Data Association Aware POMDP Planning With Hypothesis Pruning Performance Guarantees

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Israel Institute
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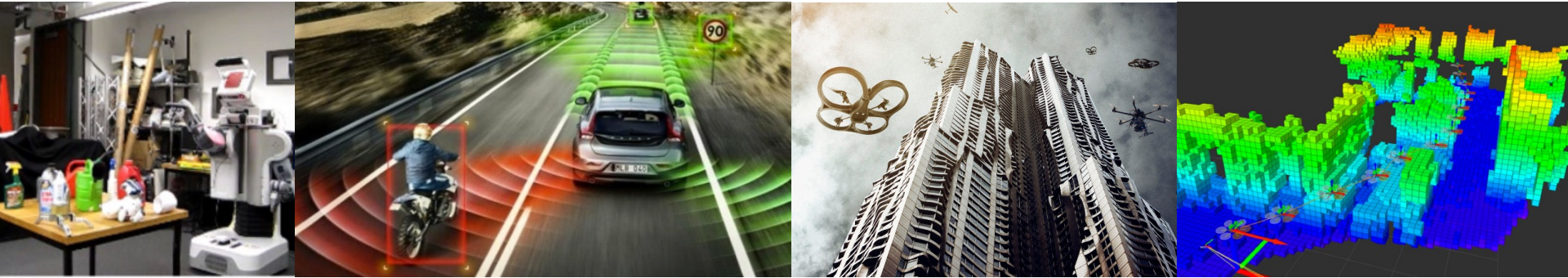
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Perception Lab

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Introduction

- Sequential decision-making under uncertainty
- These are commonly formalized as POMDPs

Introduction

A common approach for solving POMDPs is through online tree search methods

- Each node represents a belief
- Each edge represents an action or an observation
- Given a prior belief, the posterior belief is calculated via probabilistic inference
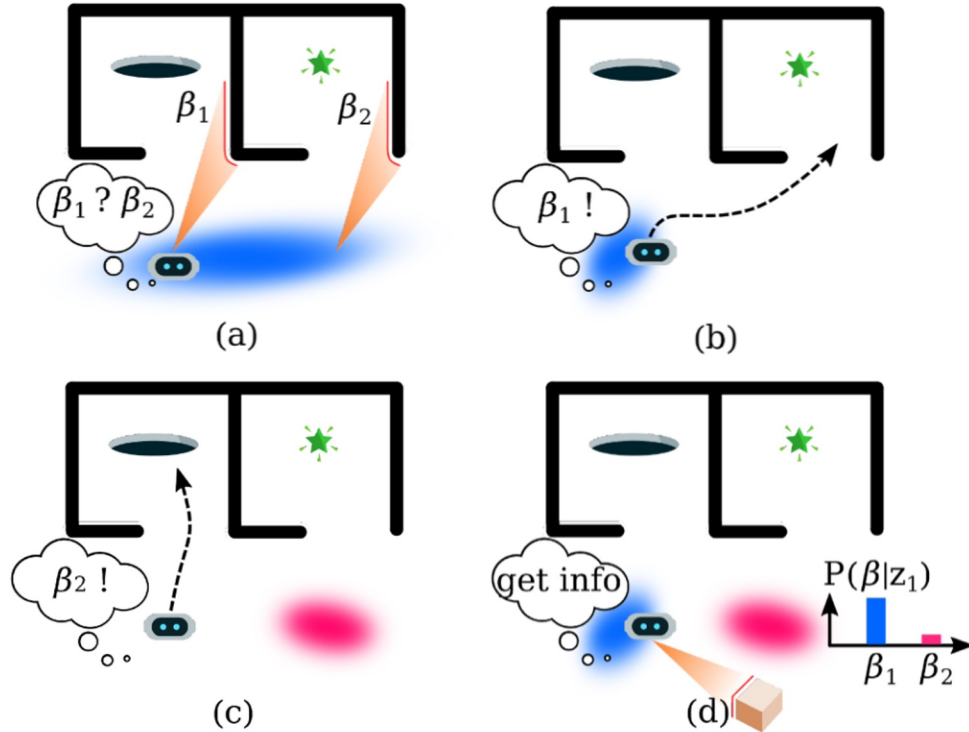
$$b_{t+1} = \psi(b_t, a_t, z_{t+1})$$

Data Association Aware Planning - Motivation

This paper focuses on POMDP planning with ambiguous data associations (DA).

Ambiguous DA refers to the case where observation source is uncertain.

