\)
    • \(S\) : set of world states
    • \(A\) : set of actions
    • \(T\) : state transition function
      – Deterministic Transition \(T: S \times A \rightarrow S\)
      – Probabilistic Transition \(T: S \times A \times S \rightarrow [0,1]\)

  – Flat vs. Factored state/action representation
    • Single variable vs. Multiple variables
Probabilistic Conformant Planning

• Probabilistic Planning
  – the effect of an action is random
  – the initial state is uncertain

• State Observability
  – Fully Observable $\rightarrow$ FOMDP
  – Partially Observable $\rightarrow$ POMDP
  – Non Observable $\rightarrow$ NOMDP
Probabilistic Conformant Planning

- \( P = \langle S, b_i, s_G, A, T \rangle \)
  - \( S \) : a set of states,
  - \( b_i \) : initial belief state, \( \Pr(S_i) \)
  - \( s_G \) : a set of goal states
  - \( A \) : a set of actions
  - \( T : S \times A \times S \to [0, 1] \)

- Finite Horizon PCP \( <P, L> \)
  - \( L \) : time horizon

- PCP with threshold \( <P, \theta> \)
  - \( \theta \) : threshold for probability of success

- Optimal Probabilistic Conformant Plan
  - a plan that achieves the maximum probability of success given fixed time horizon
Probabilistic Conformant Planning

• The joint conditional prob. distribution over all states from time 0 to L time horizon is

\[ Pr(s^0..s^L|a^0..a^{L-1}) = \prod_{i=0..L} Pr(s^i|s^{0..i-1}, a^{0..i-1}) = \prod_{i=0..L} Pr(s^i|s^{i-1}, a^{i-1}) = Pr(s^0)Pr(s^L|s^{L-1}, a^{L-1}) \prod_{i=1..L-1} Pr(s^i|s^{i-1}, a^{i-1}) \]

• Initial belief state and goal are given in advance,

\[ Pr(s^0..s^L|s^0 = s_I, s^L = s_G, a^0..a^{L-1}) = Pr(s^0 = s_I)Pr(s^L|s^L = s_G, s^{L-1}, a^{L-1}) \prod_{i=1..L-1} Pr(s^i|s^{i-1}, a^{i-1}) \]

• PCP as Marginal MAP

\[ (a^0..a^{L-1}) = \arg\max_{(a^0..a^{L-1})} \sum_{s^1 \in S} Pr(s^1..s^{L-1}|s^0 = s_I, s^L = s_G, a^0..a^{L-1}) \]
Mixed Network

- Mixed network
  - Belief network + Constraint network
  - The joint probability distribution of Mixed network

\[
P_{\mathcal{M}}(\bar{x}) = \begin{cases} 
  P_{\mathcal{B}}(\bar{x}), & \text{if } \bar{x} \in \rho(X_C) \\
  0, & \text{otherwise.}
\end{cases}
\]
Compiling PCP into Mixed DBN

- Overview of Process
- What is PPDDL?
- SAT Encoding of PPDDL
- Converting SAT Encoding into Mixed DBN.
- Example
Compiling PCP into Mixed DBN

1. PPDDL Instance
2. SAT Encoding
3. Mixed 2TDBN
4. Mixed DBN
Planning Formalisms

- Classical Propositional STRIPS \( \langle P, O, I, G \rangle \)
  - \( P \): a set of propositional atoms
  - \( O \): a set of operators
  - \( I \): a list of positive atoms at init.
  - \( G \): a list of atoms that must be true at goal
  - operator \( o \) \( \langle \text{pre}(o), \text{add}(o), \text{del}(o) \rangle \)
    - Precondition list
    - Add list
    - Delete list
  - Closed world assumption
Action Description Language

- ADL
  - more expressive than STRIPS

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Planning Domain Definition Language

