MONASH University

Beyond Pairwise Reasoning in Multi-Agent Path Finding (ICAPS 2023)

Bojie Shen, Zhe Chen, Jiaoyang Li, Muhammad Aamir Cheema, Daniel D.Harabor, Peter J. Stuckey

Monash University

Background
Multi-Agent Path Finding (MAPF)

MONASH University

- Multi-Agent Path Finding:
  - Automated warehouse:
    - Each robot is often assigned a task
      - picks up a shelter from one location and delivers to another.
    - But the robots must work together
      - there is no collision between robots during their execution.

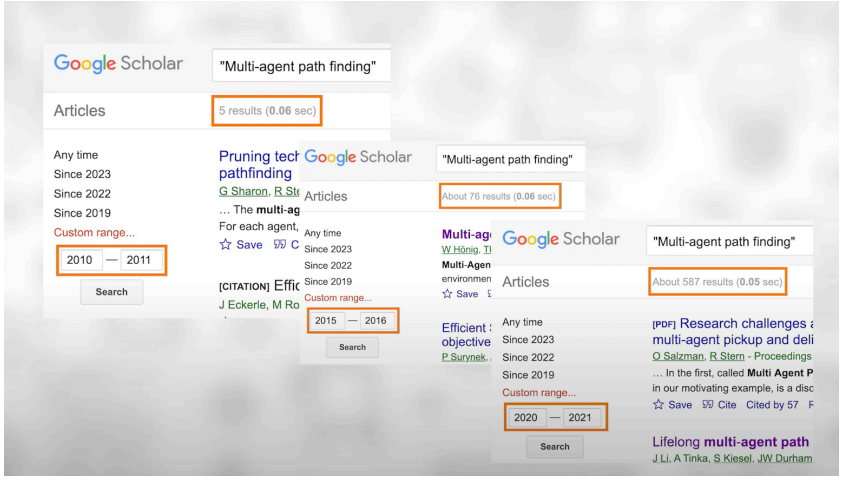
Background
Multi-Agent Path Finding (MAPF)

MONASH University

- Multi-Agent Path Finding:
  - Automated warehouse:
    - Each robot is often assigned a task
      - picks up a shelter from one location and delivers to another.
    - But the robots must work together
      - there is no collision between robots during their execution.
  - Optimization:
    - Centralized system should aim to plan the paths as fast as possible.
    - Each individual path needs to be as short as possible.

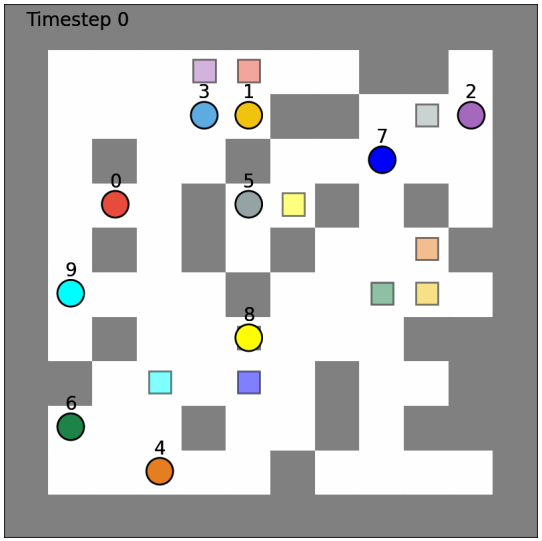
Background
Multi-Agent Path Finding (MAPF)

- Multi-Agent Path Finding:
  - Automated warehouse:
    - Each robot is often assigned a task
      - picks up a shelter from one location and delivers to another.
    - But the robots must work together
      - there is no collision between robots during their execution.
  - Optimization:
    - Centralized system should aim to plan the paths as fast as possible.
    - Each individual path needs to be as short as possible.
  - Research Interests:
    - Capture the broader attention of both the AI and database communities.



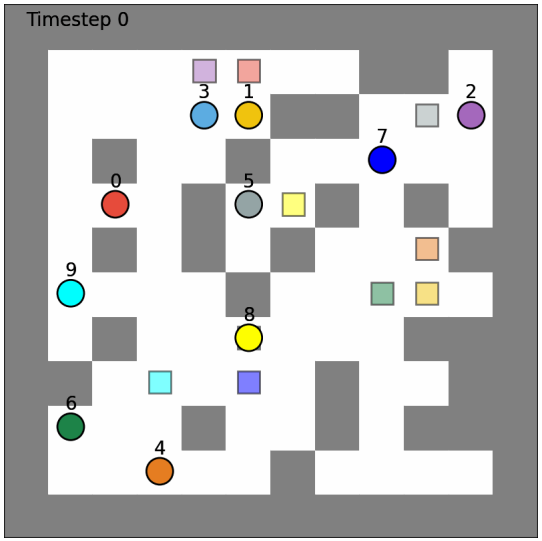
Background
Multi-Agent Path Finding (MAPF)

- Multi-Agent Path Finding:
  - Automated warehouse:
  - Environment:
    - 4-connected grid map.
    - Discretized timesteps.