Optimality requires reasoning about different hypotheses

(a) (b) (c) (d)

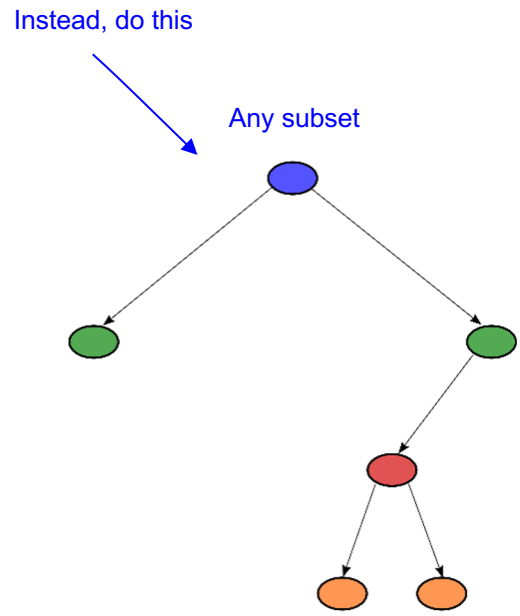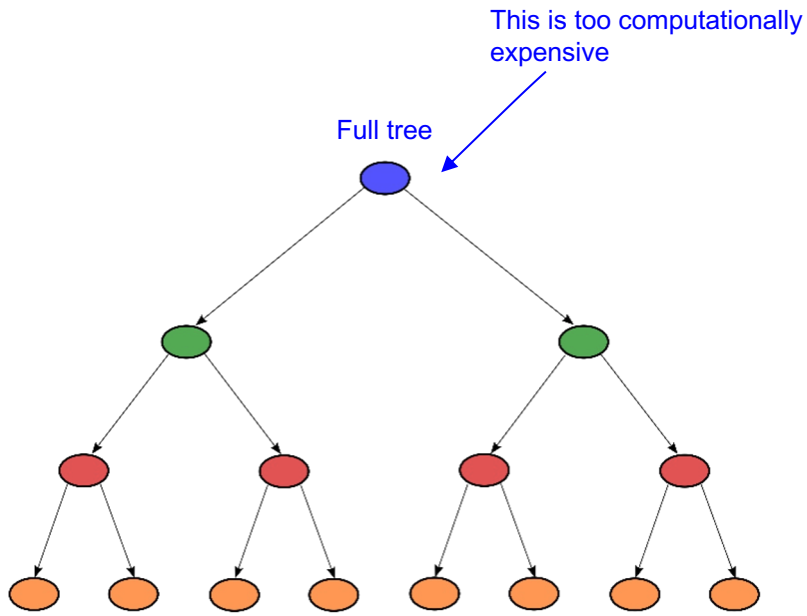# Data Association Aware Planning - The Challenge

Computing the value function requires explicit knowledge of the hypotheses

However, the number of hypotheses may grow **exponentially** with the horizon!
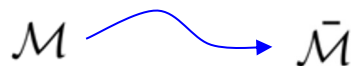

Belief tree

Hypothesis tree
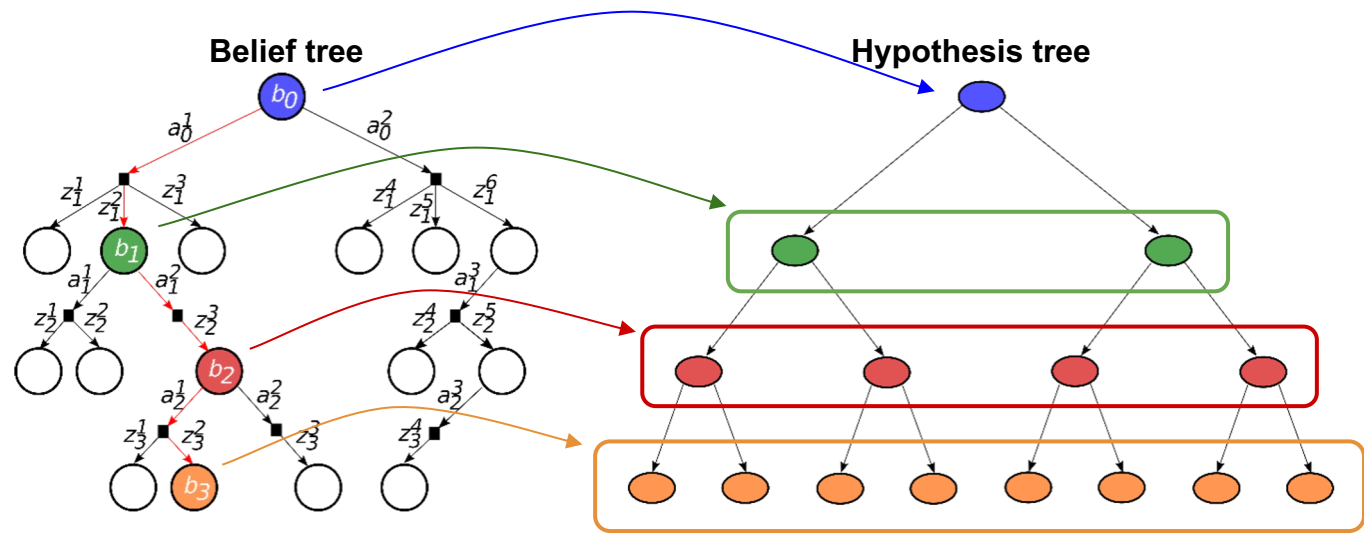
$$b_t \triangleq \mathbb{P}(X_t, \beta_{0:t} \mid H_t) = \underbrace{\mathbb{P}(X_t \mid \beta_{0:t}, H_t)}_{b[X_t]_{\beta_{0:t}}} \underbrace{\mathbb{P}(\beta_{0:t} \mid H_t)}_{b[\beta_{0:t}] \equiv \omega_t}$$

