Search-Based Multi-Agent Multi-Objective Multi-Target Path Planning

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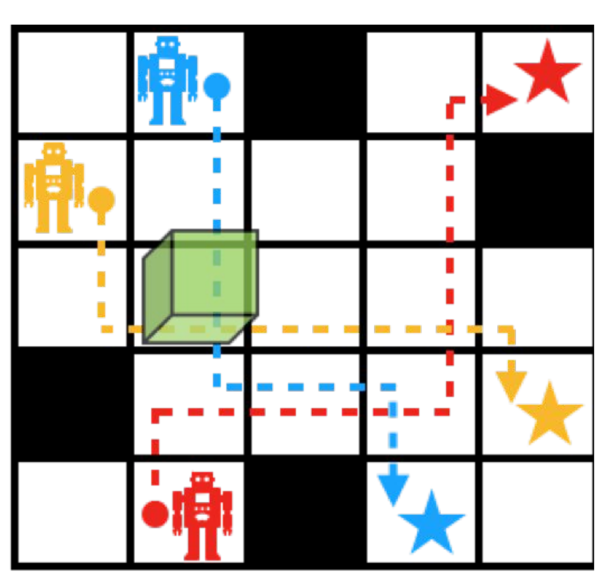
Abstract

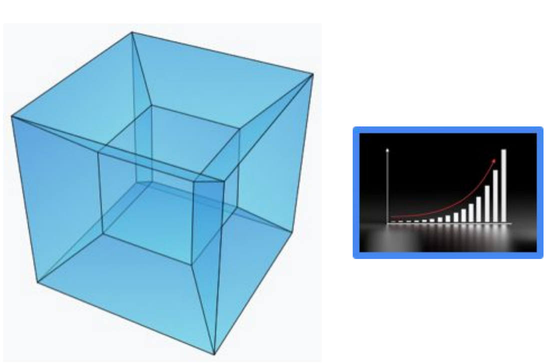
This project develops search methods that can direct multiple heterogeneous agents to efficiently search and acquire information. This multi-agent planning is not just a problem in Humanitarian Assistance Disaster Relief (HADR) missions, but also in customized manufacturing, critical infrastructure management, pandemic response, automated construction of field hospitals, and post-disaster forensics. Since lives are on the line, the approaches used must not only find feasible paths that maximize the likelihood of finding life, but also finds "best" possible solutions within a given response time. Therefore, this project seeks to create a comprehensive framework to address a wide family of multi-agent multi-objective planning problems operating under several logistic constraints.

The intellectual merit of this project investigates how to couple, partially decouple, or completely decouple the coordinated planning of the agent's trajectories, and therefore defer planning until absolutely needed. As such, the work develops formal guarantees, either in terms of completeness and optimality properties, or approximation bounds, for the sub-optimal solutions obtained for various generalizations of the multi-agent problem. The performance of the approaches are corroborated through large-scale simulations. This project aims to substantiate that deferred planning, until necessary, offers computational, as well as path quality, and efficacy, benefits for several important generalizations of multi-agent path finding problems.

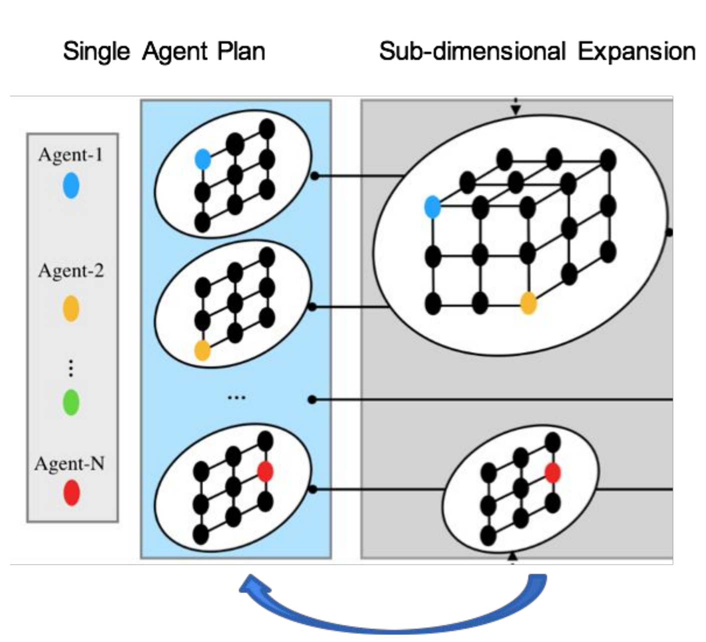
Background - Multi-Agent Path Finding



Multi-Agent Path Finding:
Plan collision-free paths for multiple agents from their respective start to goal locations.



