Assured Abstraction for Robotic Hierarchical Planning

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TC2: Secured Autonomy

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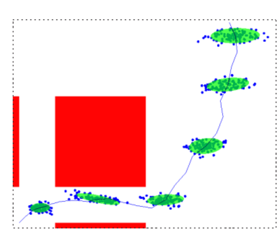
Motivation

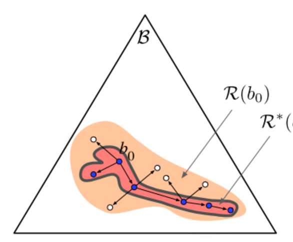
How to enable **real-time** robotic decision-making in **unknown**, **unstructured**, and **dynamic** environments?

Challenges

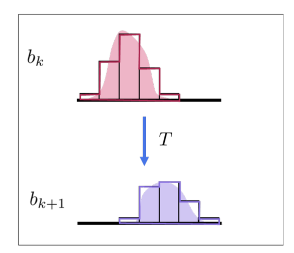
Model fidelity — Computation efficiency



Gaussian/GMM-based parameterization

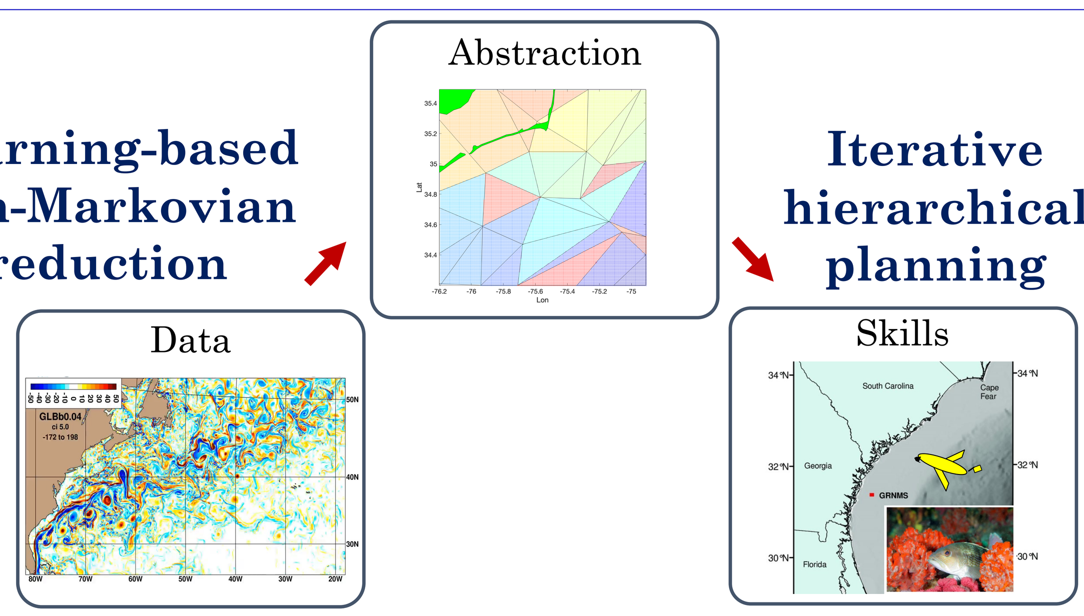


Randomized methods: MCTS, DESPOT, PBVI



Grid-based methods: Generalized Cell Mapping

Objectives



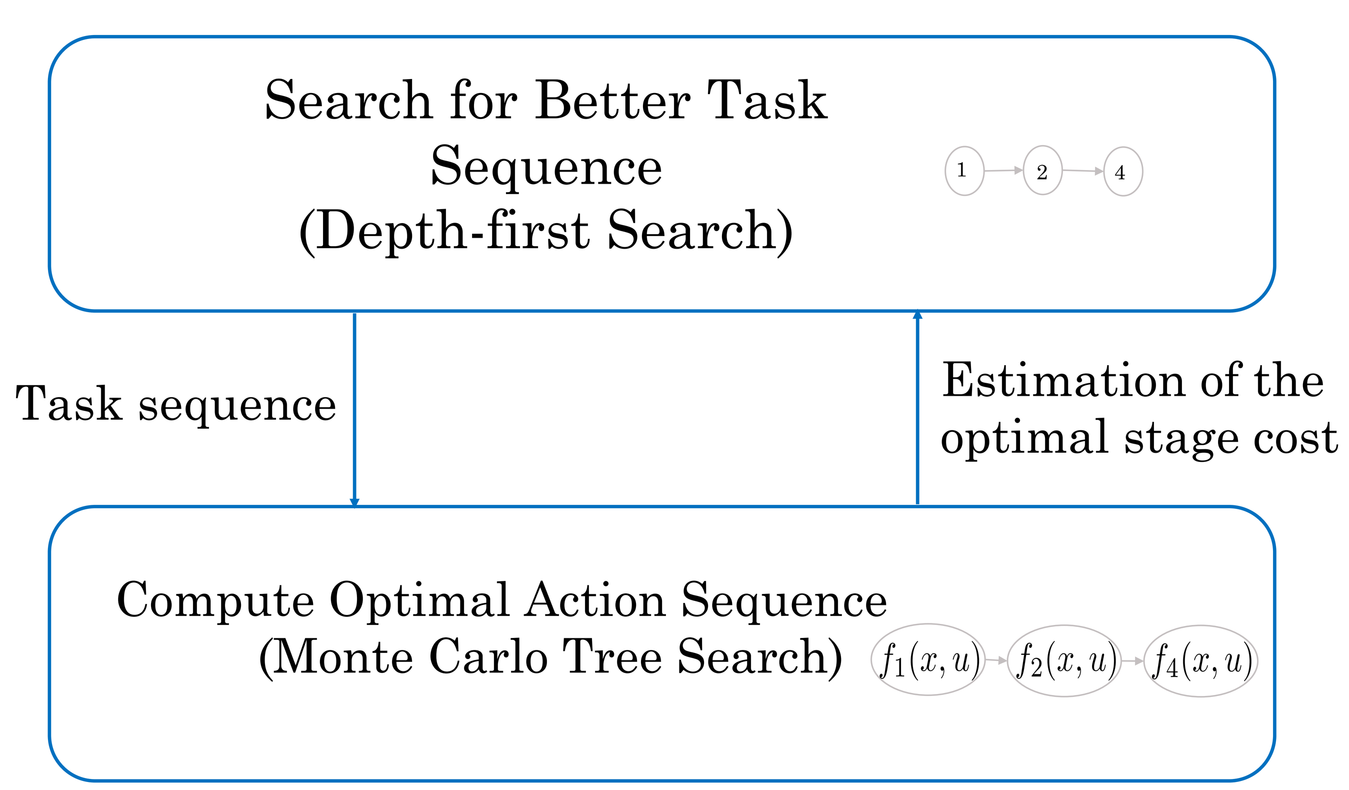
Learning-based non-Markovian reduction

Iterative hierarchical planning

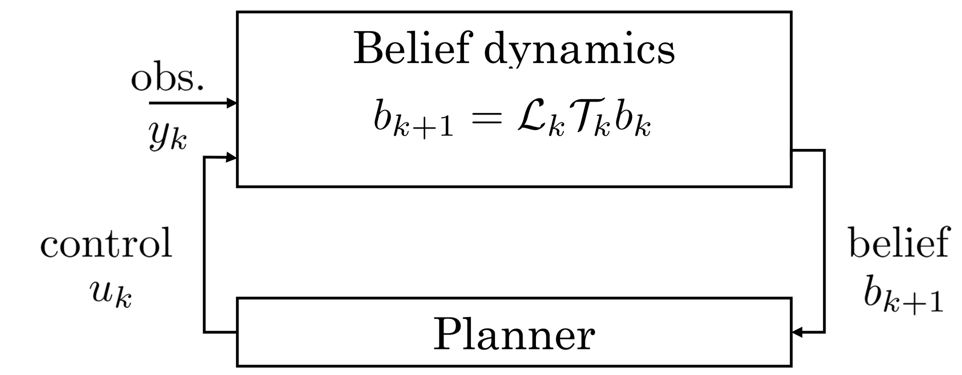
✔ **Assurance**

✔ **Scalability**

Iterative Hierarchical Planning



