TECHNION
Israel Institute of Technology

iX-BSP: Belief Space Planning through Incremental Expectation

Elad I. Farhi & Vadim Indelman

ANPL | Autonomous Navigation and Perception Lab
TASP | TECHNION AUTONOMOUS SYSTEMS PROGRAM

Introduction

- We denote the full unapproximated solution of BSP problem as X-BSP

$$J(u) \doteq \mathbb{E}_z\left[\sum_{i=k+1}^{k+L} c_i\left(b[X_{i|k}], u_{i-1|k}\right)\right]$$

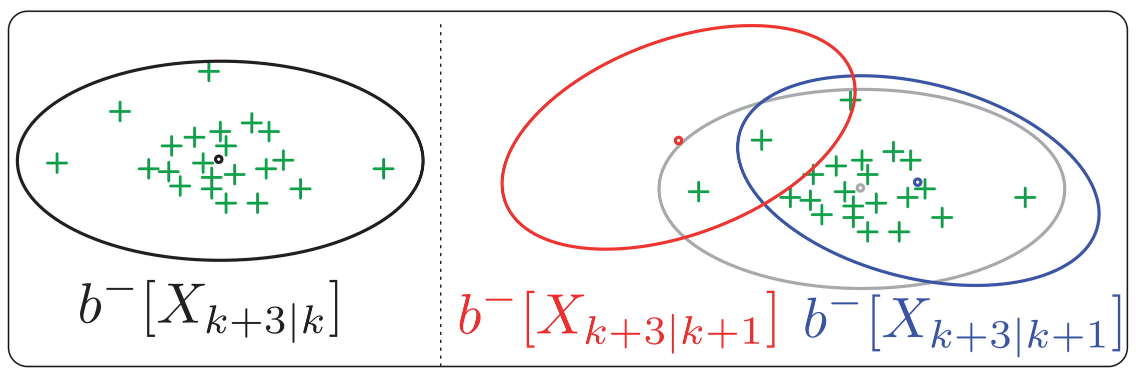
- The ML approximation for X-BSP is denoted by ML-BSP
- Calculation re-use in BSP has only been done over ML-BSP with restricting assumptions

Problem Statement

- Planning at time k - executed
- Optimal action chosen - $u^{\star}_{k:k+L-1|k}$
- $u^{\star}_{k:k+l-1|k} \in u^{\star}_{k:k+L-1|k}$ executed
- Acquired measurements $z_{k+1:k+l|k+l}$
- Next planning is with respect to future measurements $z_{k+l+1:k+l+L|k+l}$
- Existing approaches perform these costly calculations from scratch
- **Our goal** - develop approach for re-using calculations from precursory planning sessions
- Assumptions:
  - Precursory planning calculations are accessible
  - Horizon overlap, i.e. $l \in [1, L)$
  - $u^{\star}_{k+l:k+L-1|k}$ partially resides in the set of candidate actions for planning time k+l

Key Observation

- Two successive X-BSP sessions from times k and k+l are similar
- Calculations in planning time k can be re-used for planning time k+l
- By re-using samples we can avert from costly calculations at time k+l



(a) Belief distance affecting sample re-use

Approach

- Consider the objective calculations from planning time k $\forall u \in \mathcal{U}_k$

$$J(u) \approx \frac{1}{n}\sum_{\{z_{k+1|k}\}_1^n}\left[w^i_{k+1|k}\cdot c_{k+1|k} + \cdots\right] \quad (1)$$

- and the desired objective for planning time k+l $\forall u' \in \mathcal{U}_{k+l}$

