Tear Down that Wall: Calculations Reuse Across Inference and Belief Space Planning

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Introduction

- We denote the iSAM2 efficient inference methodologies as iSAM

$$b[X_{k|k}] \propto p(X_0)\cdot\prod_{i=1}^{k}\left[p(x_i|x_{i-1},u_{i-1|k})\prod_{j\in\mathcal{M}_{i|k}} p\left(z^j_{i|k}|x_i,l_j\right)\right]$$

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

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

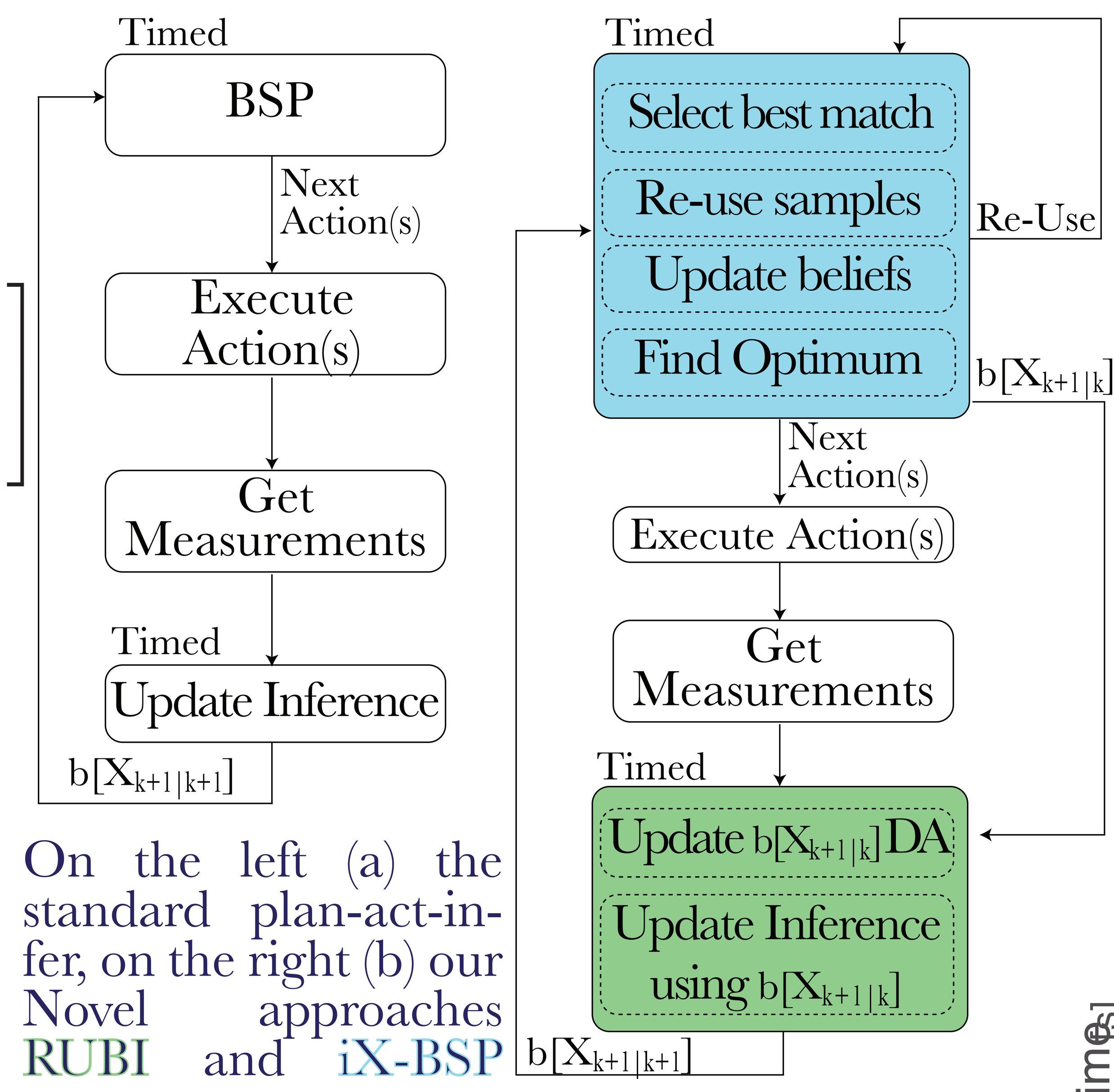
- The ML approximation for X-BSP is denoted by ML-BSP
- Despite recent research efforts, inference and BSP are still being treated as two separate processes
- Calculation re-use in BSP has only been done over ML-BSP with restricting assumptions