Challenge:
Curse of dimensionality: the dimensionality of the joint configuration space of all agents grows exponentially with respect to the number of agents.



Dynamically Coupled Approaches:
Begin by planning for each agent in a decoupled manner;
Plan the agents together when needed to avoid agent-agent collision;
Defer the expensive multi-agent planning until necessary.

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Standley, Trevor. "Finding optimal solutions to cooperative pathfinding problems." In Proceedings of the AAAI Conference on Artificial Intelligence, vol. 24, no. 1, pp. 173-178. 2010.
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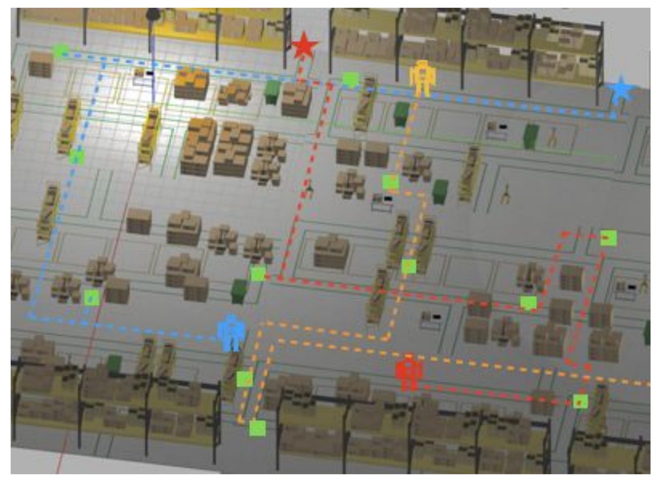
Sharon, Guni, Roni Stern, Ariel Felner, and Nathan R. Sturtevant. "Conflict-based search for optimal multi-agent pathfinding." *Artificial Intelligence* 219 (2015): 40-66.
Wagner, Glenn, and Howie Choset. "Subdimensional expansion for multirobot path planning." *Artificial intelligence* 219 (2015): 1-24.

Problem 1 - Multi-Agent Traveling Salesman Path Finding (MA-TS-PF)