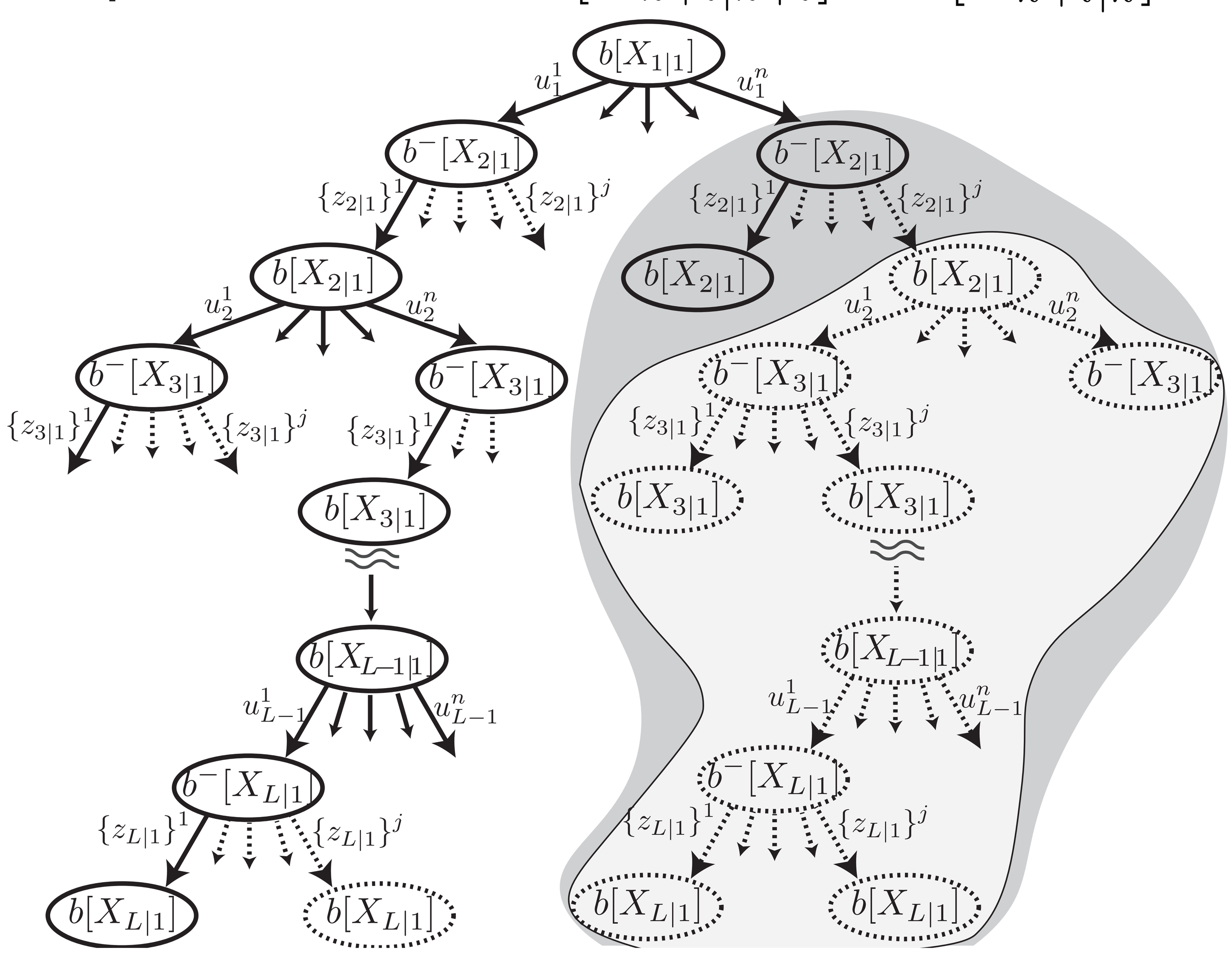
$$J(u') \approx \frac{1}{n}\sum_{\{z_{k+l+1|k+l}\}_1^n}\left[w^j_{k+l+1|k+l}\cdot c_{k+l+1|k+l}\cdots\right] \quad (2)$$

- Measurements from horizons k+l+1 to k+L are sampled from similar distributions

$$(3)\ \mathbb{P}\left(z_{k+l+1|k}|H^{-}_{k+l+1|k}\right)$$

$$(4)\ \mathbb{P}\left(z_{k+l+1|k+l}|H^{-}_{k+l+1|k+l}\right)$$

- Assuming (1) has been sampled from original distribution, e.g. (3), we get $w^j_{i|k} \doteq 1 \quad \forall i,j$
- Denote belief $b[X_{k+l|k}]$ closest to the posterior belief $b[X_{k+l|k+l}]$ as $\tilde{b}[X_{k+l|k}]$



(b) Selecting beliefs for re-use

- All beliefs from planning time k rooted in $\tilde{b}[X_{k+l|k}]$ are considered for re-use in planning time k+l
- We assume all samples can be re-used, will be relaxed in future work
- Incrementally update all candidate beliefs with actual information received up-to time k+l (Farhi17icra)
- Since samples are re-used rather than freshly sampled, the jth weight at the ith horizon step is given by

$$w^j_{i|k} = \frac{\mathbb{P}\left(z^j_{i|k}|H^{-}_{i|k+l}\right)}{\mathbb{P}\left(z^j_{i|k}|H^{-}_{i|k}\right)} \quad \forall i,j$$

