Boosting Computational Performance and Solution Optimality for Multi-Robot Path Planning with Principled Heuristics

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Summary of Main Results in Last Performance Year (NCE)

During the last performance period (NCE), we focused on (1) the development of efficient algorithms for multi-robot path and motion planning and (2) applications of multi-robot systems. On the development of core multi-robot path planning algorithms,

- We exploited the spatio-temporal partitioning of planning domain to dramatically boost planner performance (ICRA 2021, to appear).
- We further developed the path-diversification heuristics from our RA-L 2020 work to a full set of heuristics. (to submit to IROS 2021).

On the application side,

- We developed algorithms for collaborative de-cluttering, with applications to disaster relief (IROS 2020)
- We developed multi-sensor deployment algorithms for optimally guarding 2D and 3D regions, with applications to many sensor coverage problems (RSS 2020, ICRA 2021, to appear)

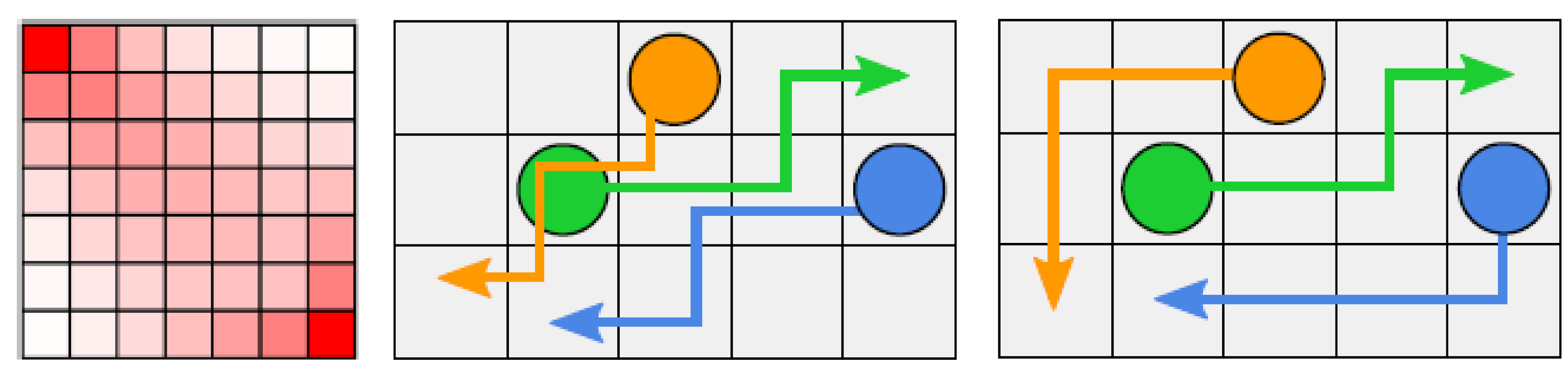
Products during the past performance year:

- ❑ T. Guo, S. D. Han, and J. Yu. Spatial and Temporal Splitting Heuristics for Multi-Robot Motion Planning. 2021 IEEE International Conference on Robotics and Automation (ICRA 2021).
- ❑ S. D. Han and J. Yu. Optimizing Space Utilization for More Effective Multi-Robot Path Planning. 2020 IEEE/RSJ International Conference on Intelligent Robots and Systems (to submit to IROS 2020).
- ❑ S. W. Feng, K. Gao, and J. Yu. Mobile Sensor Placement for Globally Optimal Coverage of 3D-Embedded Surfaces. 2021 IEEE International Conference on Robotics and Automation (ICRA 2021).
- ❑ W. N. Tang, S. D. Han and J. Yu. Computing High-Quality Clutter Removal Solutions for Multiple Robots. 2020 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 2020).
- ❑ S. W. Feng and J. Yu. Optimally Guarding Perimeters and Regions with Mobile Range Sensors. 2020 Robotics: Science and Systems (RSS 2020).
- ❑ S. D. Han and J. Yu. DDM: Fast Near-Optimal Multi-Robot Path Planning using Diversified-Path and Optimal Sub-Problem Solution Database Heuristics. IEEE Robotics and Automation Letters, 2020 (RA-L 2020).
- ❑ S. W. Feng and J. Yu. Optimal Perimeter Guarding with Heterogeneous Robot Teams: Complexity Analysis and Effective Algorithms. IEEE Robotics and Automation Letters, 5(2), page(s): 430-437, 2020 (RA-L 2020).

