Integrated task and motion planning in belief space

A PNM/HPN approach

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Introduction

- Integrated task and motion planning in belief space
  - Represent belief sub-space as *predicates* by using PNM
  - Define *operators* over predicates with deterministic action/observation models
  - Perform goal-regression based HPN planning
  - Execute resulted plan and do replanning if necessary
- Perspective from a view of traditional task and motion planning
  - Inference on *belief states* in task planning
  - *Deterministic planning* in motion planning

HPN

- Hierarchical Task and Motion Planning in the Now
  - World States: a completely detailed description of both the geometric and non-geometric aspects of a situation
  - Fluents: symbolic predicates applied to a set of states
  - Goals: a set of world states, described using a conjunction of ground fluents
  - Operators: hierarchical "actions" defined over fluents
- Algorithm; c.f. Section V in [Kaelbling and Lozano-Pérez(2011)]
- Example; c.f. Figure 2 in [Kaelbling and Lozano-Pérez(2011)]

HPN to MDPs

- Determinizing the MDP model into a weighted graph
  - $W(s, a, s') = \alpha C(s, a) - \log T(s, a, s')$
- Regression with costs
  - A weighted graph in which the nodes are sets of states (pre-images) and arcs are labeled by actions and costs
  - Use logical expressions to compactly denote subsets of the state space
  - Perform regression search, chaining pre-images backward from the goal to eventually reach a set of states that contains the initial state

HPN to MDPs (cont.)

- HPN plan in MDPs with uncertainty
  - Crude open-loop control policy
  - Only ensure positive probability of achieving the goal
  - Exist a coverage area (a.k.a. envelope)
- Execution and replanning
  - To continue executing: transition to a forward or backward state in the envelope
  - To return to high-level HPN: execution failed or exit the envelope
  - To replan: all levels of HPN returned
- Markov HPN; c.f. Section 3.1.3 in [Kaelbling and Lozano-Pérez(2013)]

PNM

- Probability near mode of a distribution
  - Specify a property shared by a set of underlying distributions
  - PNM fluents; c.f. Section 4.2 in [Kaelbling and Lozano-Pérez(2013)]
    - $BV(X, \epsilon, \delta)$
    - $ModeNear(X, v, \delta)$
    - $B(X, v, \epsilon, \delta)$

PNM with beliefs

- Use PNM fluents to specify properties of belief states
- A PNM fluent corresponds to a set of belief states
- Example:
  - $B(RobotPositionX, 2.0, 0.05, 0.5)$
    - $Pr[1.5 <= RobotPositionX <= 2.5] >= 0.95$
    - $\mu \in [1.5, 2.0]$, $\sigma \in [g(\mu), f(\mu)]$
    - Sub-space in μ-σ space; c.f. Figure 12 (b) in [Kaelbling and Lozano-Pérez(2013)]

PNM/HPN to POMDPs

- HPN in belief space
  - Fluents: PNM fluents applied to a set of belief states
  - Goals: a set of belief states, described using a conjunction of PNM fluents
  - Operators: actions (including observing actions) as operators defined over PNM fluents (with deterministic action/observation models)
- Algorithm; c.f. Section 3.2.1 in [Kaelbling and Lozano-Pérez(2013)]

References


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