Data Association Aware Belief Space Planning (DA-BSP)

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In planning under uncertainty, when data association is incorporated within plan-infer framework of belief space planning (BSP), it results in a more general form of BSP capable of dealing with non-Gaussian beliefs, and perceptual aliasing; providing a framework for robust active perception and active disambiguation that avoids catastrophic failures.

**Data association in BSP**

*State of the art:* Considers data association within BSP as given and perfect, typically through maximum likelihood assumption.

*How to incorporate data association?*

- **Maximum likelihood:** assumes association corresponding to planner’s nominal position is the correct one (e.g. [1], [2])
- **Passive robust inference:** models association within passive inference via binary latent variables (e.g. [3])
- **Non-parametric inference:** infers passively based on available data (e.g. [4])
- **Multiple hypothesis tracking:** framing it as an MHT problem (e.g. [5])

*Why care about data-association?*

- Data association may be ambiguous due to perceptual aliasing
- Incorrect data association may lead to catastrophic failures

**Experimental results**

*Abstract example*

**Figure:** DA-BSP for a single observation $x_{i+1,}\text{while the true pose that generated } x_{i+1}\text{ is shown by inverted triangle. Smaller ellipses are the posterior beliefs } \pi[X_{i+1}^j|A_i]. \text{Top row } x_i\text{ is near center, observing } A_1; \text{bottom row } x_i\text{ is on the left, observing } A_2. \text{Columns represent different perceptual aliasing cases. Weights } w_i\text{, corresponding to each scene } A_i\text{, shown in inset bar-graphs.}*

**Table:** Evaluating DA-BSP

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<th>A2</th>
<th>A3</th>
<th>B1</th>
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</table>

**Comparison with state of the art**

Real-world

Figure: Using Pioneer robot in simulation and real-world. (a) a counter-example for hypothesis reduction in absence of pose-uncertainty in prior (b) two (of three) severely-aliased floors, and belief space planning for it (c) DA-BSP can plan for fully disambiguating path (otherwise sub-optimal) while usual BSP with maximum likelihood assumption can not.

To wrap up

- Data association was incorporated within belief space planning (DA-BSP)
- DA-BSP is more general form of plan-infer framework of BSP
- Other approaches are degenerate cases of it
- Affects active disambiguation in a formal framework
- Is a crucial step towards realistic long term planning & autonomy
- Parsimonious data association

Not all possible associations have significant weights

More effective strategies of pruning are currently explored.

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**References**


Active visual SLAM for robotic area coverage: Theory and experiment.


Planning in the continuous domain: A generalized belief space approach for autonomous navigation in unknown environments.


Towards robust back-end for pose graph slam.


Inference on network of mixtures for robust robot mapping.


Motion planning in non-gaussian belief spaces for mobile robots.