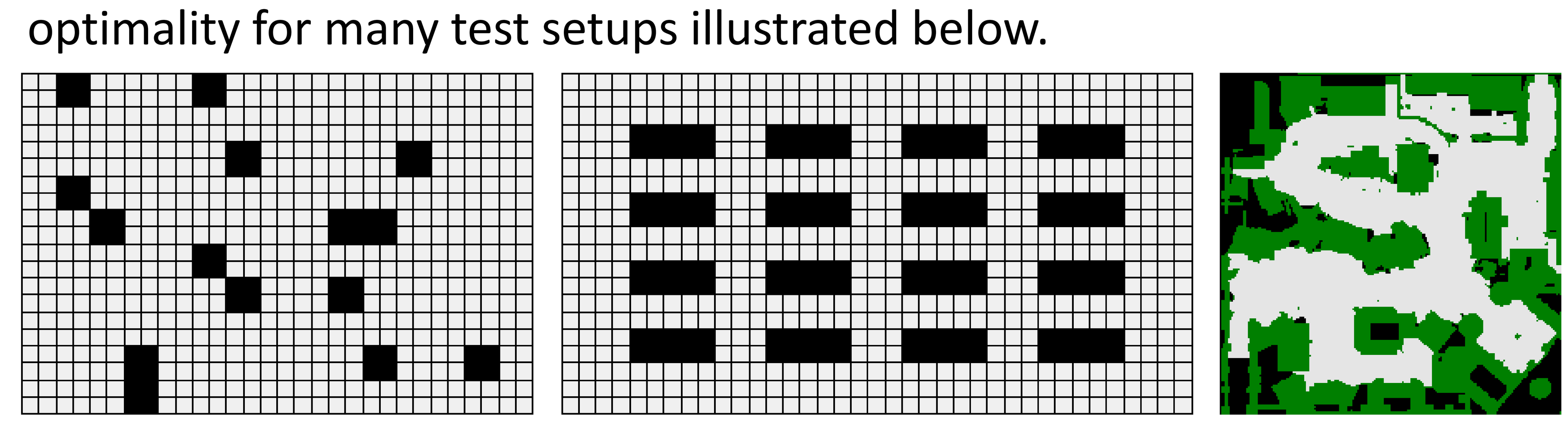
Principled Heuristics for Boosting Multi-Robot Path Planning

Continuing our effort on making multi-robot planning algorithms more efficient and solutions more optimal, building on our RA-L 2020 DDM work, we systematically exploit the ideas of ***Space Utilization Optimization*** (**SUO**) and ***Spatio-Temporal Splitting*** (**STS**) to develop heuristics for multi-robot path planning.

In decoupled multi-robot path planning, as robots plan individual paths, space utilization tend to be unbalanced. For example, planning optimal paths to go from top left to bottom right on the 7x7 grid (below, top left) will result cell usage as indicated by the red shade, which is uneven. By recording different types of space usage during the process, faster algorithms can be constructed. The idea (vertex version) is shown in the right two figures below, where if the orange robot is not aware of the green one, then a planned path would contain collisions; if the orange robot is aware (indirectly) of green robot's trajectory, then path can be planed without collision that needs to be resolved later.