Mori-Zwanzig based Belief Abstraction

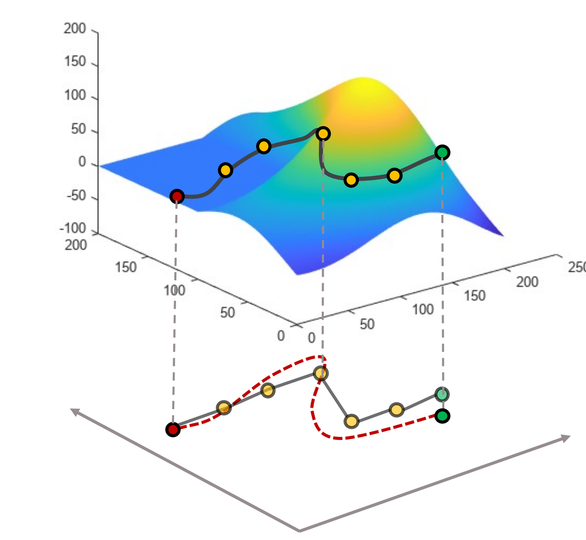


$\mathcal{T}: b_k \to \mathcal{T}b_k$, where $T(x, x') = \Pr(x_{k+1} = x | x_k = x', u_k)$, $\mathcal{L}: b_{k+1}^{(-)} \to \frac{\Psi_{k+1} b_{k+1}^{(-)}}{\langle \Psi_{k+1}, b_{k+1}^{(-)} \rangle}$, where $\Psi_{k+1} = p(y_{k+1}|x_{k+1})$

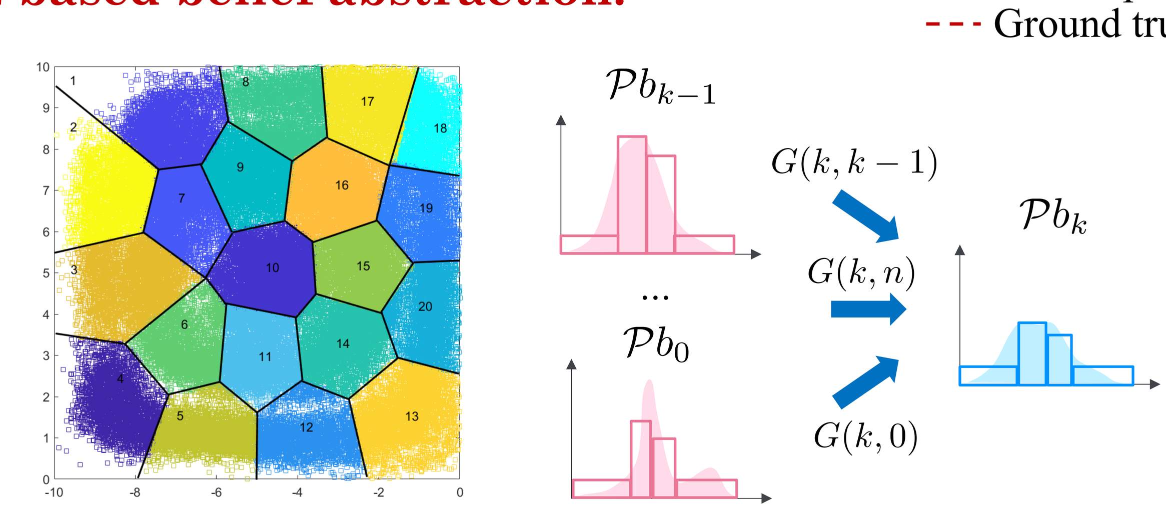
Data → Representation: derive a finite-rank approximation model of belief dynamics