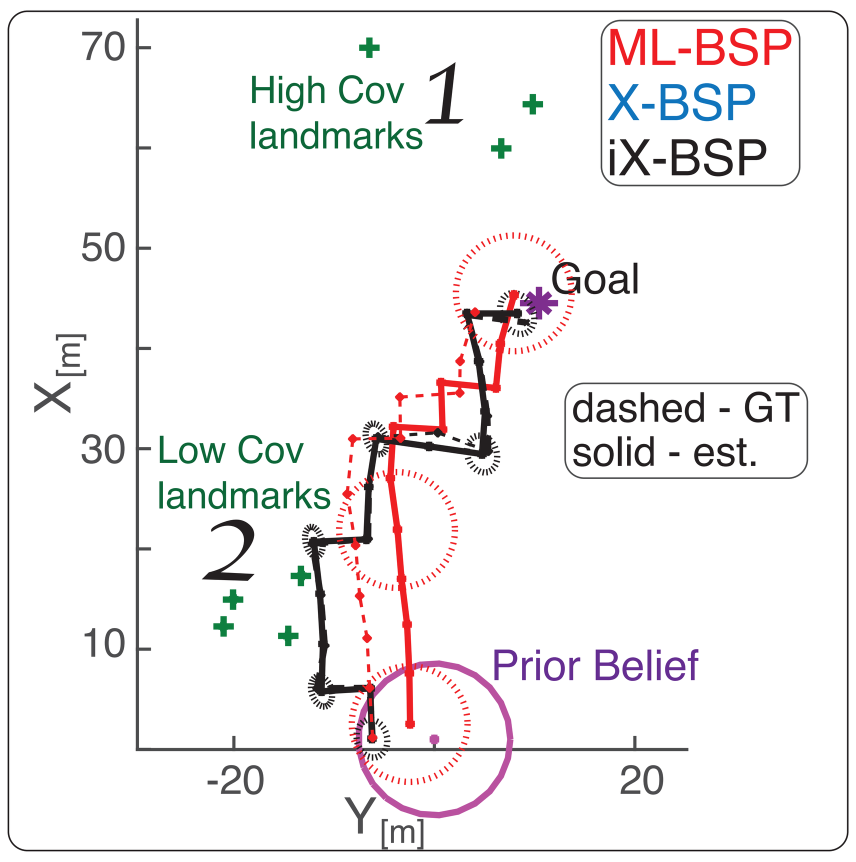
- Since (3) nor (4) can be directly calculated we use

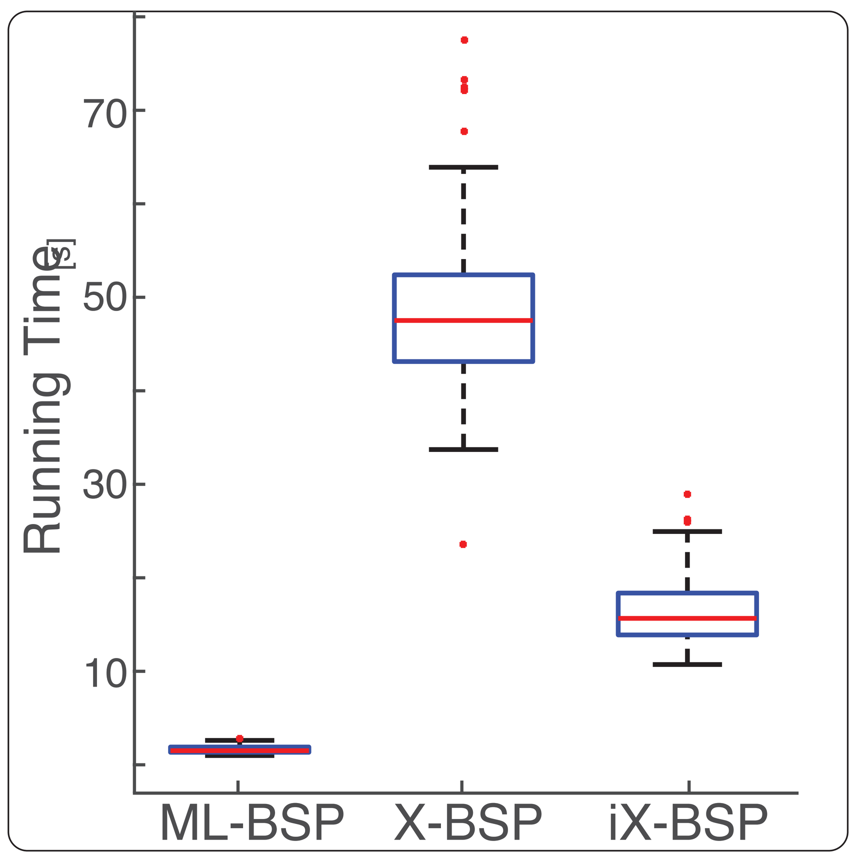
$$\mathbb{P}\left(z_{i|k}|H^{-}_{i|k}\right) \approx \frac{1}{n}\sum_{X_i}\mathbb{P}\left(z_{i|k}|X_i\right)\mathbb{P}\left(X_i|H^{-}_{i|k}\right)$$