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 $z_{k+1:k+l|k+l}$
- Inference performed by updating precursory inference with executed action and the new measurements
- Next planning is with respect to future measurements $z_{k+l+1:k+l+L|k+l}$
- **Our 1st goal** - develop approach for updating inference using calculations from precursory planning
- **Our 2nd 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

- Inference and BSP share similar calculations
- Calculations from BSP can be re-used in the succeeding inference
- 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



On the left (a) the standard plan-act-infer, on the right (b) our Novel approaches RUBI and iX-BSP

Approach

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

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

- Denote the belief $b[X_{k+l|k}]$ containing the chosen action and closest to the measurements obtained in present time k+l as $\tilde{b}[X_{k+l|k}]$
- Calculate $b[X_{k+l|k+l}]$ by incrementally updating $\tilde{b}[X_{k+l|k}]$ with new measurements $z_{k+1:k+l|k+l}$ - RUBI
- Denote 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 $w^j_{i|k} \doteq 1 \quad \forall i,j$
- 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 - RUBI
- Since samples are re-used rather than freshly sampled, the j[th] weight at the i[th] horizon step is given by

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

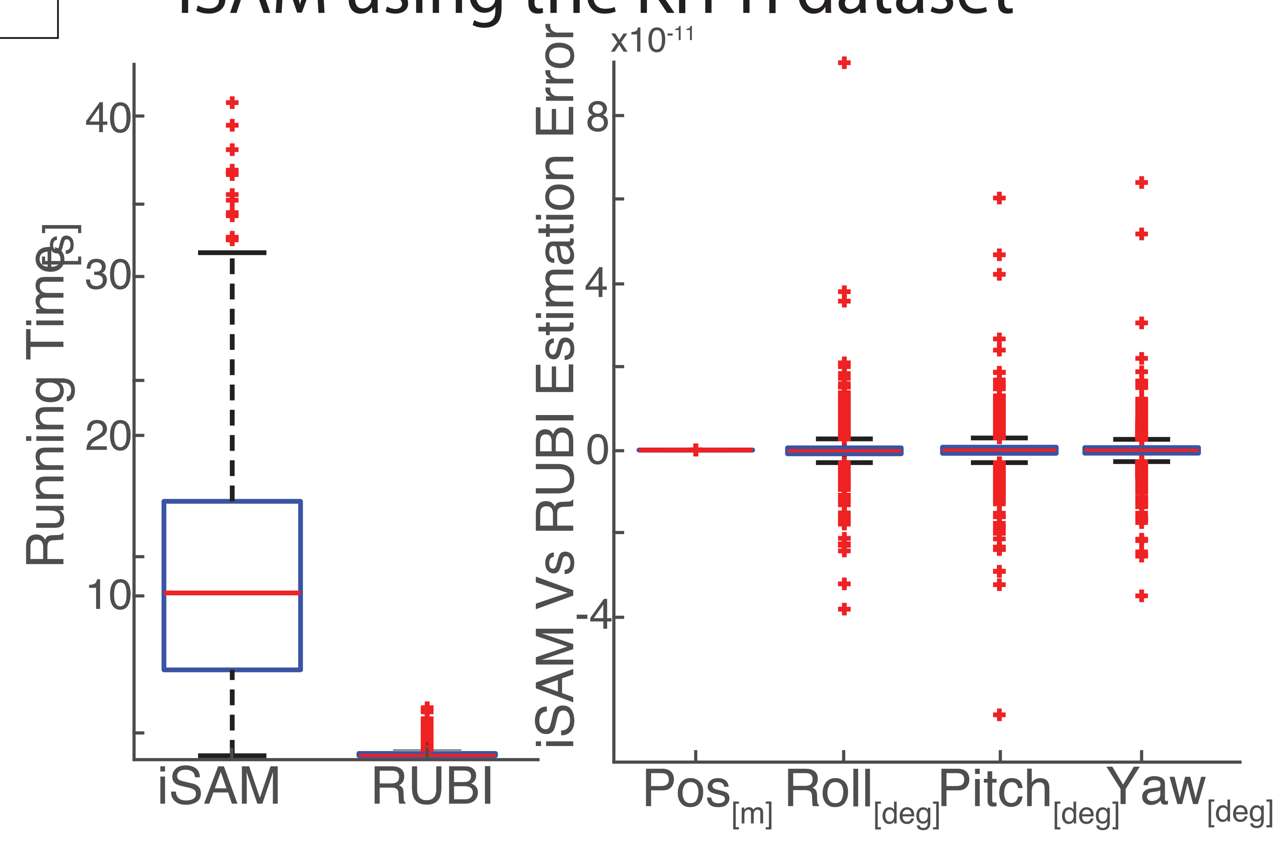
- Since (3) nor (4) can be directly calculated we use

