Complexity Results in Epistemic Planning

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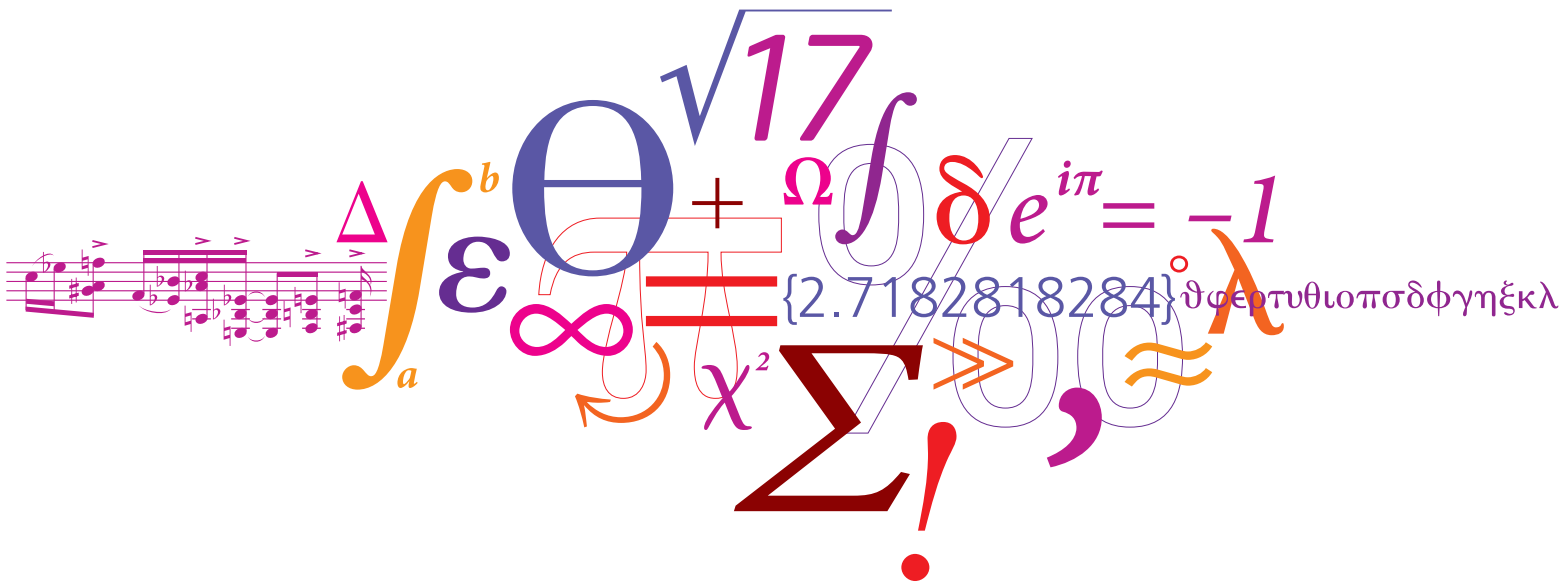

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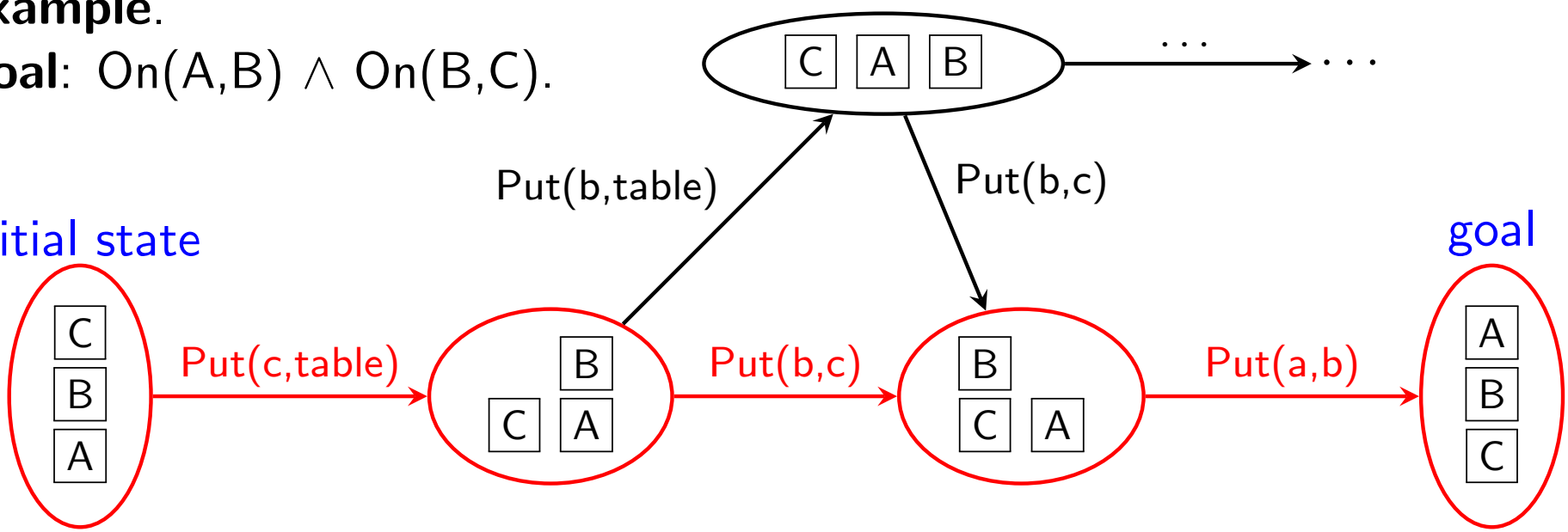
Automated planning