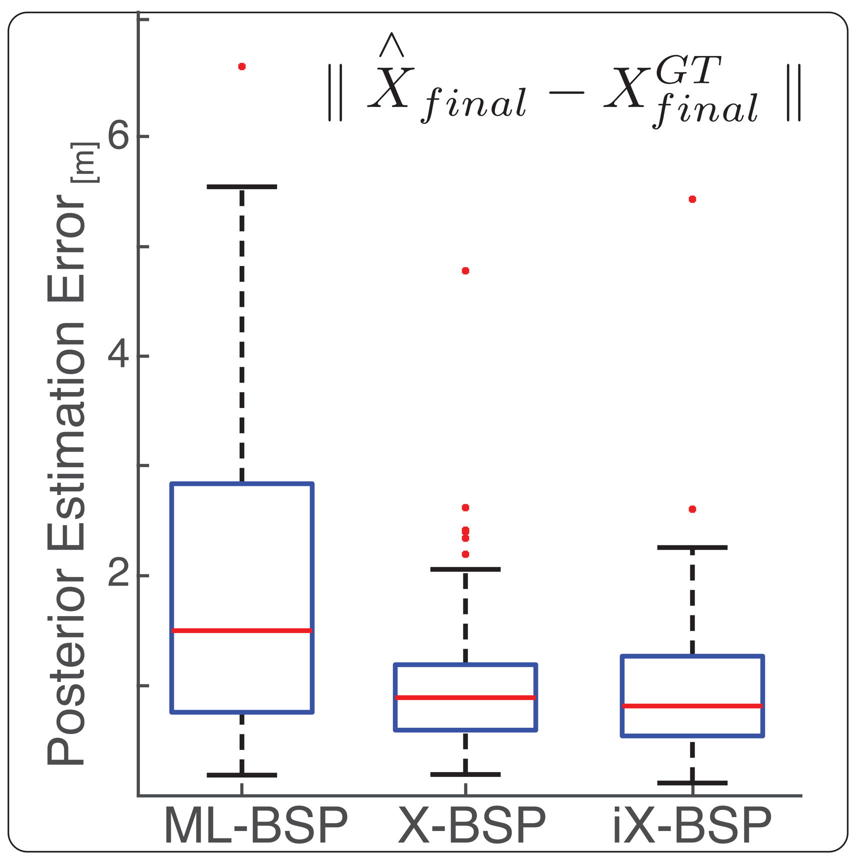
- We complete the rest of the horizon (k+L+1:k+L+l) with X-BSP
- With solved beliefs and updated weights we can now solve (4) $\forall u' \in \mathcal{U}_{k+l}$

Results

- We performed 100 rollouts, each with a different sampled ground-truth for prior state. Map illustrates a single rollout.







Conclusions

- BSP using expectation can be efficiently updated using a precursory planning session, presenting iX-BSP
- iX-BSP provides the same statistical accuracy as X-BSP for a reduced computational effort
- Since iX-BSP alters the solution approach of the original, un-approximated, problem (X-BSP), we believe it can also be utilized for existing approximations of X-BSP

References

- E. I. Farhi and V. Indelman, "Towards efficient inference update through planning via jip - joint inference and belief space planning," in IEEE Intl. Conf. on Robotics and Automation (ICRA), 2017

ICRA 2019