NRI: FND: Life-long Learning for Motion Planning in Human Populated Environments

University of Colorado Boulder

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Featuring work by PhD Students:
Himanshu Gupta
Kyle Harlow
& Mike Miles

Overview

Scaling up belief-space planning for social navigation

- **Online Intention-Aware Planning for Social Navigation with POMDPs**

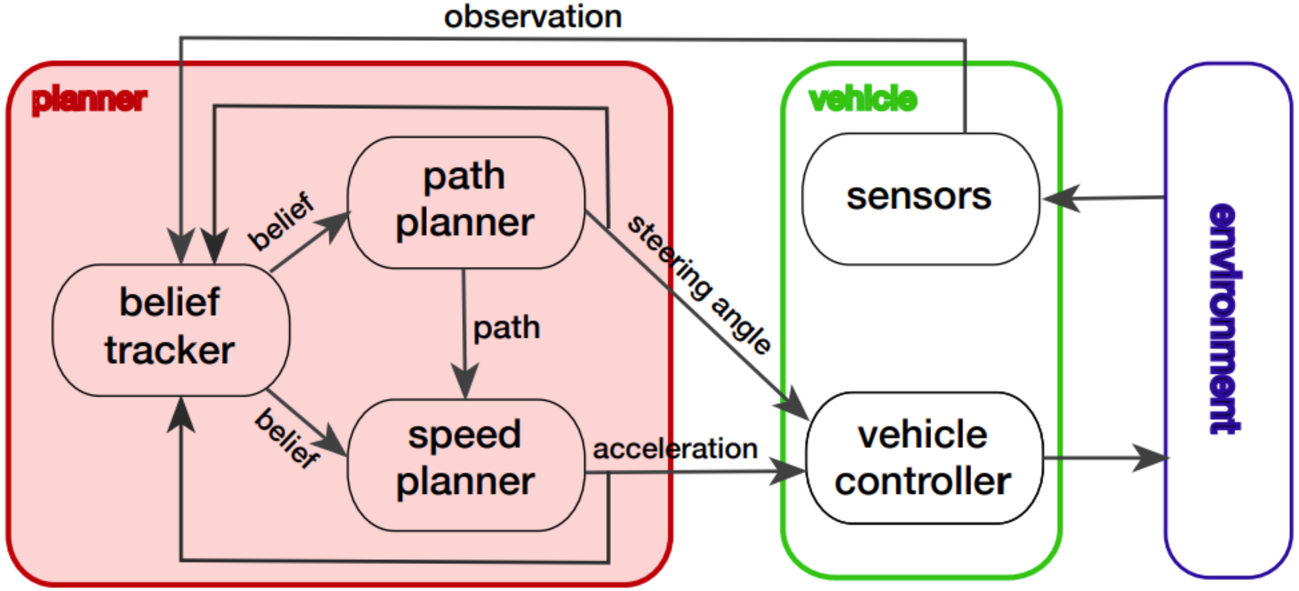
Improving robots' notions of where they can go

- Augmenting Motion Planning with Traversability Estimation

Intention-Aware Navigation in Crowds with Extended-Space POMDP Planning

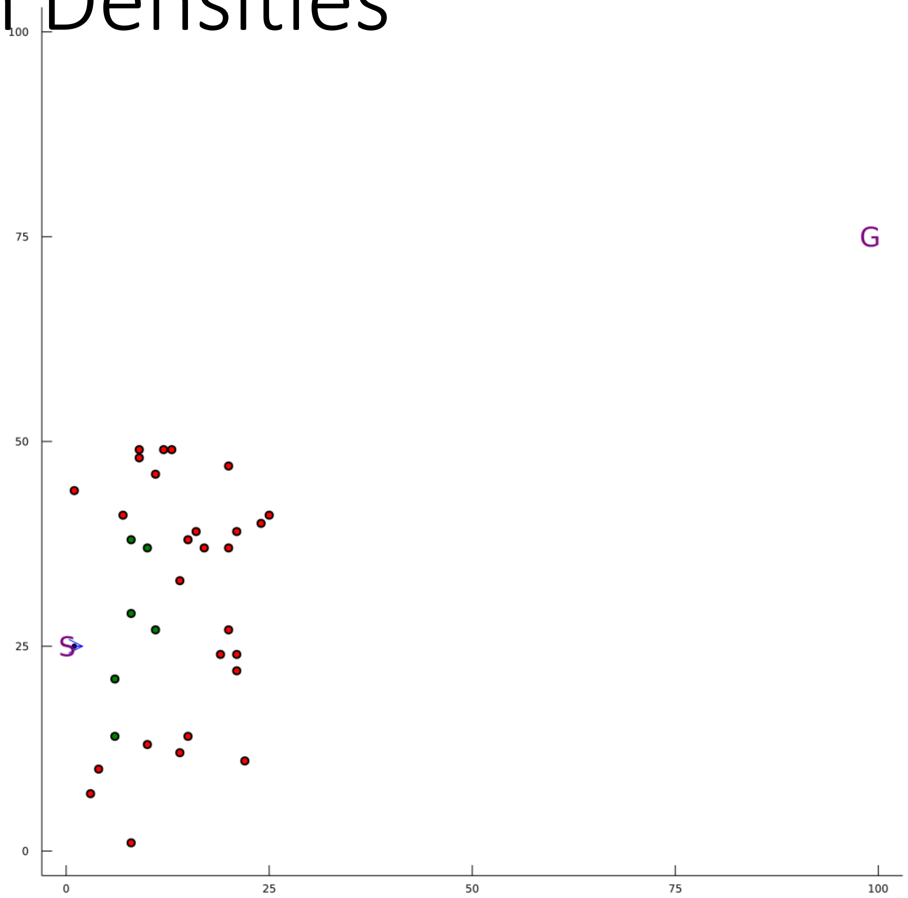
To Appear: AAMAS 2022

Planning for Social Navigation

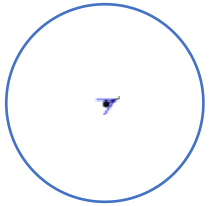


Intention-Aware Online POMDP Planning for Autonomous Driving in a Crowd. Bai et al. (2015)

