

# Epistemic Plan Recognition

**Maayan Shvo**<sup>1,2</sup>    **Toryn Q. Klassen**<sup>1,2</sup>  
**Shirin Sohrabi**<sup>3</sup>    **Sheila A. McIlraith**<sup>1,2</sup>

Department of Computer Science<sup>1</sup>  
University of Toronto  
Toronto, Canada

Vector Institute<sup>2</sup>  
Toronto, Canada

IBM Research<sup>3</sup>

LAMAS 2020



# Plan Recognition

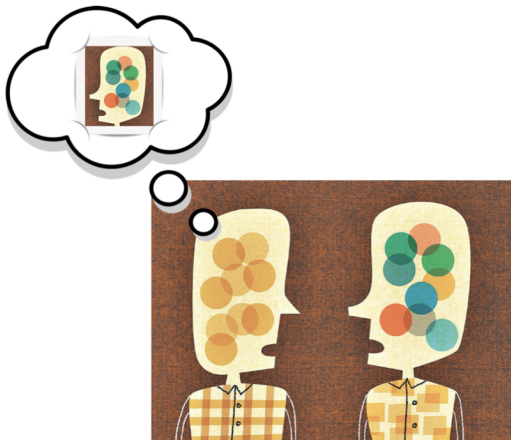


# Plan Recognition



# Motivation

Why epistemics?



# Motivation

Why epistemics?



- ▶ Incorporating a notion of **epistemics** into the recognition process enables the observer to:
  1. Assume the actor's perspective when recognizing her plan.
  2. Recognize the actor's epistemic goals.

# Our Contributions

- ▶ A specification of epistemic plan recognition (EPR).
- ▶ A computational realization of EPR as **epistemic planning**.
- ▶ An evaluation of our approach on a set of EPR problems.

## Building on Broad Shoulders

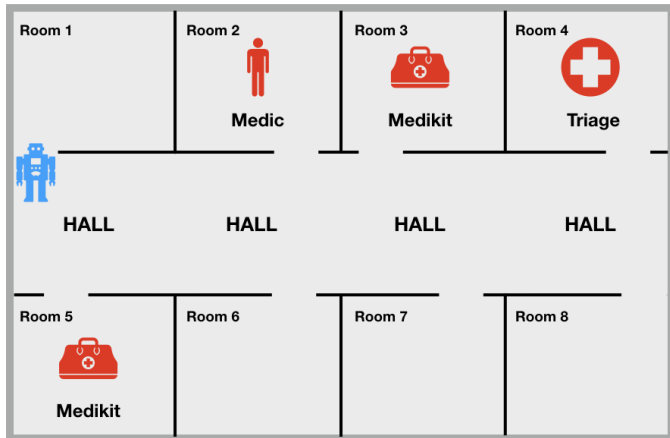
(Schmidt et al., 1978)  
(Cohen, Perrault, & Allen, 1981),  
(Kautz & Allen, 1986),  
(Pollack, 1986),  
(Levesque, 1988),  
(Liu et al., 2004),  
(Avrahami-Zilberbrand et al., 2005),  
(Sindlar et al., 2008),  
(Ramírez & Geffner, 2009),  
(Baker et al, 2011),  
(Bolander et al., 2011),  
(Talamadupula et al., 2014),  
(Kominis & Geffner, 2015),  
(Muisse et al., 2015),  
(Huang et al., 2017) ,  
(Engesser et al., 2017),  
(Le et al., 2018)

# Background

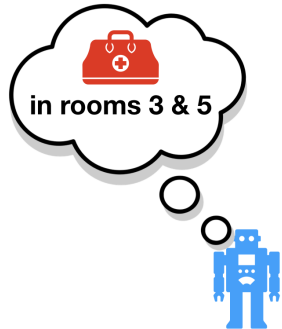
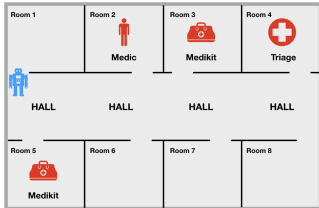
- ▶ Multi-agent epistemic logic framework
- ▶ KD45 axioms (Fagin et al., 1995)
  - ▶ For example, *positive introspection* –  $B_i\phi \Rightarrow B_iB_i\phi$
- ▶  $B_i\phi$  which should be interpreted as “Agent  $i$  believes  $\phi$ ”