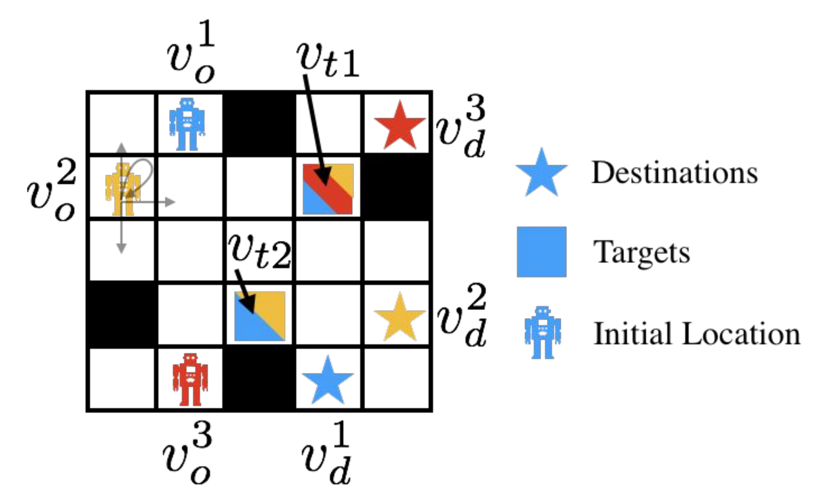
Search and Rescue



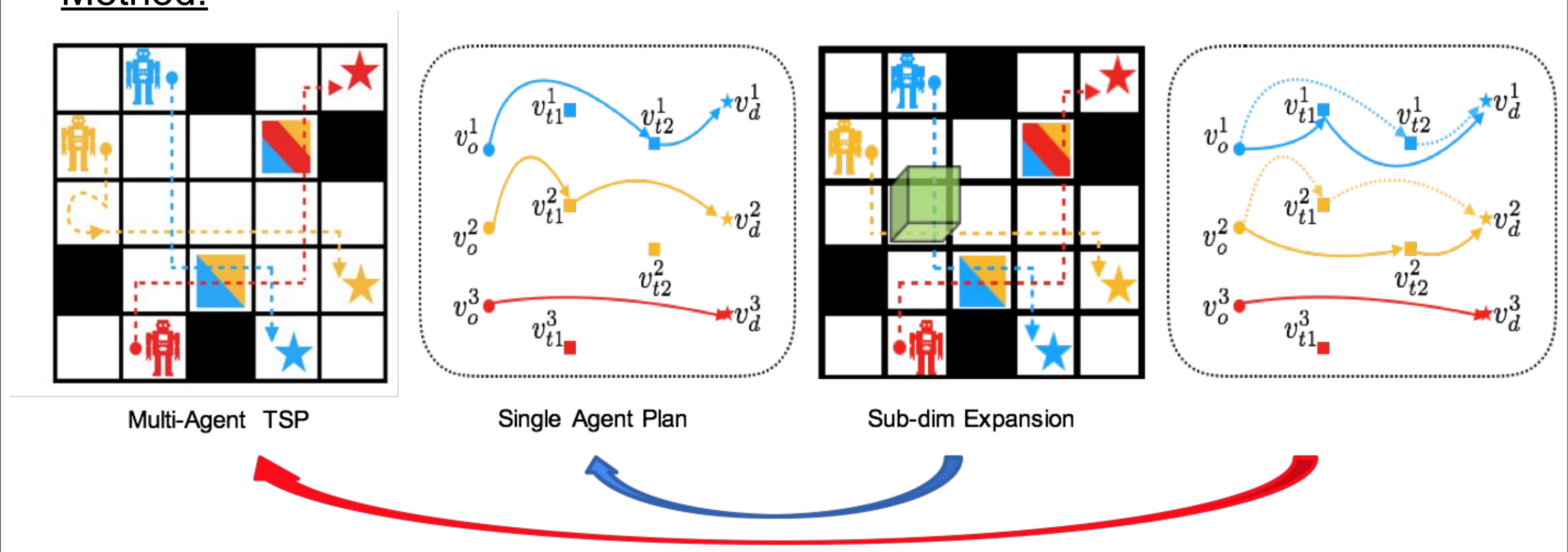
Warehouse Logistics

Problem:
- Cluttered environments:
  - **Collision avoidance** between agents.
- Gather info / pick items / load the machines:
  - **Multiple intermediate target** locations.
  - **Heterogeneous capability** (different grippers, sensors, etc.)
- Reduce logistic cost (manufacturing), efficiently gather info (search and rescue):
  - **Optimal / near-optimal** solution paths.

Graph Formulation:

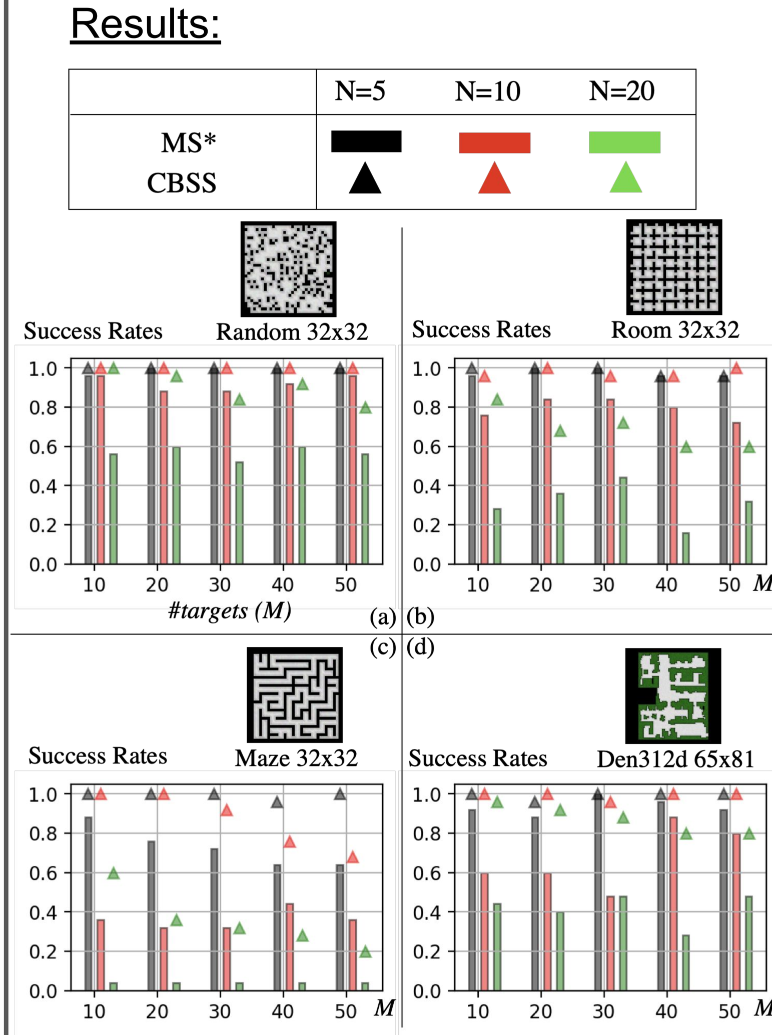


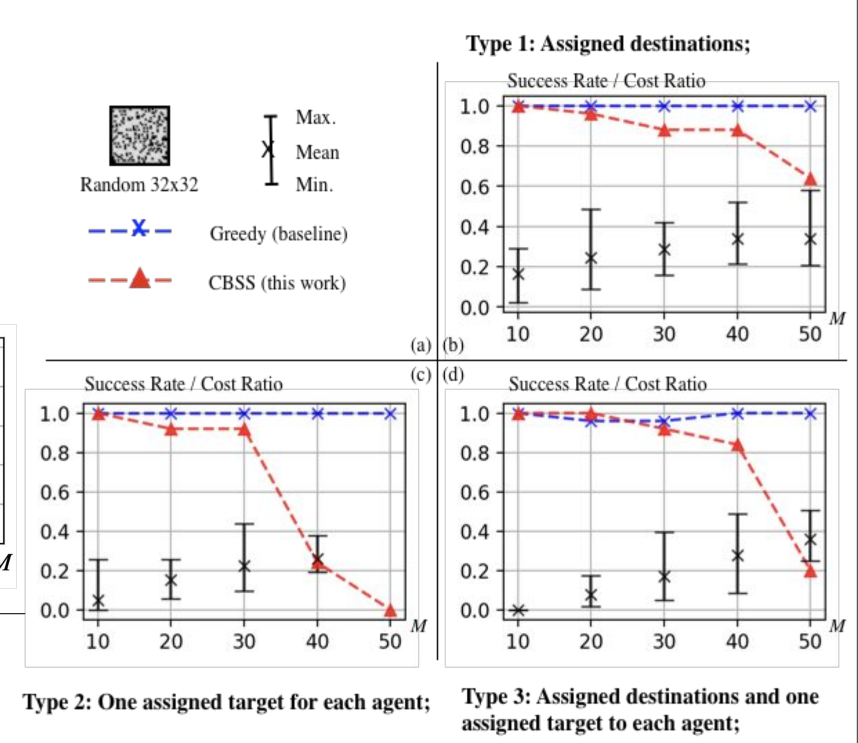
Method:



- Alternate between solving Traveling Salesman Problems and path planning.
- Generate Traveling Salesman Problems when needed.
- Solution optimality guarantees.