Decoupling Path from Speed Raises Issues at High Densities



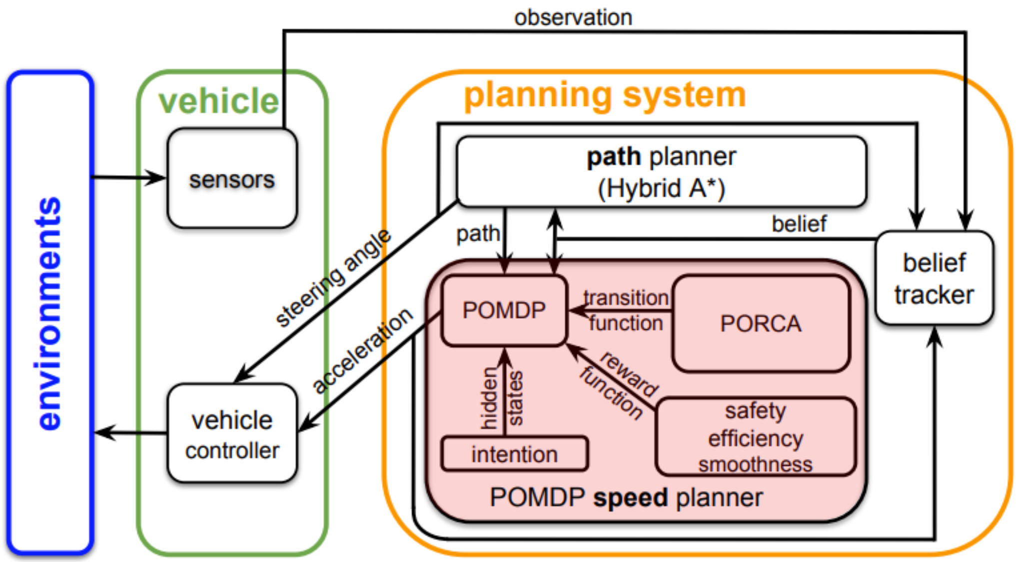
Path: Hybrid A* finds a collision-free path-to-goal considering *n* identified pedestrians within a sensing radius.



Speed: POMDP planner solves for speed along the path by reasoning over pedestrian intentions.

Outcome: Frequent stopping behavior along the path, unable to perform small adjustments to avoid nearby pedestrians.