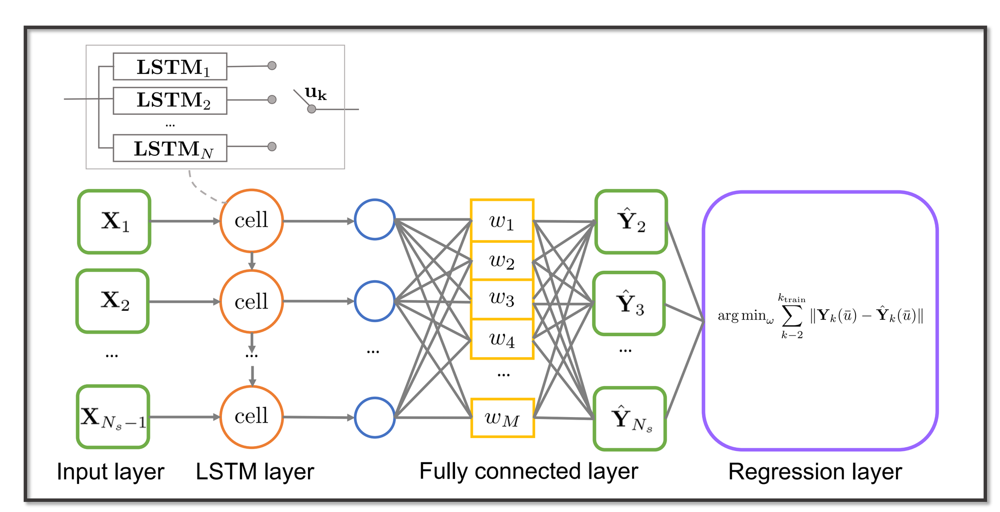
Representation → Skills: solve the belief space planning problem given the approximation model

Intuition: improve the fidelity of the reduced-order model by modeling the coupling between the error state and the reduced state



M-Z based belief abstraction:



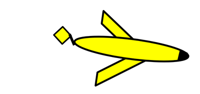


Algorithm overview:

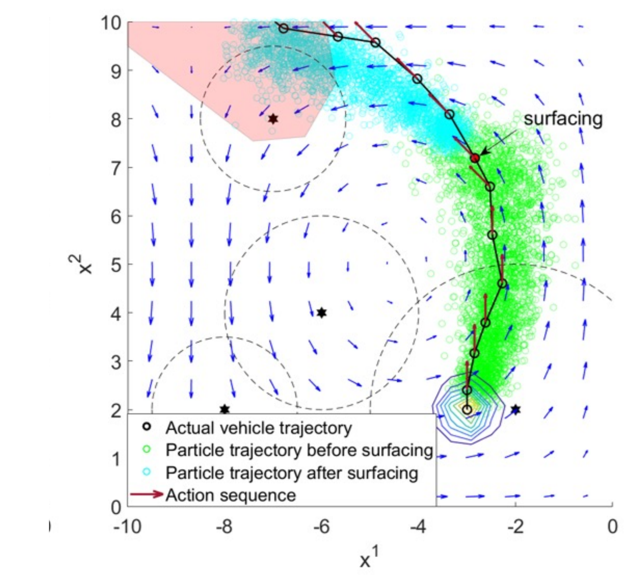
LSTM-based prediction → Approx. Bayesian update → Belief space symbolic planner → u_{k+1}

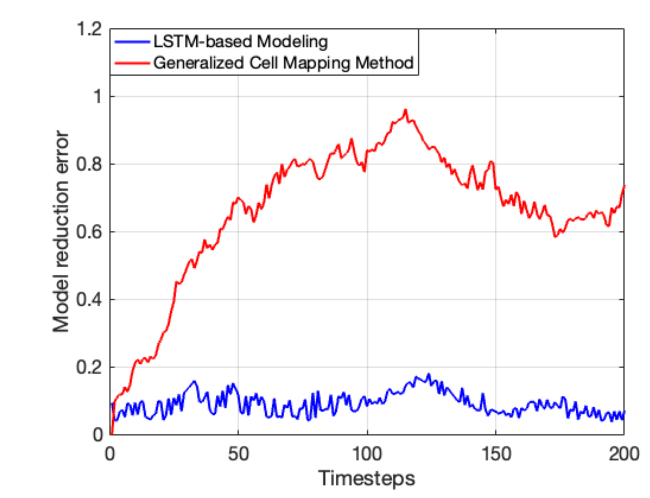
First work in applying the M-Z formalism to robotics application, where the memory kernel depends on robot action and observation.