<domain> ::= <predictes> <actions>
<predictes> ::= list of <predicate>
<predicate> ::= (<name> <list of variables>*
<actions> ::= list of <action>
<action> ::= (<name> <list of variables>* <action body>)
<action body> ::= [<precondition>] [<effect>]
<precondition> ::= <ground expression>
<ground expression> ::= <predicate> <list of variables>* |
                         equality on two predicates |
                         negation of a precondition |
                         existentially quantified precondition |
                         universally quantified precondition |
                         conjunction of preconditions |
                         disjunction of preconditions |
<effect> ::= <simple effect> |
            <conditional effect> |
            conjunction of effects
<simple effect> ::= predicate literal
<conditional effect> ::= when <precondition> <effect>
<problem> ::= <ground terms> <init state> <goal>
<ground terms> ::= list of ground objects
<init state> ::= conjunction of ground predicates
<goal> ::= <ground expression>
• Probabilistic Effect

\[
\text{<effect>} ::= \text{<simple effect>} \mid \\
\text{<conditional effect>} \mid \\
\text{<prob. effect>} \mid \\
\text{conjunction of effects}
\]

\[
\text{<prob. effect>} ::= \text{list of pairs } (p, \text{<effect>})
\]
(define (domain ext-slippery-gripper)
  (:requirements :negative-preconditions :conditional-effects
   :probabilistic-effects)
  (:predicates (gripper-dry) (holding-block) (block-painted)
   (gripper-clean))
  (:action pickup
    :effect (and (when (gripper-dry)
                     (probabilistic 0.95 (holding-block)))
               (when (not (gripper-dry))
                     (probabilistic 0.5 (holding-block)))))
  (:action dry
    :effect (probabilistic 0.8 (gripper-dry)))
  (:action paint
    :effect (and (block-painted)
                 (when (not (holding-block))
                   (probabilistic 0.1 (not (gripper-clean)))
                   (when (holding-block)
                     (not (gripper-clean))))))

(define (problem ext-slippery-gripper)
  (:domain ext-slippery-gripper)
  (:init (gripper-clean)
    (probabilistic 0.7 (gripper-dry)))
  (:goal (and (gripper-clean) (holding-block) (block-painted))))
SAT Encoding for PPDDL

SAT Variables

- For each ground predicate/action, introduce a boolean state/action variable $s_i/a_i$.
- For each action $a_i$, introduce a multi-valued effect variable $e_{a_i}$ which has $n+1$ values if the effect had $n$ outcomes. The first value of an effect variable $e_{a_i}$ is no-op, which means that the result of the effect will be null effect, and the rest of the values refer to conditional effects $c_j$ defined earlier.
- For each state variable $s_i$, we introduce two auxiliary boolean variables for state transition, $+s_i$ and $-s_i$. The $+s_i$ is true if execution of any action could add the state variable $s_i$ at the next time stage. Similarly the $-s_i$ is true if execution of any action could delete the state variable $s_i$ at the next time stage.
SAT Encoding for PPDDL

**SAT Clause for Qualifying Precondition**
- For each ground action $a_i$, let $\phi_i$ be a CNF clause for a action precondition, then
  
  \[ a_i \land \phi_i \iff (e_{a_i} \neq \text{no-op}), \text{where the } (e_{a_i} = v) \text{ is an equality predicate that is true if} \]
  
  the value of the multi-valued variable $e_{a_i}$ equals $v$.

**SAT Clause for State Transition**
- the auxiliary value $+s$ is TRUE
  
  iff one of the effect that contains positive literal $s$ happens
  
  \[ \forall (e_{a_i} = v) \iff +s_i \text{, if } +s_i \in \text{add}(e_{a_i} = v) \]

**SAT Clause for mutual exclusivity**
- only 1 action per time stage, and only single effect can happen
  
  \[ \forall_j \lor a_j, \forall_{j \neq k} a_j \rightarrow \neg a_k \quad \forall_{a_i,a_j} (e_{a_i} = v_i) \land (e_{a_j} = v_j) \rightarrow \neg +/-s_i \]