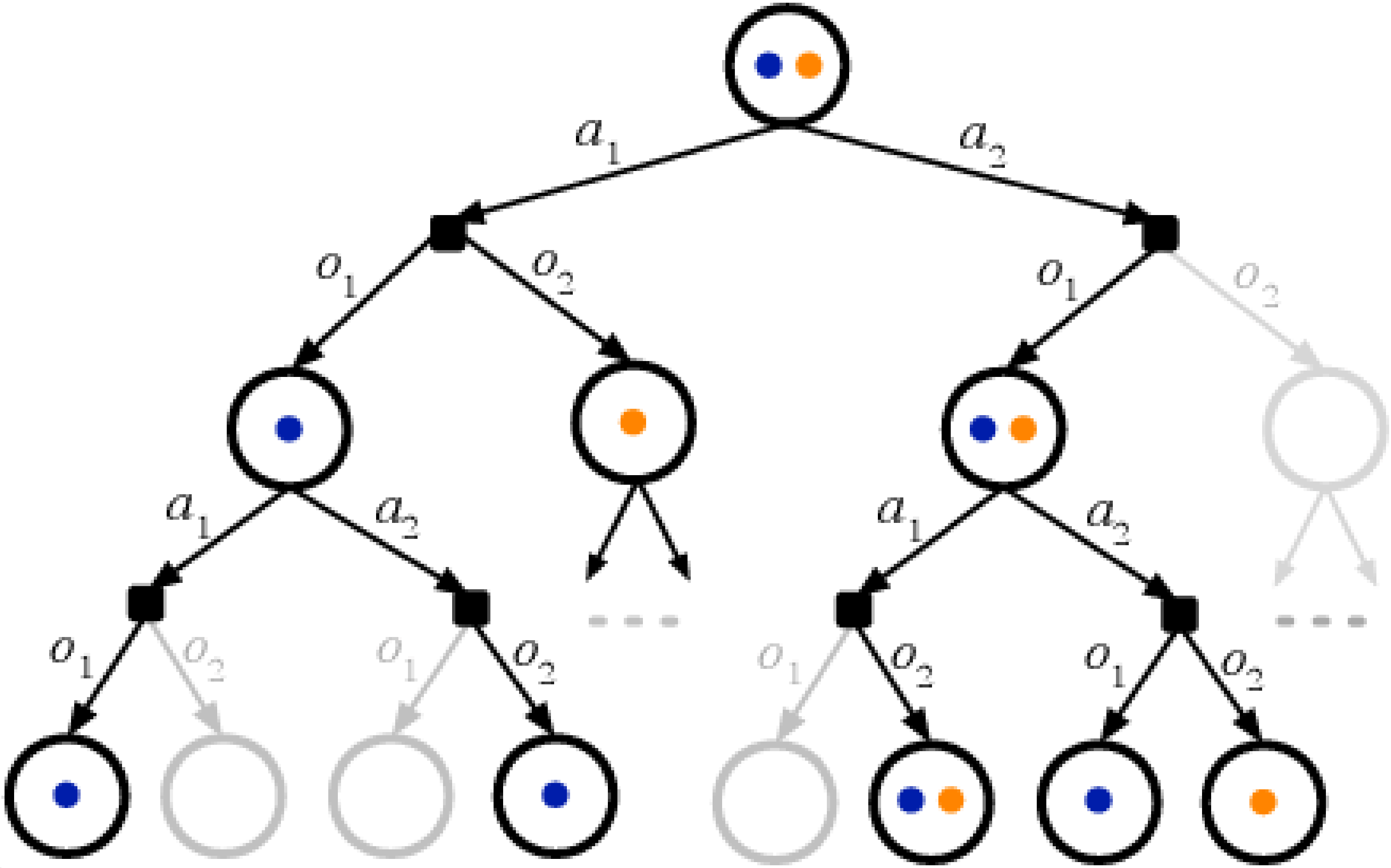
Planning for Social Navigation



PORCA: Modeling and Planning for Autonomous Driving among Many Pedestrians
Luo et al. (2018)

Combating Shallow Tree Depth with Better Priors

- Increased POMDP complexity decreases the effectiveness of the DESPOT solver
- To accommodate this tradeoff, we use a strong roll-out policy, informed by a multi-query planning algorithm (e.g., Probabilistic Road Mapping).
- This roll-out policy is used as a heuristic to guide the POMDP solution, but is not actually executed: the POMDP is solved rapidly enough to avoid executing beyond its search depth.



Extended-Space POMDP Planning

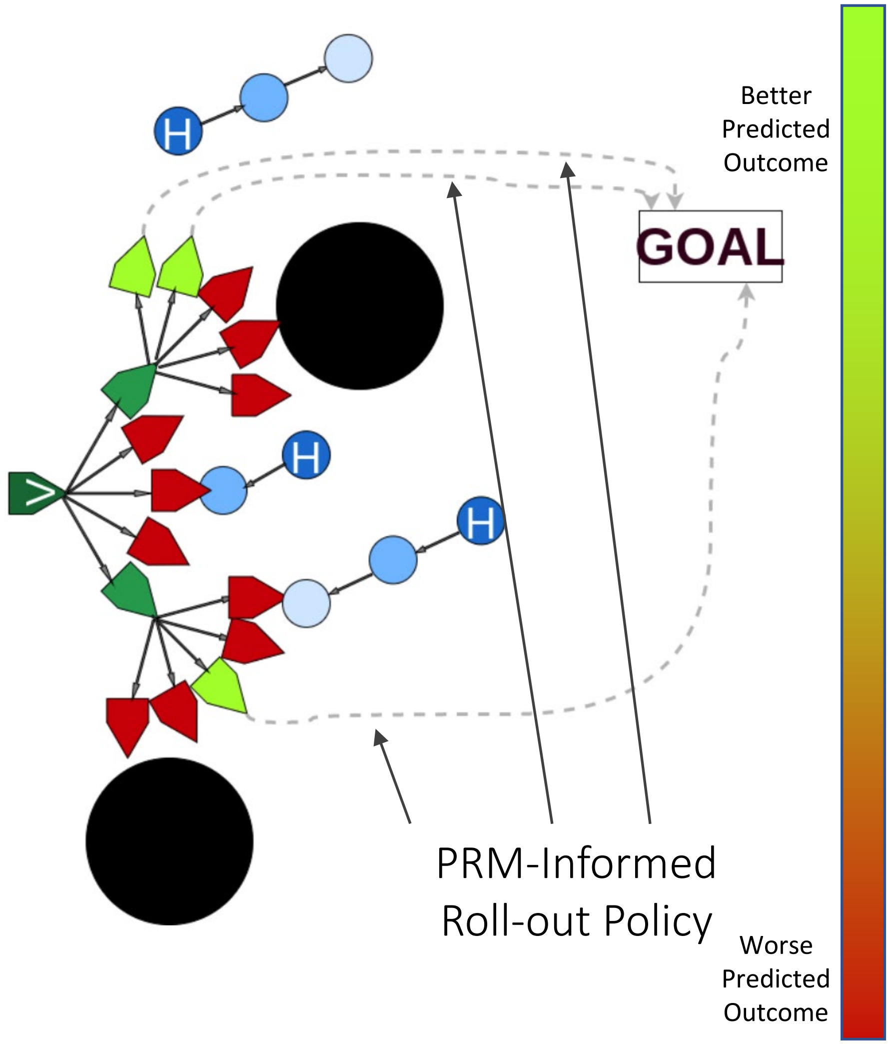
State Space: $[x_c, y_c, \theta_c, v_c, g_c]$ corresponding to 2D pose, speed, and goal of our vehicle.

$[x_i, y_i, v_i, g_i]$ corresponding to 2D pose, speed, and goal of the i^{th} pedestrian.