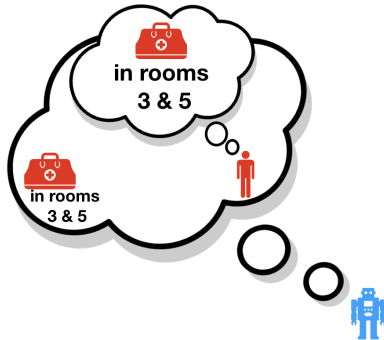
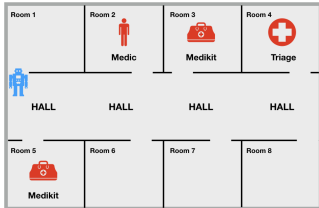
## Example - Search & Rescue (Talamadupula et al., 2014)



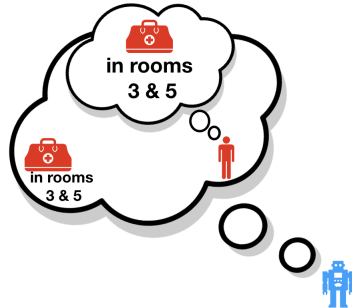
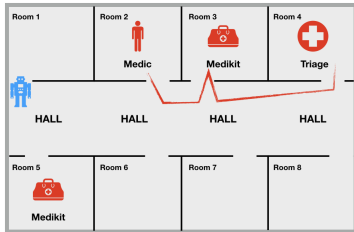
# Example - Search & Rescue (Talamadupula et al., 2014)



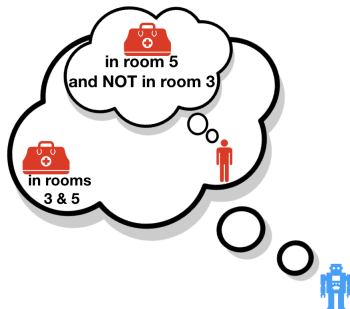
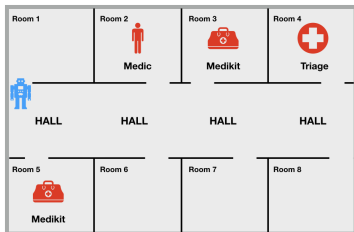
# Example - Search & Rescue (Talamadupula et al., 2014)



# Example - Search & Rescue (Talamadupula et al., 2014)

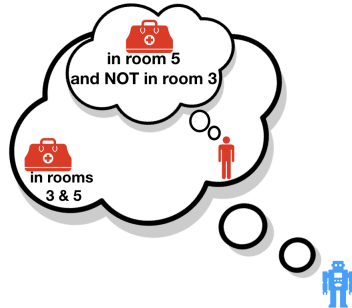
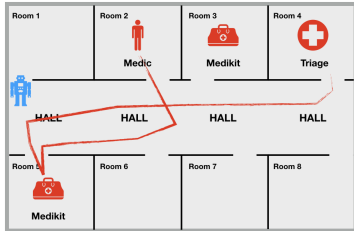


## Example - Search & Rescue (Talamadupula et al., 2014)



$$B_{Robot}(at(\text{Medikit1}, \text{Room3}) \wedge at(\text{Medikit2}, \text{Room5})) \wedge \\ B_{Robot} B_{Medic}(\neg at(\text{Medikit1}, \text{Room3}) \wedge at(\text{Medikit2}, \text{Room5}))$$

## Example - Search & Rescue (Talamadupula et al., 2014)



$$B_{Robot}(at(\text{Medikit1}, \text{Room3}) \wedge at(\text{Medikit2}, \text{Room5})) \wedge \\ B_{Robot} B_{Medic}(\neg at(\text{Medikit1}, \text{Room3}) \wedge at(\text{Medikit2}, \text{Room5}))$$

# Epistemic Plan Recognition

An **Epistemic Plan Recognition problem** is a tuple

$\langle \mathcal{P}, \mathcal{A}, \mathcal{D}, Ag, \mathcal{I}, \mathcal{G}, O \rangle$ , where:

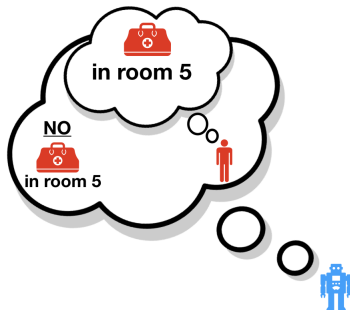
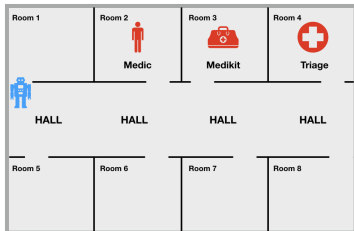
- ▶ The set of agents  $Ag$  includes the **observer** and the **actor**.
- ▶  $\mathcal{I}$  captures the observer's beliefs about the actor's beliefs about the state of the world.
- ▶  $\mathcal{D}$  captures the observer's beliefs about the actor's beliefs about the actions in  $\mathcal{A}$ .

# Epistemic Plan Recognition

Given an EPR problem,  $\langle \mathcal{P}, \mathcal{A}, \mathcal{D}, Ag, \mathcal{I}, \mathcal{G}, O \rangle$ , a **solution** is a pair  $(\pi, G)$ , where  $G \in \mathcal{G}$  is a goal and  $\pi$  is a sequence of actions – a plan – that satisfies  $O$ .

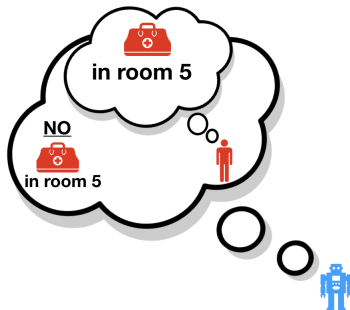
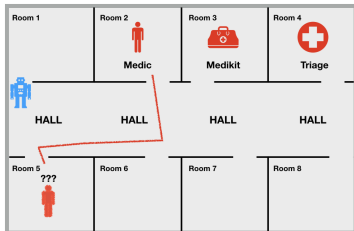


## Example - Search & Rescue (Talamadupula et al., 2014)



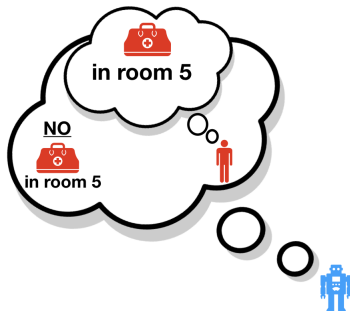
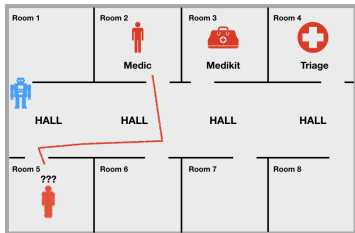
$$\mathcal{I} \models B_{Robot} \neg at(\text{Medikit1}, \text{Room5}) \wedge B_{Robot} B_{Medic} at(\text{Medikit1}, \text{Room5})$$

## Example - Search & Rescue (Talamadupula et al., 2014)



$$\mathcal{I} \models B_{Robot} \neg at(\text{Medikit1}, \text{Room5}) \wedge B_{Robot} B_{Medic} at(\text{Medikit1}, \text{Room5})$$

## Example - Search & Rescue (Talamadupula et al., 2014)



$KW(at(Medikit, Room8))$

# Epistemic Plan Recognition as Epistemic Planning

- ▶ Plan recognition as planning approach  
(Ramírez & Geffner, 2009)
- ▶ EPR problem is transformed to an epistemic planning problem

# Empirical Evaluation

- ▶ Applicability of existing epistemic planners
  - ▶ RP-MEP (Muisse et al., 2015)
  - ▶ MEPK (Huang et al., 2017)
  - ▶ EFP (Le et al., 2018)
- ▶ Comparison between epistemic planners
- ▶ Inadequacy of the observer's beliefs

# Summary

- ▶ Why epistemics?
  - ▶ The observer can assume the actor's perspective.
  - ▶ The observer can recognize the actor's epistemic goals.

## **Epistemic Plan Recognition**

Maayan Shvo, Toryn Q. Klassen,  
Shirin Sohrabi, Sheila A. McIlraith  
**[maayanshvo@cs.toronto.edu](mailto:maayanshvo@cs.toronto.edu)**