Results:

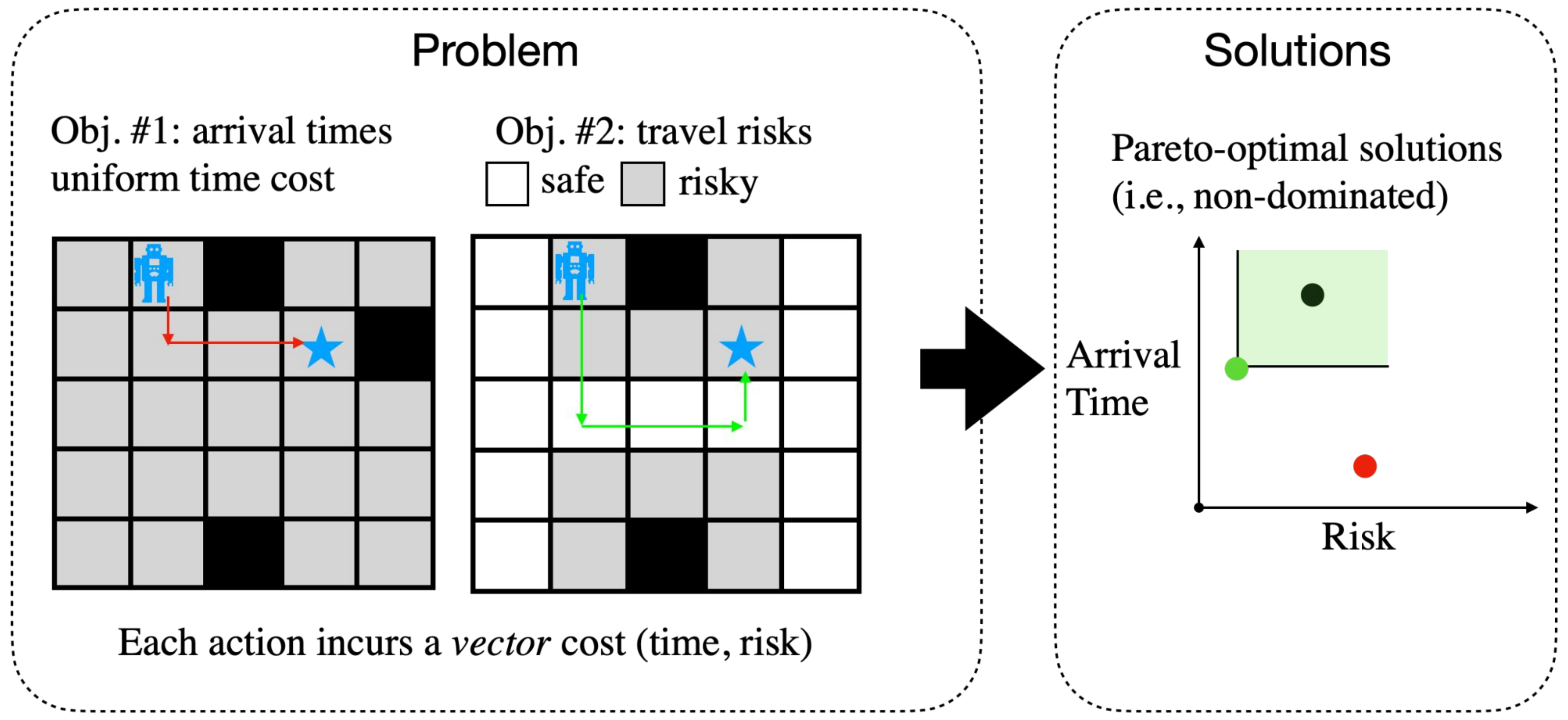




- Handle up to 20 agents and 50 targets.
- Compute up to 50% cheaper solutions than a greedy approach

