Complexity results in epistemic planning (IJCAI-15)

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Epistemic planning and our contributions to it

Planning in general Given is a **planning task** consisting of: 1) initial state; 2) finite set of actions; 3) goal formula. The aim is to compute a **plan**: sequence of actions that leads from the initial state to a state satisfying the goal formula.

Epistemic planning Replace the propositional logic underlying classical planning by **Dynamic Epistemic Logic** (**DEL**). Actions are described as *action models* of DEL.

Why epistemic planning? Allows for *multi-agent planning* with *partial observability*, *non-determinism* and arbitrary levels of *beliefs about beliefs* (higher-order reasoning, *Theory of Mind*). E.g. *private sensing*: Zoé senses the truth-value of A without Bob knowing.

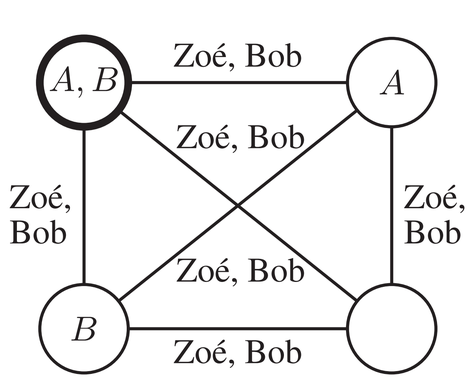
Epistemic planning task 1) *Initial state*: epistemic state (Kripke model); 2) *actions*: action models of dynamic epistemic logic; 3) *goal formula*: formula of multi-agent epistemic logic.

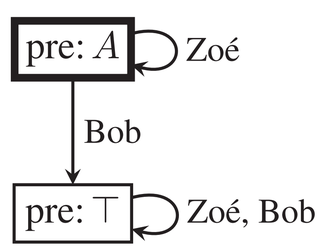
Plan existence problem in epistemic planning Given epistemic planning task, does there exist a plan for it?

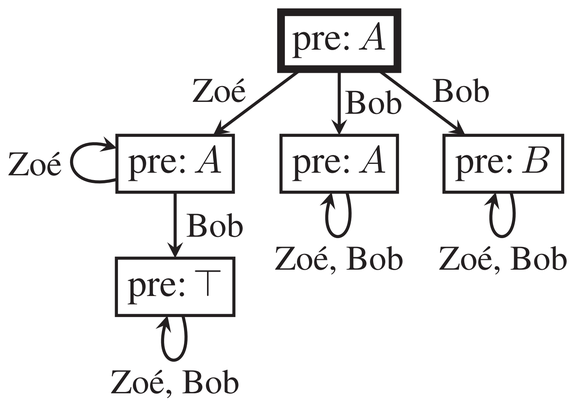
Main contribution of this paper Complexity results for the plan existence problem in epistemic planning. We look at different classes of epistemic planning tasks, and determine the complexity of the corresponding plan existence problems.

Example of an epistemic planning task

Initial state | **Action α_1:** | **Action α_2:** | **Goal formula**







$\widehat{K}_{\text{Bob}} K_{\text{Zoé}} A$

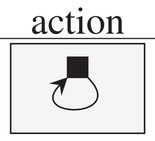
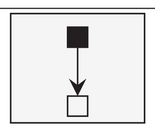
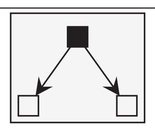
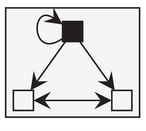
The truth of propositions A and B are not known to Zoé and Bob.

Zoé is privately sensing that A is true. Bob is completely ignorant.

Zoé believes that α_1 occurs. Bob believes that Zoé senses A or B.

Bob considers it possible that Zoé knows A.

Stablisation results

Epistemic action	Underlying frame	Stable after
	Singleton	1
	Chain	1
	Tree	$\lvert E\rvert$
	Graph	$\lvert E\rvert^{\text{depth of goal}}$

An epistemic action is *stable after* n, if its $(n+1)$*-ary product* is bisimilar to its n*-ary product* (repeating the action $n+1$ times is the same as repeating it n times).

Complexity results for the plan existence problem

Class of planning tasks	Types of epistemic actions		
	Non-factual, propositional preconditions	Factual, propositional preconditions	Factual, epistemic preconditions
SINGLETONS	NP-complete	PSPACE-hard [1]	PSPACE-hard [1]
CHAINS	NP-complete	? (open question)	? (open question)
TREES	PSPACE-complete	? (open question)	? (open question)
GRAPHS	in EXPSPACE	in NON-ELEMENT. [2]	Undecidable [3]

↑ results of this paper ↑

- Upper bound using a guess and verify algorithm; soundness and completeness via stabilisation results.
- Lower bound using polynomial time reductions from SAT (CHAINS) and QSAT (TREES).
- Singleton epistemic actions correspond to public announcements of propositional facts, chains and trees to certain forms of private announcements, and graphs capture any propositional epistemic action.

The paper

http://goo.gl/6dMzys

References

[1] Martin Holm Jensen. *Epistemic and Doxastic Planning*. PhD thesis, Technical University of Denmark, 2014. DTU Compute PHD-2014.

[2] Quan Yu, Ximing Wen, and Yongmei Liu. Multi-agent epistemic explanatory diagnosis via reasoning about actions. In Francesca Rossi, editor, *IJCAI*. IJCAI/AAAI, 2013.

[3] Thomas Bolander and Mikkel Birkegaard Andersen. Epistemic planning for single and multi-agent systems. *Journal of Applied Non-Classical Logics*, 21(1):9–34, 2011.