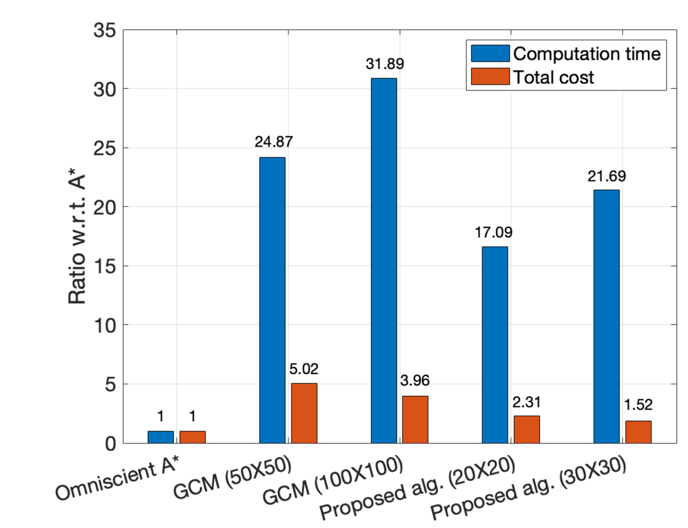
Simulation Results



System dynamics	Particle model under influence of nonlinear and uncertain flow field
Observation model	Binary detection model
Planning objective	Minimize travel time to reach target set with high probability



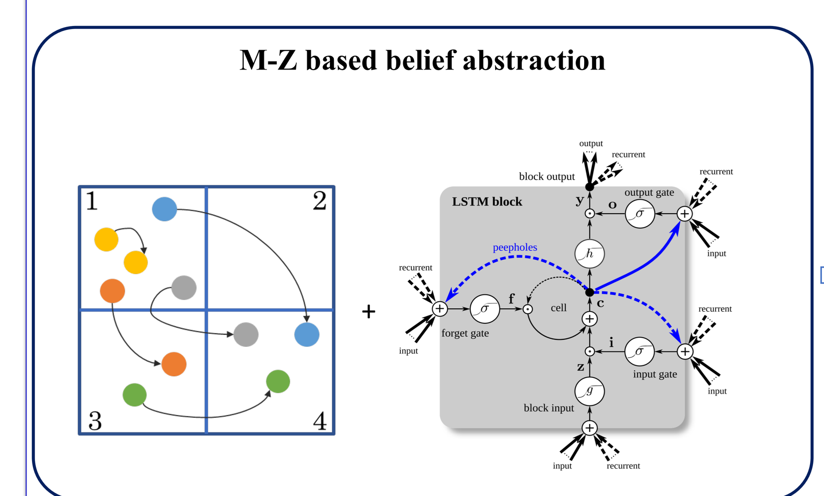


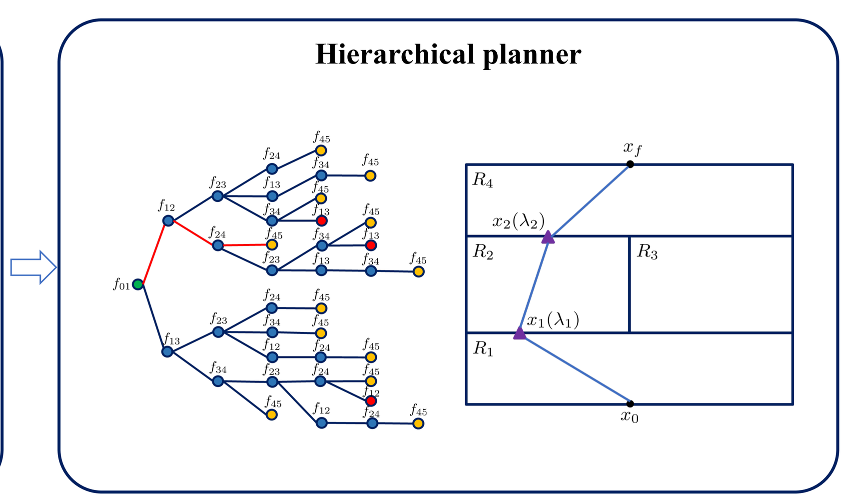


Simulation comparison between generalized cell mapping and the proposed method.

Conclusion

Q: how to enable **real-time** robotic decision-making in **unstructured and unknown environments**?





References

Mengxue Hou, Yingke Li, Fumin Zhang, Shreyas Sundaram and Shaoshuai Mou, "An Interleaved Algorithm for Integration of Robotic Task and Motion Planning", in 2023 American Control Conference (ACC), in press.

Mengxue Hou, Tony Lin, Enlu Zhou, Fumin Zhang, "Mori-Zwanzig Approach for Belief Abstraction with Application to Belief Space Planning", in preparation to submission.

Acknowledgement

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