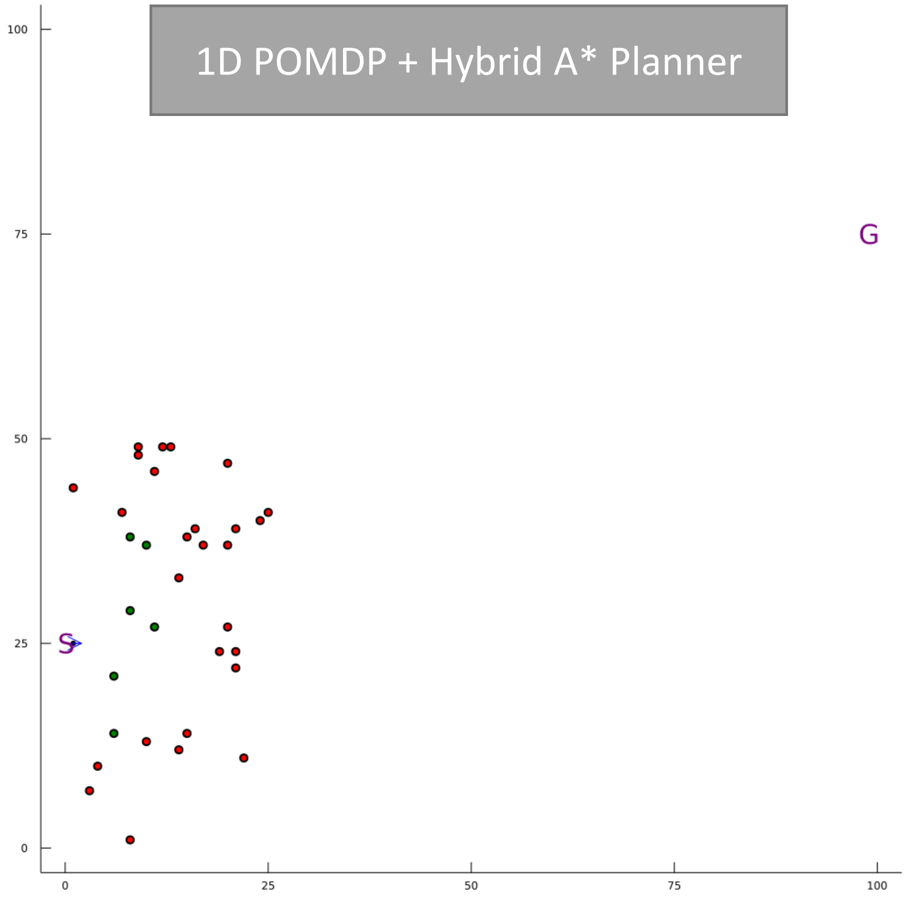
Action Space: $[\delta_\theta, \delta_v]$* corresponding to changes in orientation and speed.

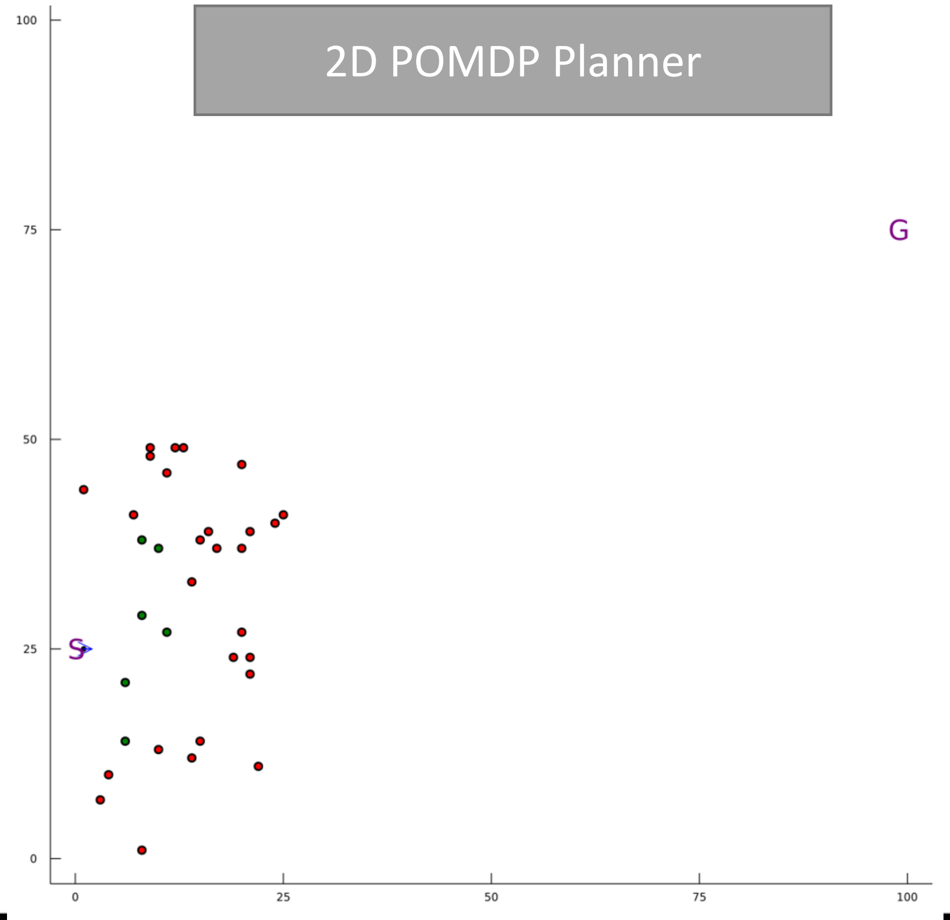
SB, or "Sudden Brake", which corresponds to a full-brake e-Stop