**SAT Clause for the frame axiom**
- $s_i, \neg +s_i \land -s_i \rightarrow (s_i \land s_i') \lor (-s_i \land \neg s_i')$
Mixed 2TDBN

- **action**
- **precondition** ($\varphi$)
- **effect** ($(p_1 \cdot v_1), (p_2 \cdot v_2)$)

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<td>$v_1$ $P_1$</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>$v_2$ $P_2$</td>
</tr>
</tbody>
</table>
Mixed 2TDBN

- **Action**
- **Precondition**: $(\varphi_1)$
- **Effect**: $(p_1 \varphi_2 \triangleright v_1), (p_2 \varphi_3 \triangleright v_2)$

(a) conditional effects inside probabilistic effect

(b) conjunction of conditional effect and probabilistic effect
Mixed 2TDBN

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<td>$(s \land y)$</td>
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<td>$(s \land x)$</td>
<td>$(s \land y)$</td>
<td>1 0</td>
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</table>
Mixed 2TDBN

(a) Auxiliary network for the frame axiaom

(b) Auxiliary network for the mutual exclusivity constraint
Mixed 2TDBN

Diagram:

- Two treestructures are shown:
  - The left structure has a root labeled 'c' with children 'a1', 'a2', and 'a3'.
  - The right structure has a root labeled 't' with children 'c', 'a1', 'a2', and 'a3'.

The structures are connected by an arrow indicating a transformation or relationship.
Complexity of Translation

• Number of Variables per time
  – n_actions = ground actions, |A|
  – n_states = ground states, |S|
  – n_effects = n_action
  – n_hidden <= 2n_states* |E|
    • E : maximum number of effects that affecting a single state; depends on the problem
  – n_constraint = n_actions (including hidden variables)
  – O (|A| + |S| + |A| + 2|S| + |A| + |S|*|E|) = O( 3|A| + (3+ |E|) |S| )

• |A|
  – number of action schema * K^p
    • K : maximum number of constant objects
    • p: maximum number of parameters for action schema

• |S|
  – number of predicates * K^q
Slippery Gripper Problem
Empirical Evaluation

• Benchmark Sets

• AOBB-JG vs. BBBTi vs. Yuan’s algorithm

• AOBB-JG vs. Probabilistic-FF
Benchmark Sets

- 3 Benchmark Problems

<table>
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<tr>
<th>PPDDL Domain</th>
<th>Source</th>
<th>Instance</th>
<th>Init. State</th>
<th>State Transition</th>
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- 3 Marginal MAP algorithms
  - AOBBA-JG : (i, c, j)
    AND/OR branch and bound search algorithm using weighted mini bucket heuristic with join graph cost shifting scheme
  - BBTi : (i, c)
    Branch and bound search algorithm using incremental mini cluster tree elimination heuristics
  - Yuan’s :
    Depth first branch and bound search algorithm using incremental joint tree upper bound with unconstrained variable orderings
Slippery Gripper

- 2TDBN
  - 4 state vars
  - 3 action vars
  - 23 vars
Slippery Gripper

• Run time results
  – Yuan < BBTI < AOBBI-JG

• Heuristic Upper bounds
  – WBM-JG provided the tightest bound
  – AOBBI-JG solved up to 7 horizon w/o search

• Induced width:
  – unconstrained induced width 6
  – constrained induced width increases with L
Comm

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<th>L.</th>
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- 2TDBN : 45 state vars, 46 action vars, 349 vars
Comm

• AOBB-JG was the only algorithm that solved up to 9 time horizon.

• The induced width of the constrained ordering is 103 for the length 2 plan problem and 467 for the length 9 plan problem.

• The only probabilistic tables in the problem are two state variables at the initial state.

• AOBB-JG could solve the problem efficiently by detecting the zero probability subplans early by constraint processing.

• The large induced width of the problem not only makes the heuristic inaccurate but also consumes huge amount of memory.