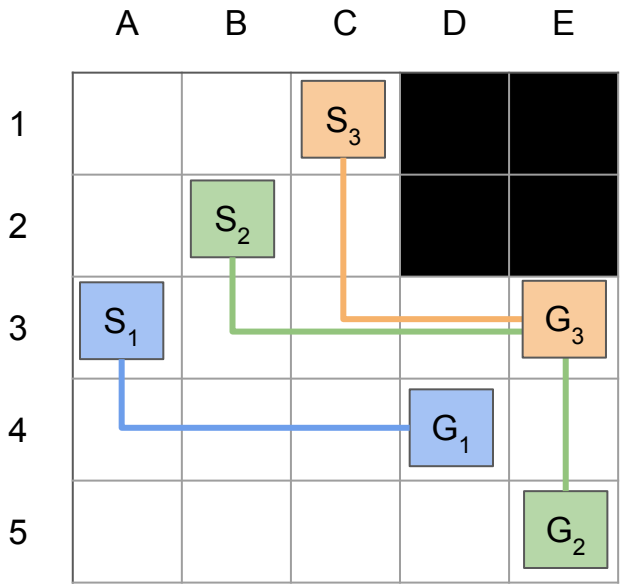
Background
Multi-Agent Path Finding (MAPF)

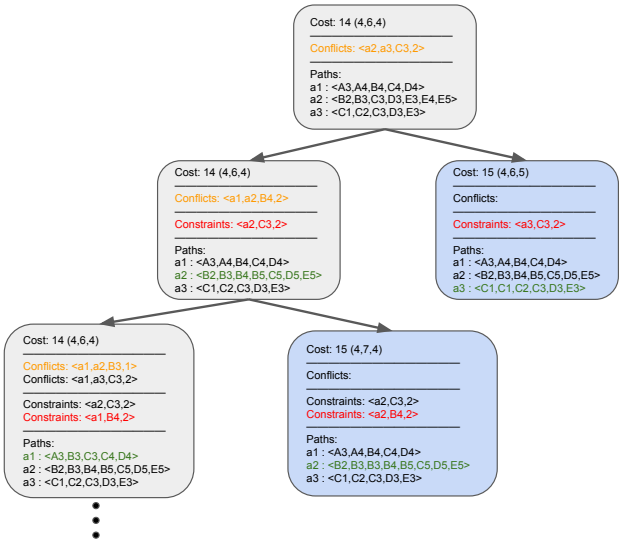
- Multi-Agent Path Finding:
  - Automated warehouse:
  - Environment:
    - 4-connected grid map.
    - Discretized timesteps.
  - Objectives:
    - Given a set of agents with source and destination.
    - Find a collision-free plan that minimizes the Sum of Individual Cost (SIC).



Our Contribution

- Conflict-Based Search [1]:
  - Two-level search algorithm:
    - Finds the optimal solution by reasoning the conflicts.