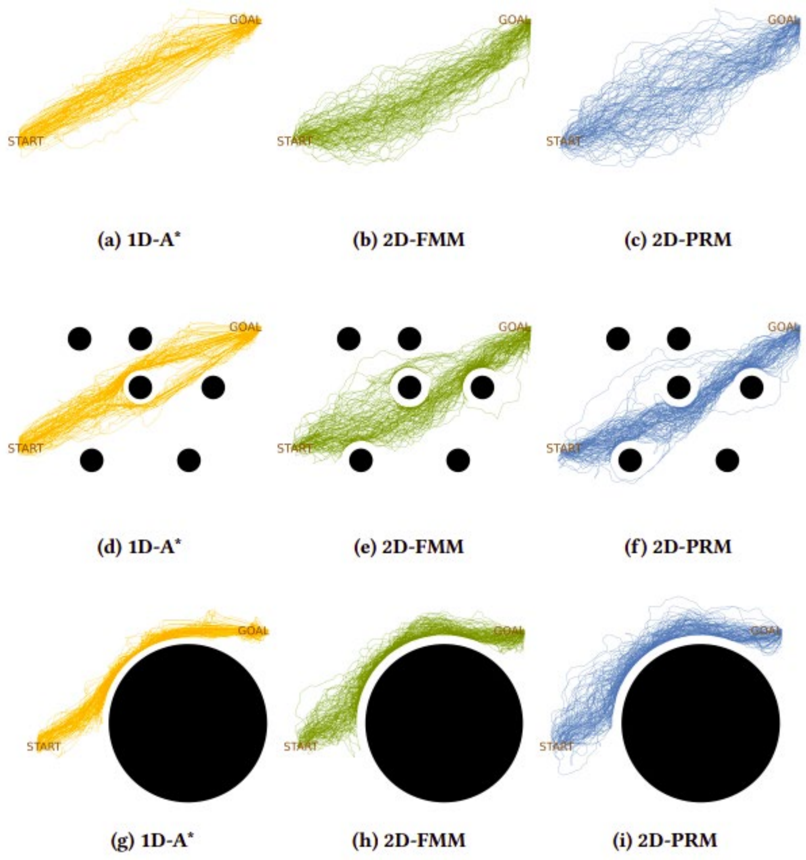
*Discretized to 11 different actions



Result: Faster Navigation with Fewer Near-misses!