Data Association Aware Planning - Simplified Version

This is too computationally expensive

Instead, do this
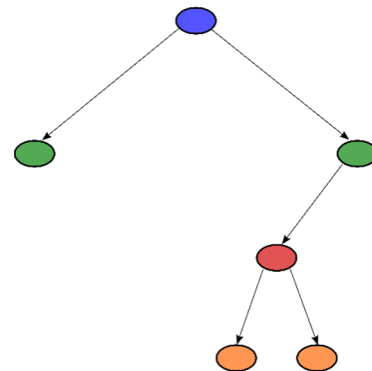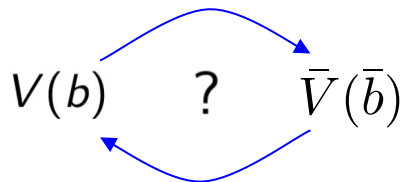
Full tree

Any subset

Data Association Aware Planning - Our Approach

In this work, we aim to approximate the solution for the original POMDP, using the simplified version of that POMDP.

$$\mathcal{M} \longrightarrow \bar{\mathcal{M}}$$

Then, we derive a mathematical relationship to bridge the gap between the full hypothesis tree and a simplified tree

$$V(b) \quad ? \quad \bar{V}(\bar{b})$$

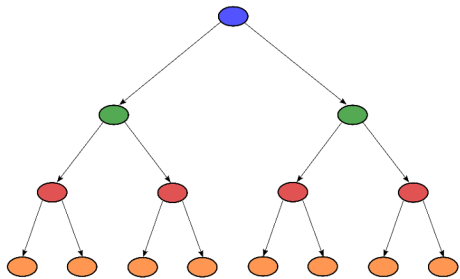# Data Association Aware Planning - Our Contribution

Derived a deterministic bound to relate the full set of hypotheses to a subset thereof,
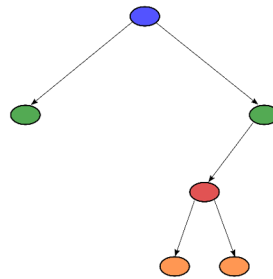
Corollary

For any policy π, and selection of hypotheses set $\{\beta_{0:\mathcal{T}}^i\}_{i=0}^{|\mathcal{B}|}$ the following holds,

$$\left| V^\pi(b_0) - \bar{V}^\pi(\bar{b}_0) \right| \leq \mathcal{R}_{max} \left[\mathcal{T}\delta_0^\beta + \sum_{k=1}^{\mathcal{T}} \sum_{\tau=1}^{k} \overline{\mathbb{E}}_{z_{1:\tau}} \left[\delta_\tau^\beta \right] \right].$$

Full tree   Any subset

Importantly, the bound relies on the available hypotheses
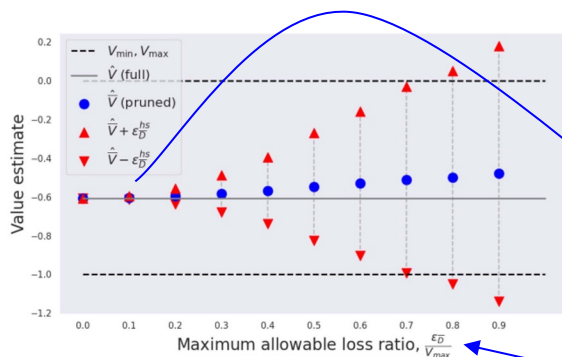
Can bound the theoretical value with access only to the simplified tree
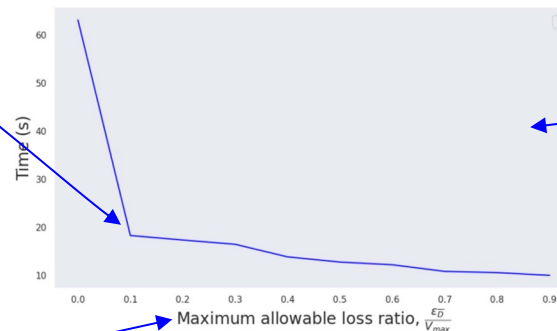
Data Association Aware Planning - Results

We derive an algorithm that uses the bound to select a subset of the hypotheses.

Increasing the allowable loss,
Leads to reduction in the planning time

Value estimation

Planning time

Tunable loss limit (hyperparameter)

Data Association Aware Planning - Conclusion

To conclude,

- Ambiguous DA is a result of an unknown observation source

- Finding a value function for a POMDP with ambiguous DA is computationally infeasible

- Instead, we suggest to compute only a subset of the hypotheses and derive deterministic bounds relative to the theoretical POMDP

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