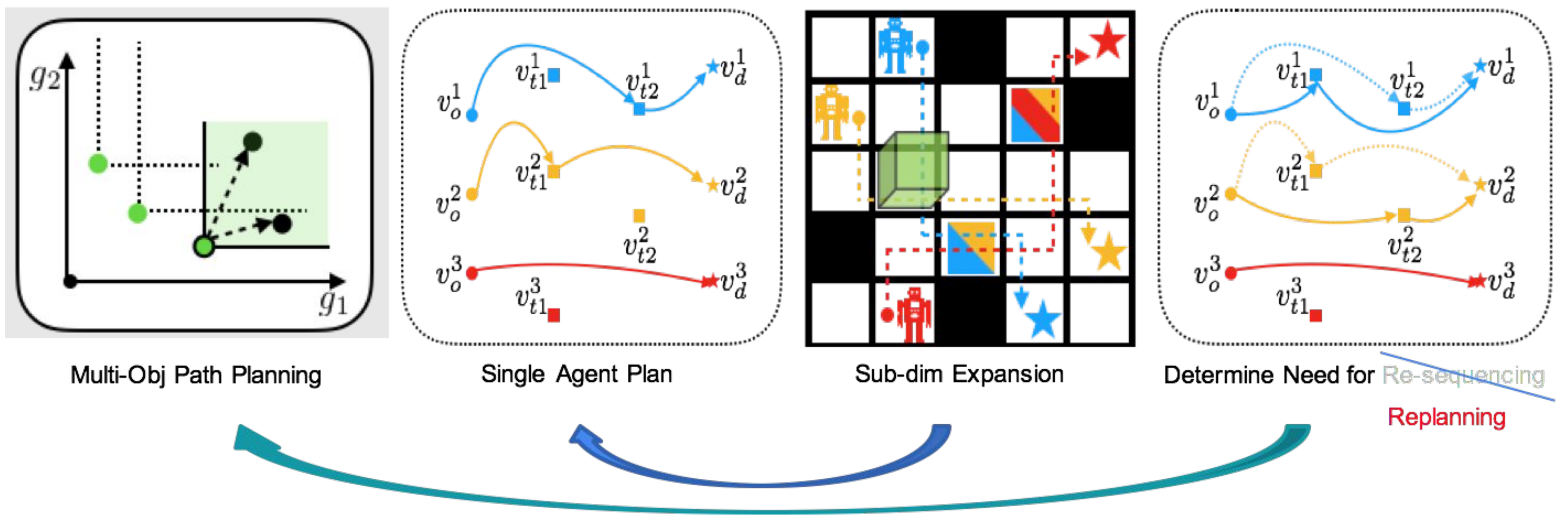
[1] Ren, Zhongqiang, Sivakumar Rathinam, and Howie Choset. "MS: A New Exact Algorithm for Multi-agent Simultaneous Multi-goal Sequencing and Path Finding." In *2021 IEEE International Conference on Robotics and Automation (ICRA)*, pp. 11560-11565. IEEE, 2021.
[2] Ren, Zhongqiang, Sivakumar Rathinam, and Howie Choset. "Conflict-Based Steiner Search for Multi-Agent Combinatorial Path Finding." In *Proceedings of Robotics: Science and Systems*. 2022.

Problem 2 - Multi-Agent Multi-Objective Path Finding (MA-MO-PF)



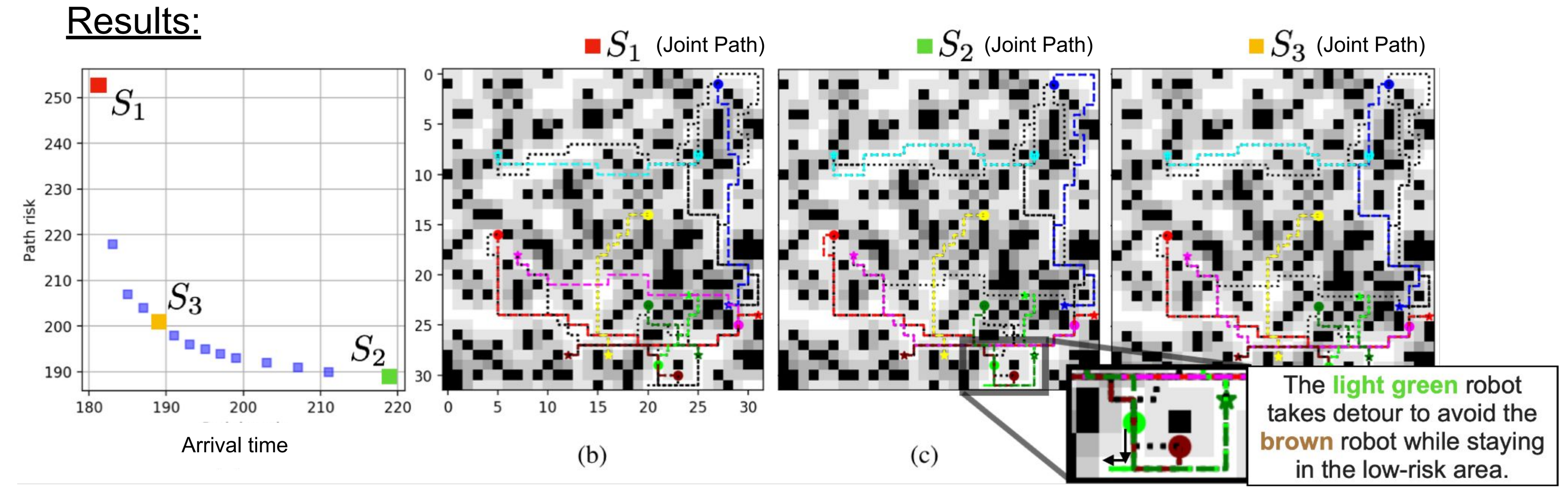
Problem:
- Plan collision-free paths while optimizing multiple objective functions defined ovr paths at the same time.
- Find a set of Pareto-optimal solutions.