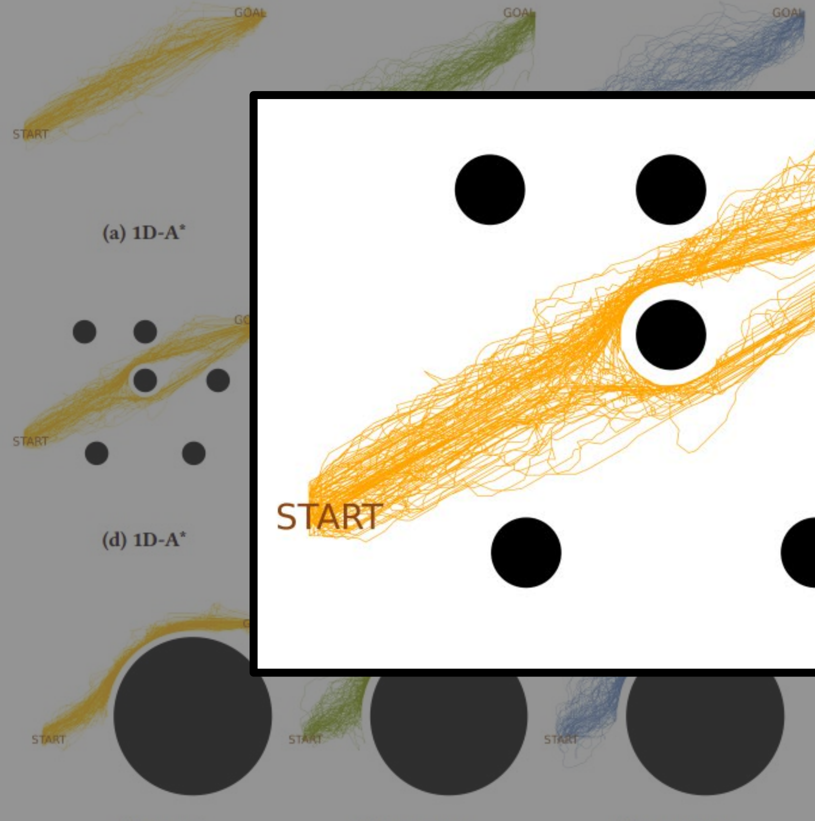


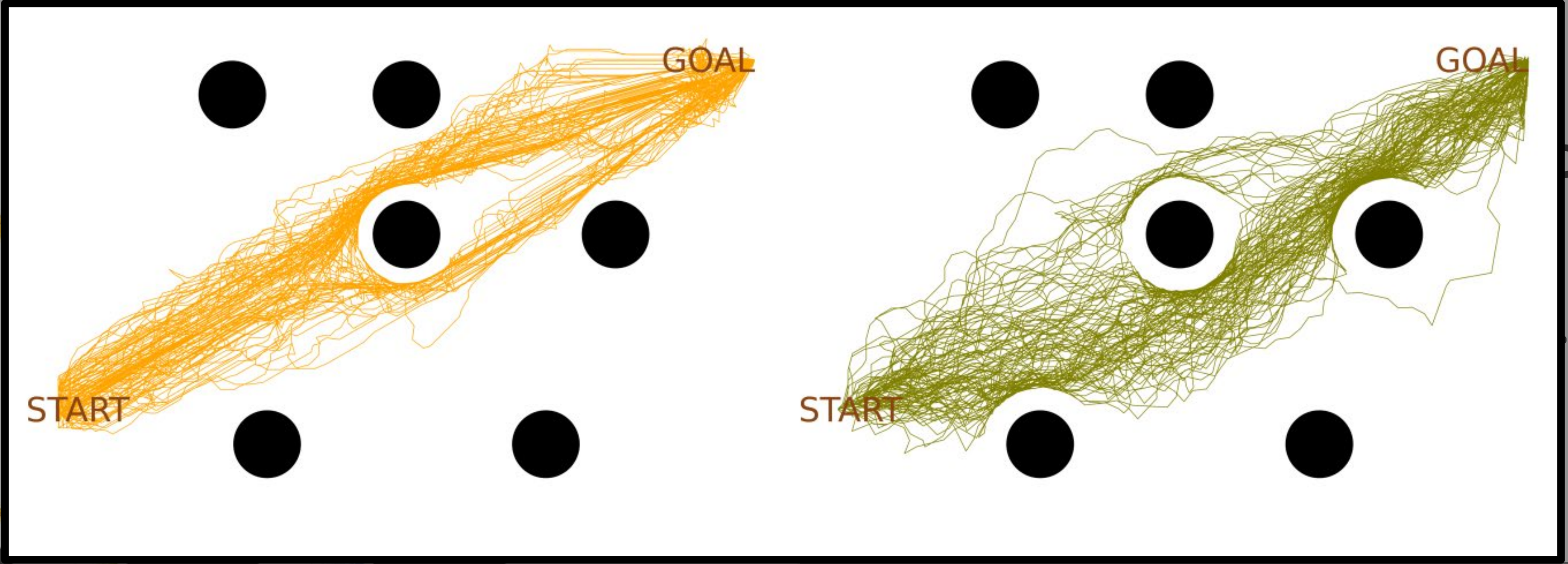




Extended Space POMDP Planning significantly outperforms approaches with decoupled reasoning over uncertainty

	*1D-A**		*2D-NHV*		
#Ped	Time (in s)	# SB action	Time (in s)	# Outperformed	# SB action
100	53.62 ± 0.91	1.84 ± 0.11	**36.54 ± 0.45**	98	**0.26 ± 0.04**
200	72.54 ± 1.09	2.84 ± 0.14	**43.79 ± 0.85**	96	**1.04 ± 0.09**
300	95.43 ± 1.74	3.62 ± 0.15	**62.37 ± 1.57**	95	**2.55 ± 0.12**
400	110.41 ± 2.32	3.98 ± 0.15	**81.07 ± 1.80**	95	**3.54 ± 0.13**





P Planning
proaches with
uncertainty

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Talk Overview

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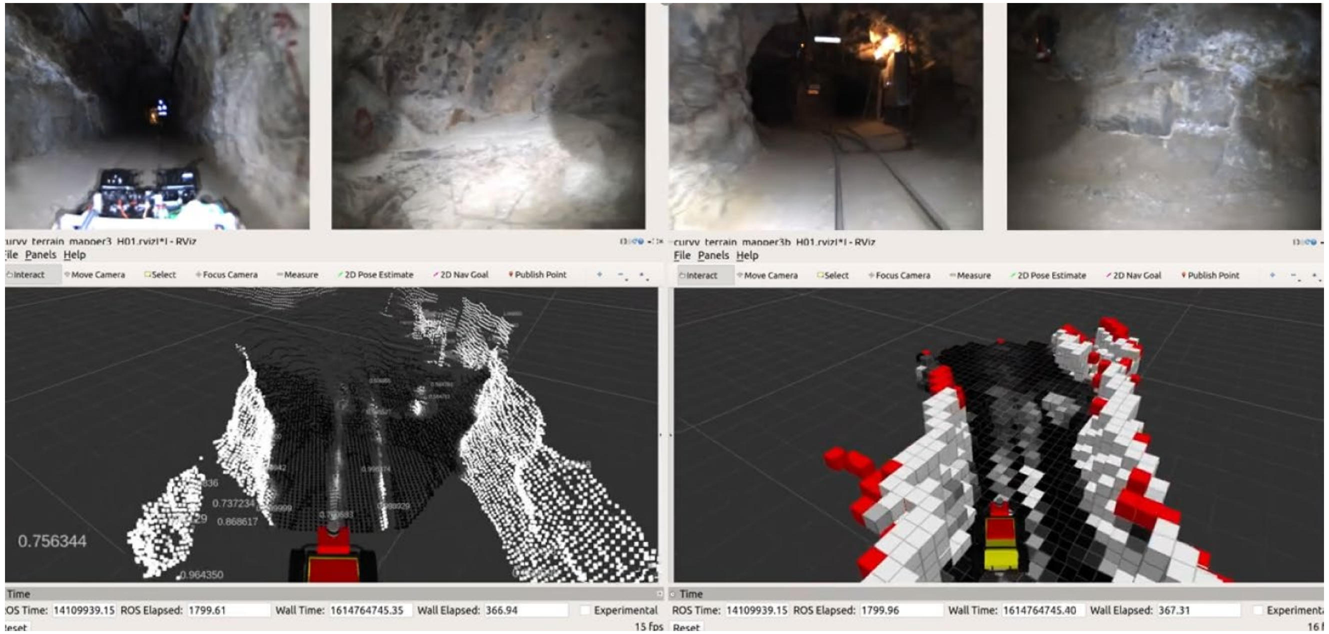
Improving robots' notions of where they can go