Automated planning (or, simply, **planning**):

- 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**: a sequence of actions that leads from the initial state to a state satisfying the goal formula.

Example.
Goal: On(A,B) $\wedge$ On(B,C).



Epistemic planning

Epistemic planning: Planning where agents can reason about their own and other agents' beliefs as part of the planning process.

Epistemic planning application examples:

Games with strong epistemic components (Cluedo, Hanabi, etc.). What will the other agents know if I choose to announce that I have this card?

Robots or intelligent software assistants taking and giving instructions. "Fetch a cup of coffee. The beans are in the cupboard."

Cryptographic protocols. How can agent a get to know φ without agent b knowing?

Our framework for Epistemic Planning

Epistemic planning: Our framework for planning with epistemic reasoning based on **Dynamic Epistemic Logic** (**DEL**).

From **classical planning** to **epistemic planning**: Replace the propositional logic underlying classical planning by DEL.

	Classical planning	**Epistemic planning**
States	models of prop. logic	models of MA epist. logic
Goal formula	formula of prop. logic	formula of MA epist. logic
Actions	induced by action schemas	action models of DEL

Epistemic planning can deal with: non-determinism, partial observability, sensing actions, multiple agents, arbitrary nestings of beliefs about beliefs.

Epistemic planning tasks and plan existence problem

Epistemic planning task: Planning task in epistemic planning.

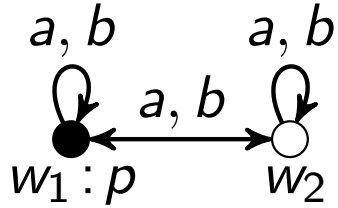
Plan existence problem for class of epistemic planning tasks X: "Given an planning task in X, does there exist a plan for it?".

Our paper: Complexity results for the plan existence problem for various classes of epistemic planning tasks.

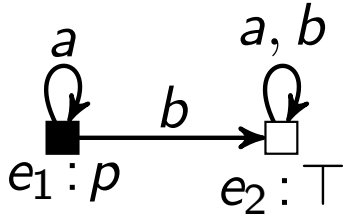
Example

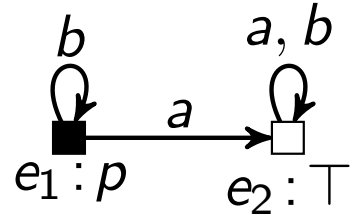
Consider the epistemic planning task with

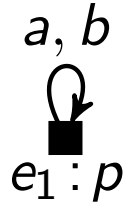
1) **Initial state**:



2) **Actions**:

$\alpha_1 =$ 

$\alpha_2 =$ 

$\alpha_3 =$ 

(α_1: privately announcing p to a; α_2: privately announcing p to b; α_3: publicly announcing p to both agents)

3) **Goal formula**: $K_a p \wedge K_b p \wedge \neg K_a K_b p \wedge \neg K_b K_a p$