• i-bound was limited by 2 up to 9 time horizon and solver was terminated due to out of memory from 10 time horizon.
**Blocks World**

- 2TDBN: 9 state vars, 8 action vars, 73 vars

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|            | 5  | 10| 10| 5181| 5660 | 0.32      | 8.93       | 0.28125  | 1.46E+13 |
|            | 6  | 12| 12| 80184| 87724| 0.64      | 242.19     | 0.808594 | 2.49E+17 |
|            | 7  | 26| 26| 947040| 1036077| 1.86     | 18231.81   | 0.870117 | 1.83E+02 |
|            | 9  | 22| 22| 4074 | 4169 | 29.95     | out        | 0.943176 | 2.02E+03 |
|            | 10 | 28| 28| 2024 | 2068 | 31.67     | out        | 0.990327 | 1.80E+04 |

| Yuan       | 3  | - | - | 25  | -    | 5.51      | 7.53       | 0.140625 | 0.140625 |
|            | 4  | - | - | 62  | -    | 7.55      | 10.81      | 0.5625  | 1.47E+06 |
|            | 5  | - | - | 1148| -    | 12.1      | 92.88      | 0.703125 | 8.96E+04 |
|            | 6  | - | - | 11982| -    | 13.46     | 1029.82    | 0.808594 | 49.533   |
|            | 7  | - | - | 209726| -    | 17.55     | 18809.1    | 0.870117 | 296.851  |
|            | 8  | - | - | 247596| -    | 21.31     | out        | 0.870117 | 702.582  |
|            | 9  | - | - | 380441| -    | 23.08     | out        | 0.885498 | 2691.55  |
|            | 10 | - | - | 245637| -    | 27.55     | out        | 0.931504 | 20239.9  |
Comparison with COMPLAN

• COMPLAN
  – Depth First Branch & Bound Search using approximate marginal MAP query to DNNF (compiled diagram).
    • similar to Yuan’s algorithm
  – Compiles problems as SAT with chance variables → compile CNF as DNNF

• Running time comparison?
  – NA
Comaprisou with Probabilistic-FF

• Probabilistic-FF
  – Sub-optimal planner, returns any plan that achieves a threshold
  – Heuristic Forward Search in a Belief State Space
  – Built on
    • Fast Forward Classical Planner
    • Conformant-FF
  – Internally represent belief states by DBN, and compile it into weighted CNFs \( \rightarrow \) weighted model counting
Comparison with Probabilistic-FF

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Conclusion

- Converted PPDDL Format to UAI Format

- Empirical Evaluation
  - 3 Problems (Slippery Gripper, Comm, Blocks world)
  - AOBB-JG Performed Best in overall
    - AOBB-JG equipped with constraint processing
    - w/o zero probability detection,
      - Slippery Gripper : Yuan < BBBTi < AOBB-JG
      - Blocks World : AOBB-JG < BBBTi < Yuan
  - AOBB-JG vs. Probabilistic FF
    - Probabilistic-FF generates suboptimal plans really fast
    - For optimal length plan, AOBB-JG was faster
    - In blocks world, Probabilistic FF couldn’t find solution if threshold was >= 0.6
Conclusion

• Downsides of Current Compilation
  – The number of variables is exponential in the number of ground objects
    • comm domain had 46 actions in 1 step.
    • cannot solve blocks world problem having 4 blocks
  – Large scope sized deterministic constraints
    • Mutually exclusive action constraint
    • The state transition constraint
  – All tables have huge redundancy
    • Decision diagrams
Future Work

• Compact Translation (semi-lifted model)
  – Formulate Problems in SAS+ formalism
    • Actions will be splitted
    • Reduce the coupling between state variables

• Compressed Representation
  – Constraints, CNFs
  – Decision Diagrams

• Lifted Inference
  – Incorporated lifted inference algorithms on the relational representation

• Extend the Problem Formulation to
  – Probabilistic Planning with Rewards
  – POMDP