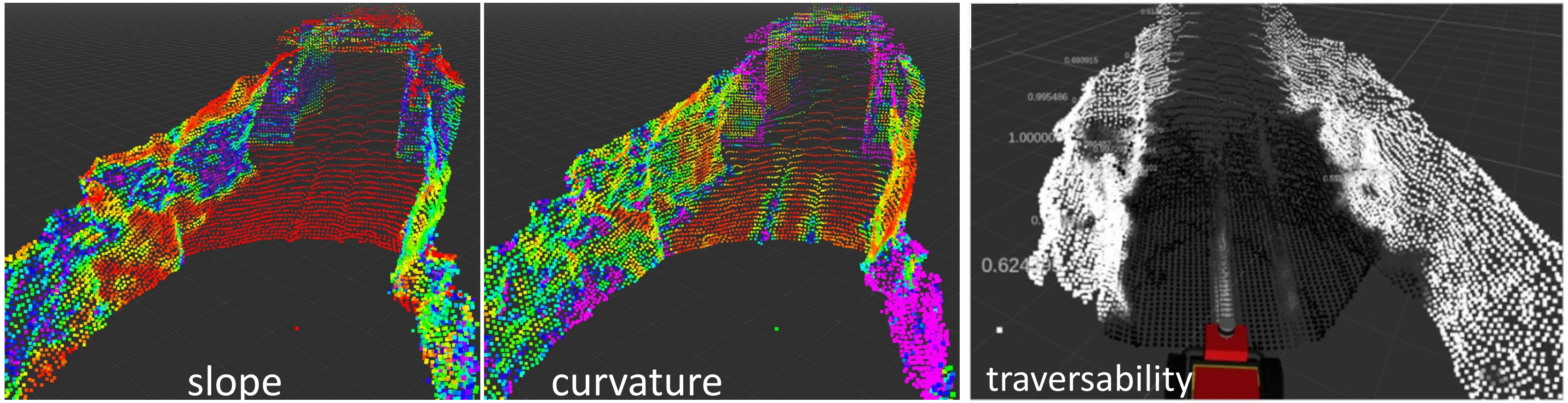
- **Augmenting Motion Planning with Traversability Estimation**

Obstacles in human populated spaces aren't always obvious

https://arxiv.org/abs/2110.04390

Traversability estimates are informed by both slope and surface curvature and are incorporated into the standard binary Bayes Filter occupancy grid formulation to determine voxel occupancy.



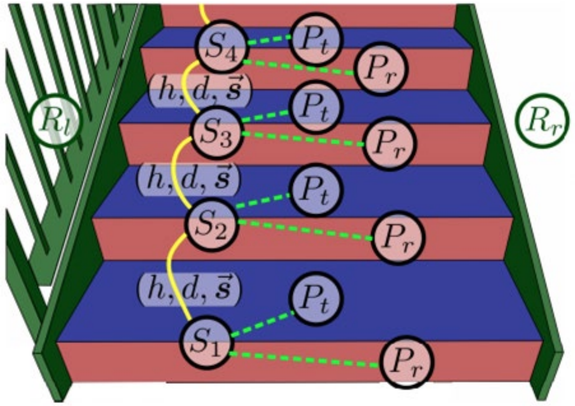


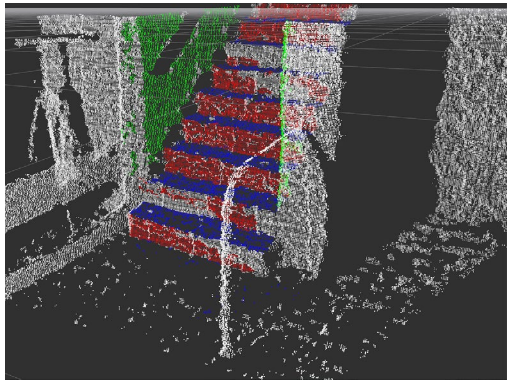
Multi-Agent Autonomy: Advancements and Challenges in Subterranean Exploration
https://arxiv.org/abs/2110.04390