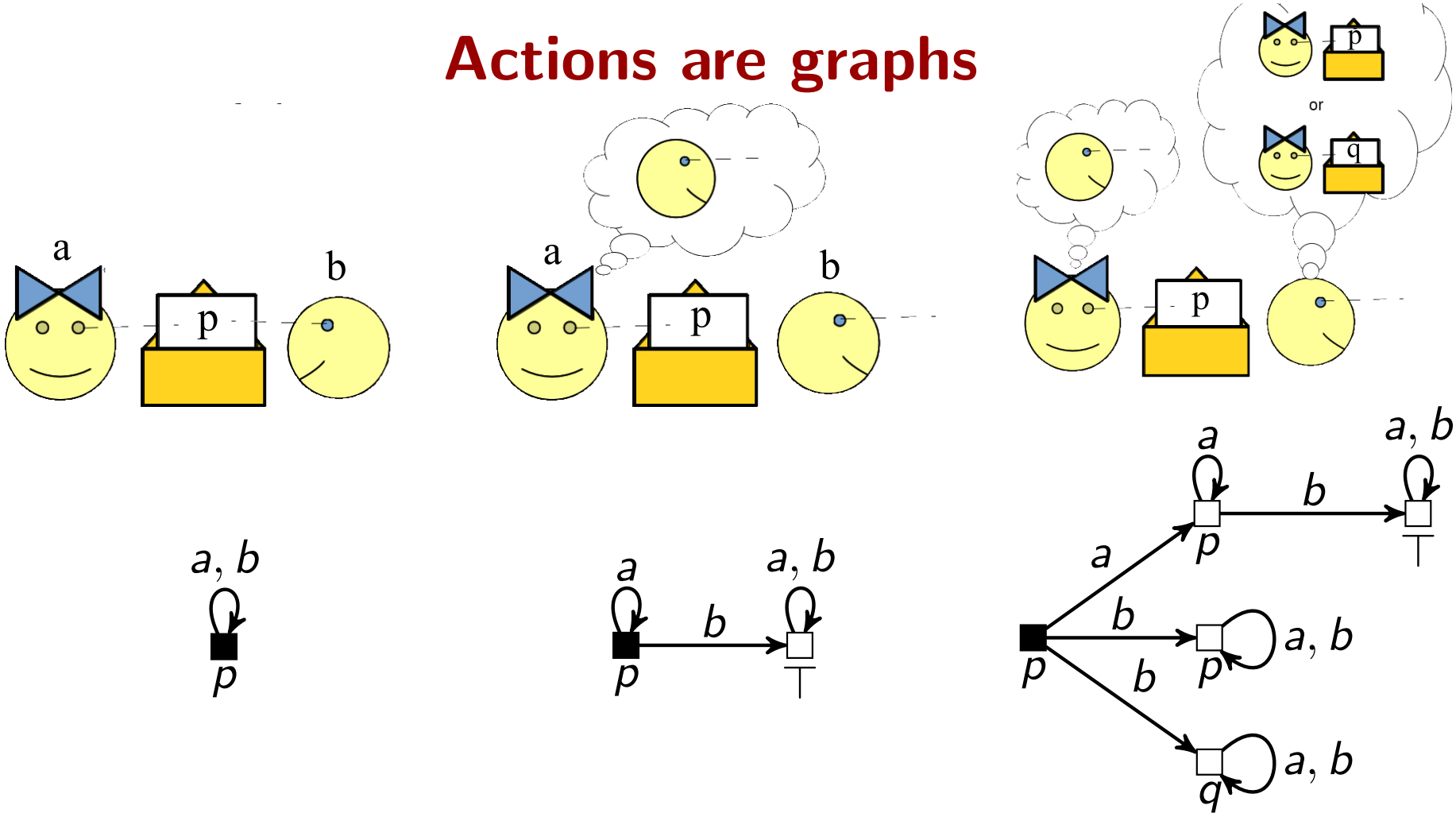
A **plan** for this task is α_1, α_2. Another plan is α_2, α_1. Also $\alpha_1, \alpha_2, \alpha_1$ and $\alpha_1, \alpha_1, \alpha_2$ are plans, etc.

Complexity of plan existence in epistemic planning

- **The bad news**: The plan existence problem in epistemic planning is undecidable. [Bolander and Andersen, 2011]
- **The even worse news**: The plan existence problem of non-factual epistemic planning (changing only beliefs, no ontic effects) is undecidable. [Aucher and Bolander, 2013]
- **Some slightly good news**: The plan existence problem in epistemic planning with **propositional preconditions** is decidable (in NON-ELEMENTARY). [Yu et al., 2013]

This paper: Getting lower complexities for further restricted (but still practically relevant) classes of planning tasks.

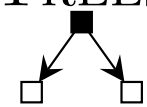
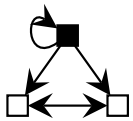
Actions are graphs



public announcement private announcement semi-private announcement

- Different graph structures allow different actions to be formed (e.g. public announcements like in Cluedo = singletons).
- We study how the underlying graph structure impact complexity of plan existence.

Summary of complexity results for plan existence

Underlying graphs of actions	Types of epistemic actions		
	Non-factual, propositional preconditions	Factual, propositional preconditions	Factual, epistemic preconditions
SINGLETONS 	NP-complete	PSPACE-hard [Jensen, 2014]	PSPACE-hard [Jensen, 2014]
CHAINS 	NP-complete	? (open question)	? (open question)
TREES 	PSPACE-complete	? (open question)	? (open question)
GRAPHS 	in EXPSPACE	in NON-ELEMENTARY [Yu et al., 2013]	Undecidable [Bolander and Andersen, 2011]

↑ in this paper ↑

APPENDIX

Why study very expressively restricted fragments?

Motivation for studying complexity of very restrictive fragments of epistemic planning:

- Still relevant for many interesting applications (e.g. Cluedo only involves public announcements = singleton action models).
- Where does the complexity come from?
- Constructing search heuristics for planning engines (relaxed problems).

Appendix: References I

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