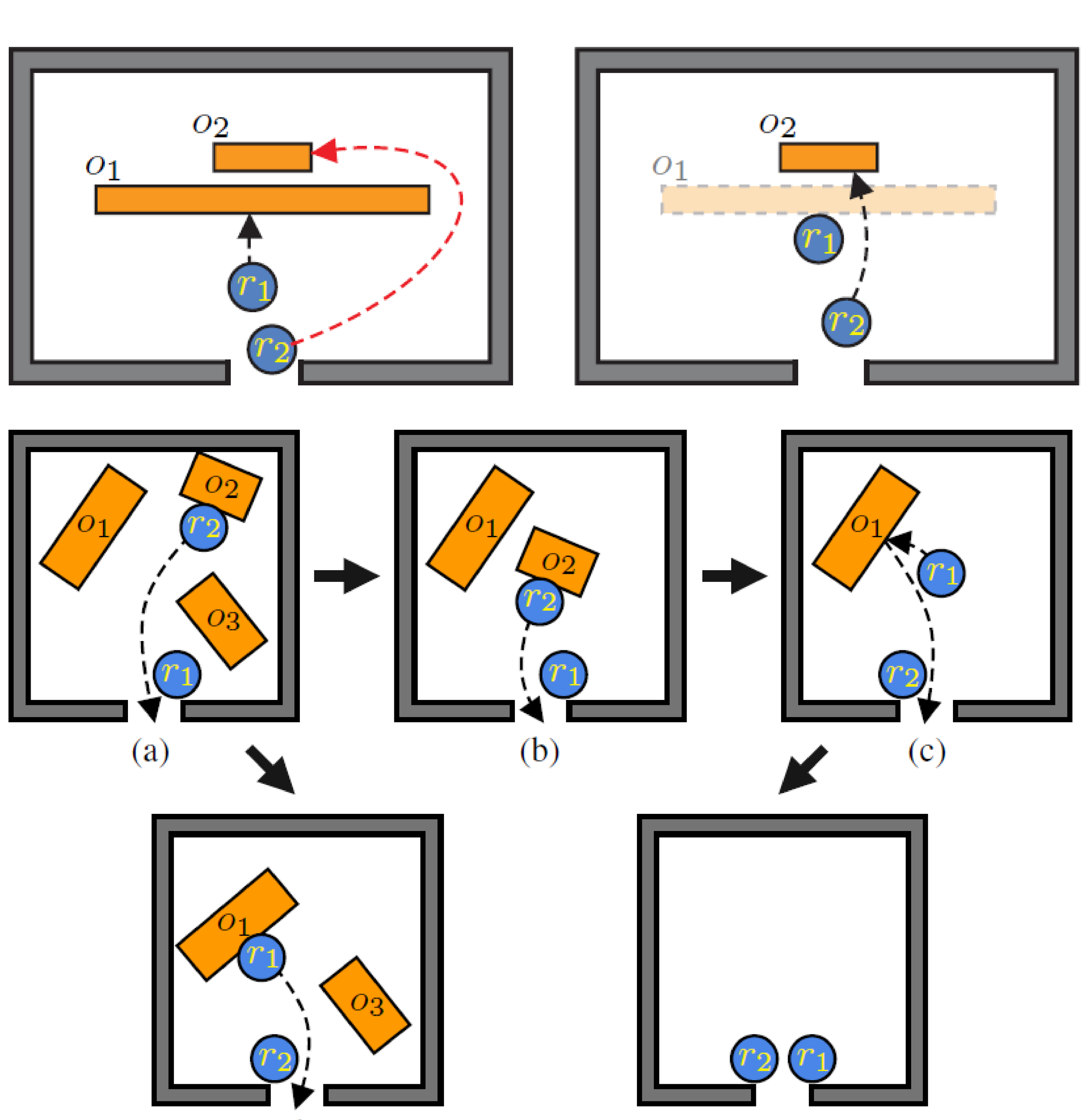


Based on the principle, full heuristics are developed that consistently reduce the computation time by up to 75% and maintain/improve optimality for many test setups illustrated below.