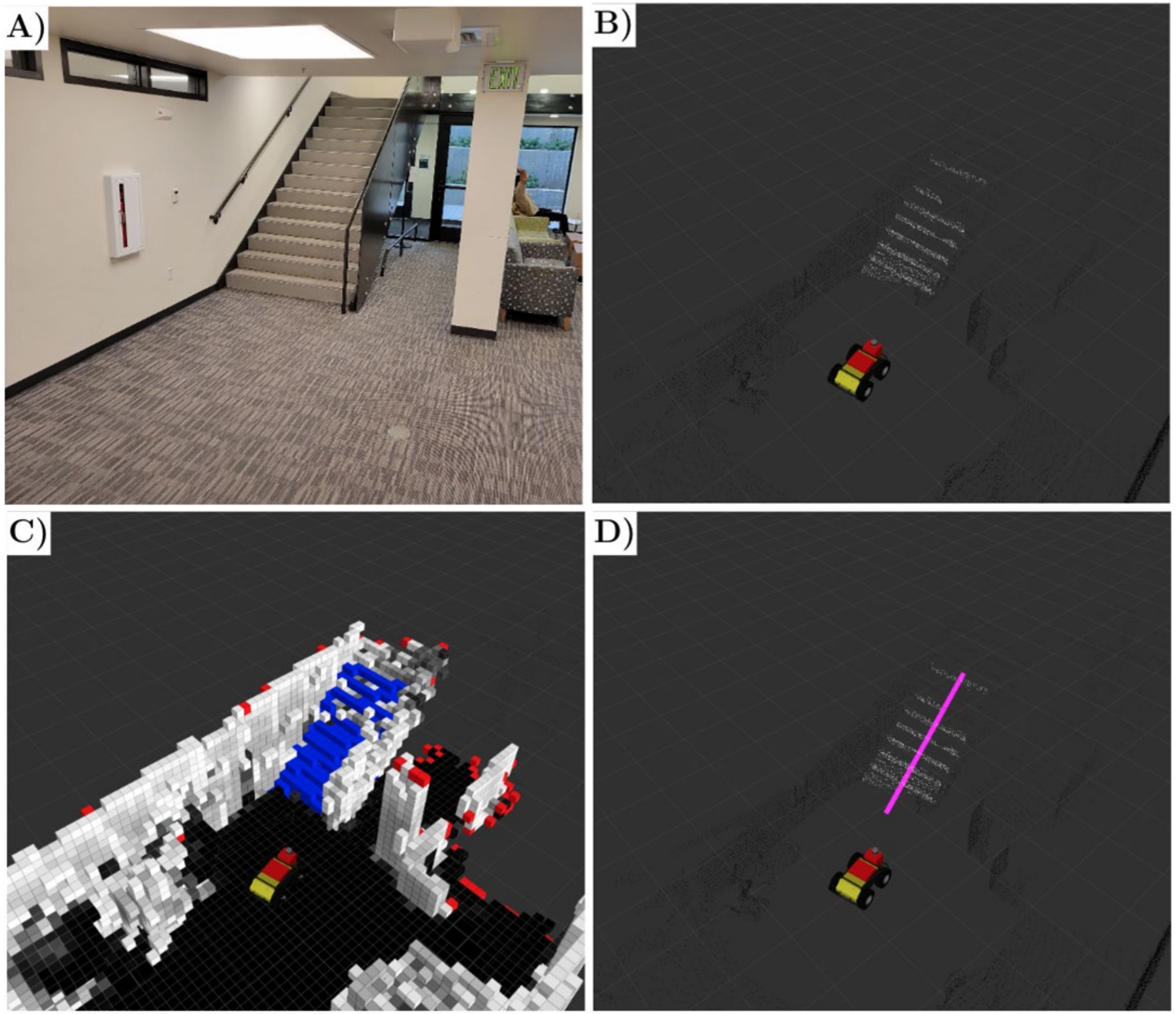
Traversability Estimation is Important!

Special Cases (Stairs)

Input point cloud
Preprocessing
Segmentation
Segmented cloud
Plane finder
Stair tread shaped segments | Stair riser shaped segments
Graph initialization | Graph initialization
Graph extension
Stairs confirmation
Detection of railing system
Localization
Localized stairway







Westfechtel, Thomas, et al. "3D graph based stairway detection and localization for mobile robots." 2016 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS). IEEE, 2016.

2022 National Robotics Initiative (NRI) Principal Investigators’ Meeting Award 1830686

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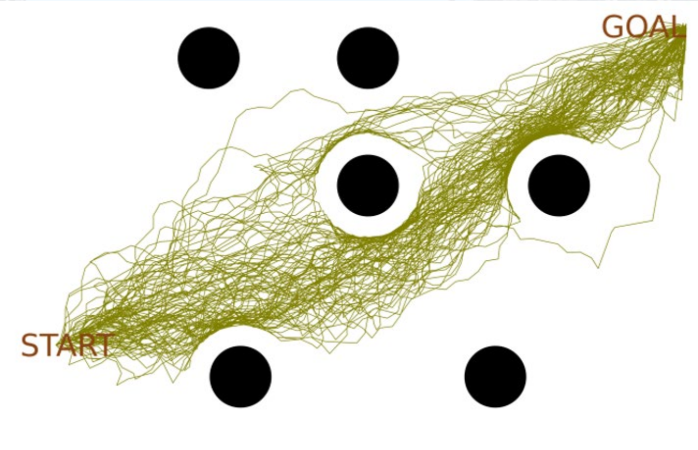

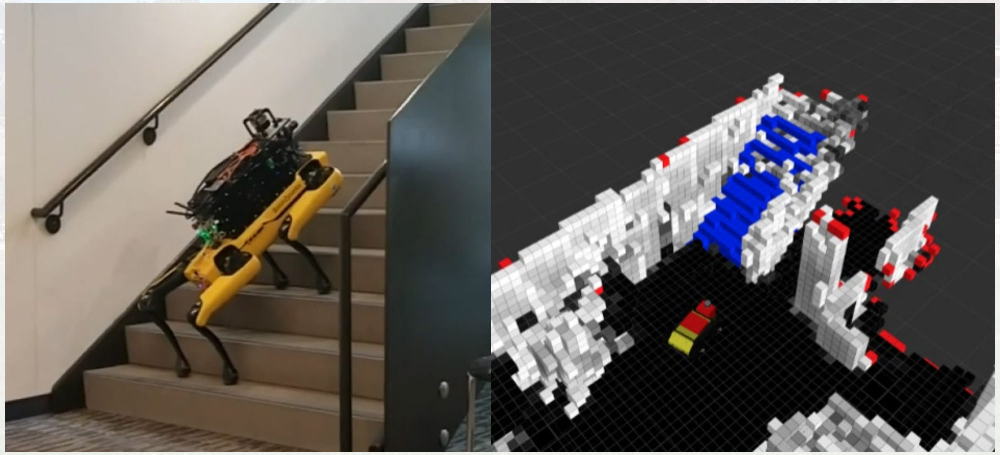

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Collaborative AI and Robotics Lab