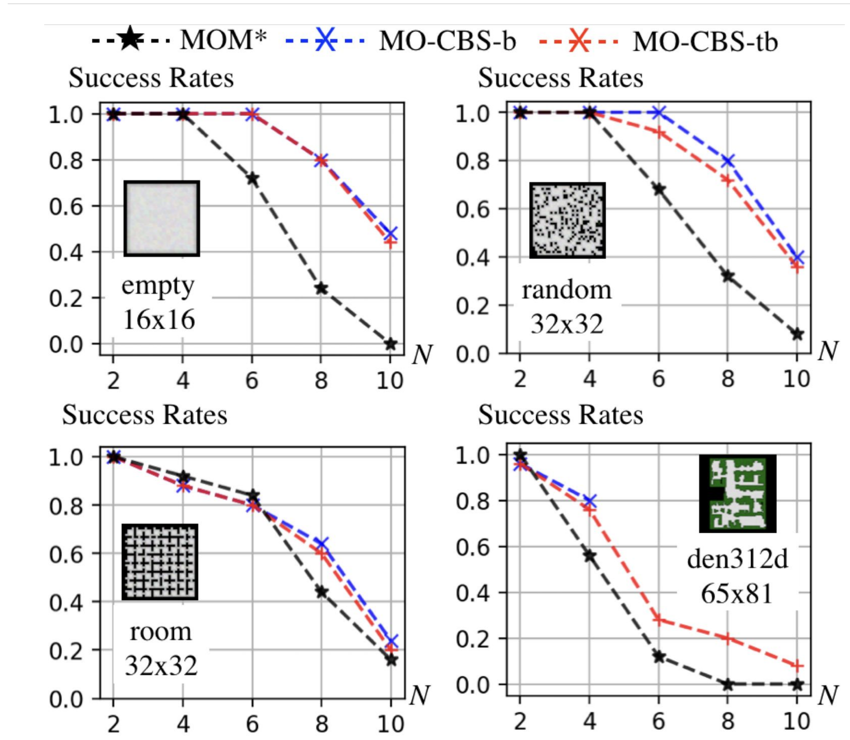
Method:



- Alternate between solving (single-agent) multi-objective path planning problems and multi-agent planning to resolve collision between agents.
- Guaranteed to find all cost-unique Pareto-optimal solutions.

Results:





Bi-Objective Tests

Acknowledgements

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[3] Ren, Zhongqiang, Sivakumar Rathinam, and Howie Choset. "Subdimensional expansion for multi-objective multi-agent path finding." *IEEE Robotics and Automation Letters* 6, no. 4 (2021): 7153-7160.
[4] Ren, Zhongqiang, Sivakumar Rathinam, and Howie Choset. "A conflict-based search framework for multiobjective multiagent path finding." *IEEE Transactions on Automation Science and Engineering* (2022).