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

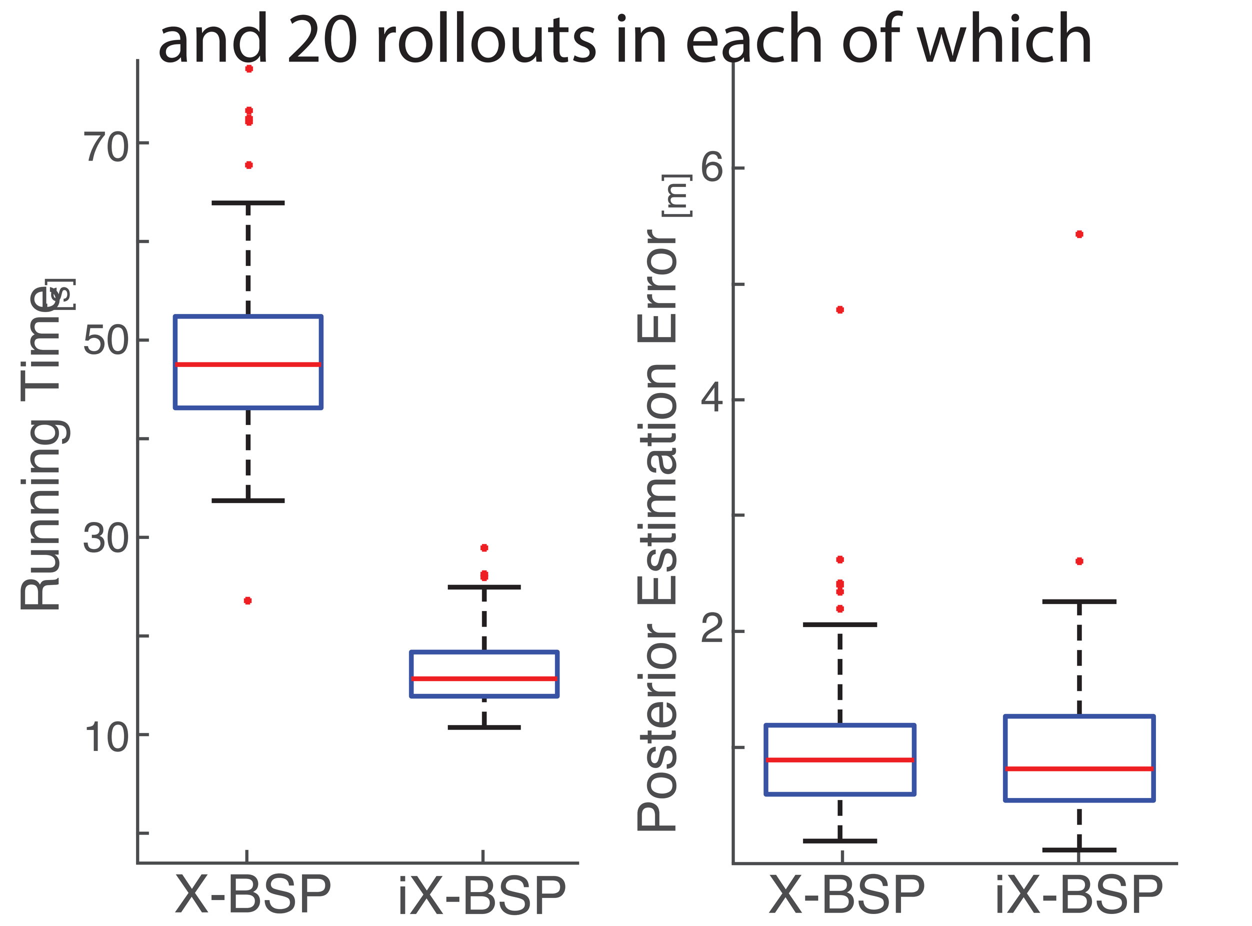
- We complete the rest of the horizon (k+L+1:k+L+l) with X-BSP
- With solved beliefs and updated weights we can now solve (4) $\forall u' \in \mathcal{U}_{k+l}$ thus selecting $u^\star_{k+l:k+L+l-1|k+l}$ - iX-BSP

Results

- We compared RUB-Inference to iSAM using the KITTI dataset



- We compared X-BSP to iX-BSP in Simulation using 10 different maps and 20 rollouts in each of which



Conclusions

- Efficient inference update is viable using calculations from planning, presenting RUBI
- BSP using expectation can be efficiently updated using a precursory planning session, presenting iX-BSP
- RUBI provides the same accuracy for a reduced computational effort
- 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), it can also be used on X-BSP approximations

References

- E. I. Farhi and V. Indelman, "Towards efficient inference update through planning via jip - joint inference and belief space planning," in IEEE ICRA, 2017
- E. I. Farhi and V. Indelman, "iX-BSP: Belief Space Planning through Incremental Expectation," in IEEE ICRA, 2019

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