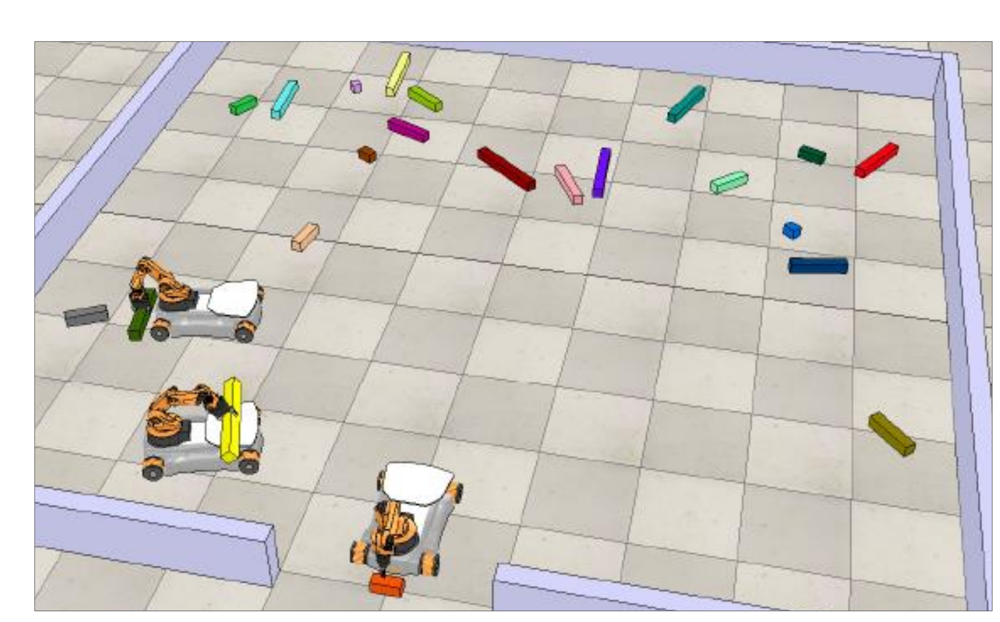
Inspired by the finite horizon computation in control and planning, we further developed a Spatio-Temporal Splitting (STS) heuristic that could further reduce the computation time dramatically, in many instances allowing the problem to scale 3-4 times than what was possible before.

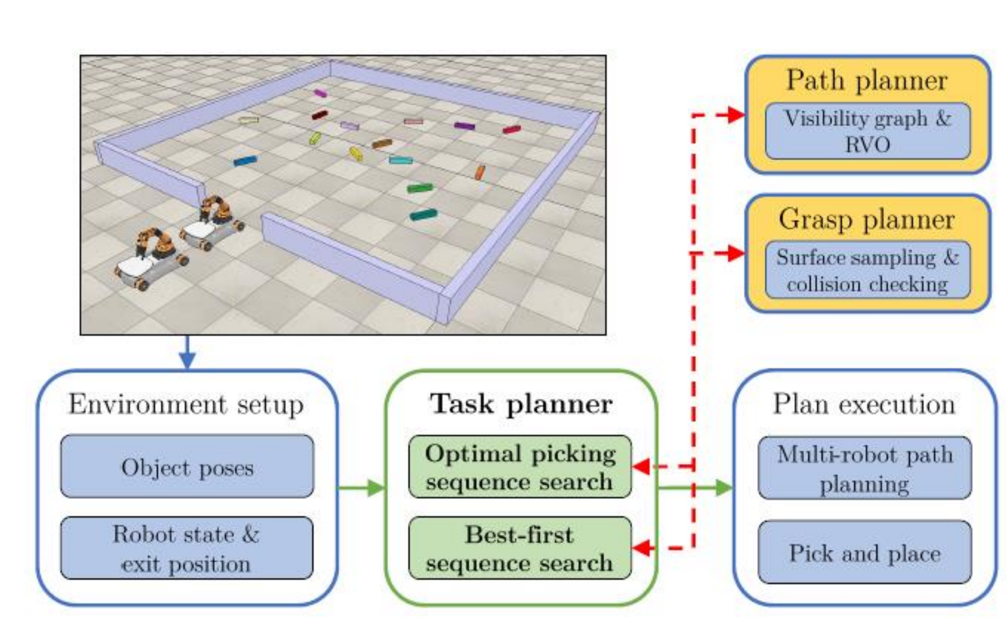
Application: Multi-Robot Coordinated De-Clutter for Search & Rescue



Building on our ISRR 2019 work of single robot clutter removal, we developed a multi-robot clutter removal framework that seeks to compute near-optimal plans for multiple robots to collaboratively remove clutter from a given environment. Our algorithms adapt a dynamic programming (DP) method to work efficiently with the unique optimality structure induced by the multi-robot clutter removal problems. In particular, the fact that robot's picking up objects changes the environment (top left two figures) makes it necessary to plan with a lookahead. That is, robots' paths must be updated as objects are picked up and removed.

The algorithms we propose can significantly boost task execution efficiency; using two robots can reduce the time to task completion by 40% (maximum possible: 50%). Our algorithms can be rendered resolution complete as well.





IIS-1734419 NRI: FND: Collaborative Multi-Robot Systems with Provable Availability, Safety, and Optimality Guarantees. PM: Ralph Wachter