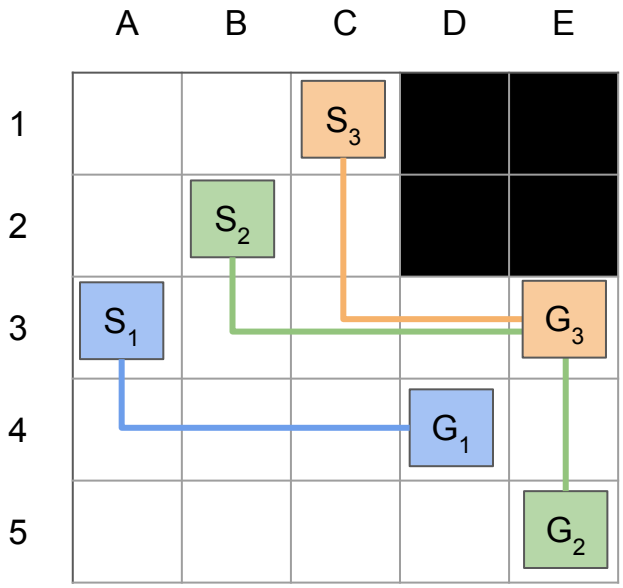


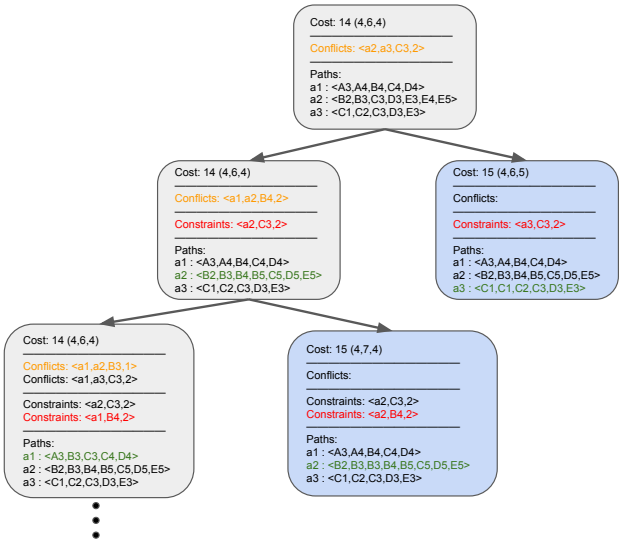


Our Contribution

MONASH University

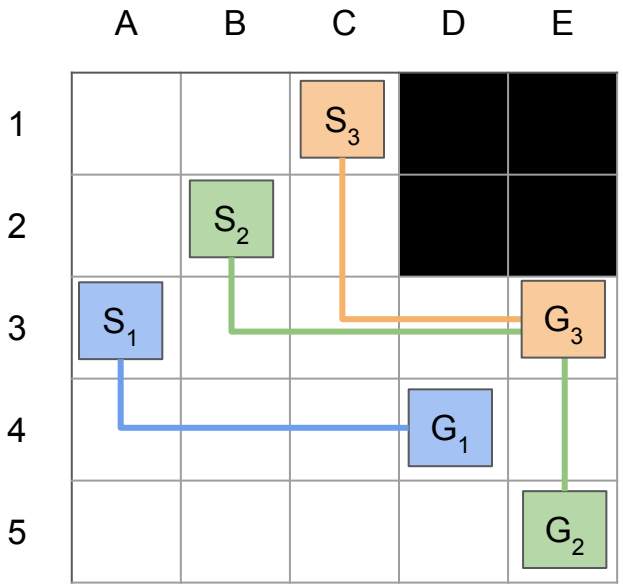
- Conflict-Based Search [1]:
  - Two-level search algorithm:
    - Finds the optimal solution by reasoning the conflicts.
  - Recent enhancements:
    - Pairwise heuristics [2 - 3].
    - Pairwise symmetry reasoning [4 - 6].
    - Pairwise conflict prioritization [7].

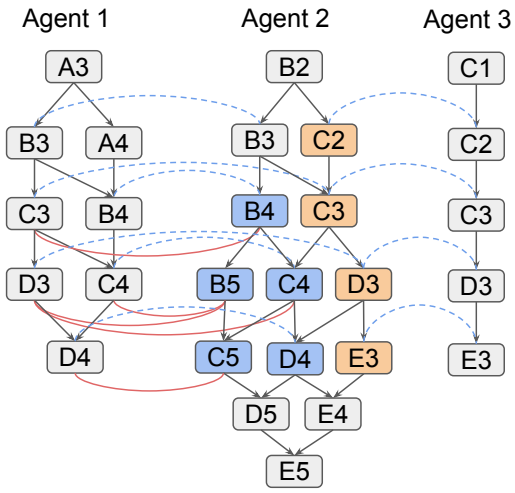




Our Contribution

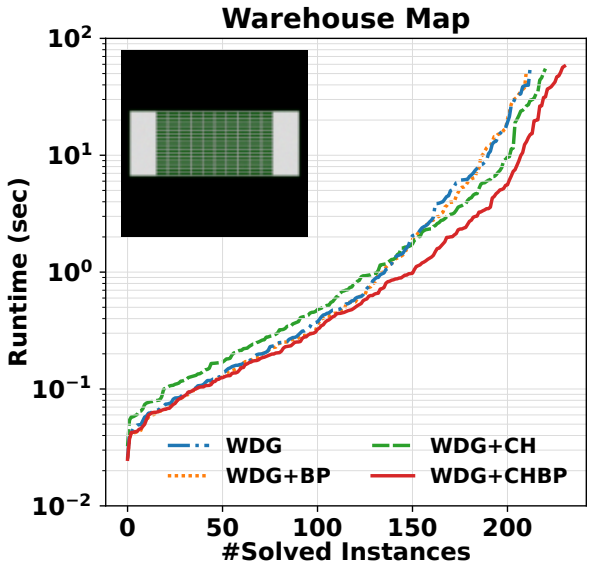
- Conflict-Based Search [1]:
  - Two-level search algorithm:
    - Finds the optimal solution by reasoning the conflicts.
  - Recent enhancements:
    - Pairwise heuristics [2 - 3].
    - Pairwise symmetry reasoning [4 - 6].
    - Pairwise conflict prioritization [7].
  - Cluster Heuristic and Bypass (CHBP)
    - Reason a cluster of agents:
      - Generate stronger heuristics.
      - Find more feasible bypasses.

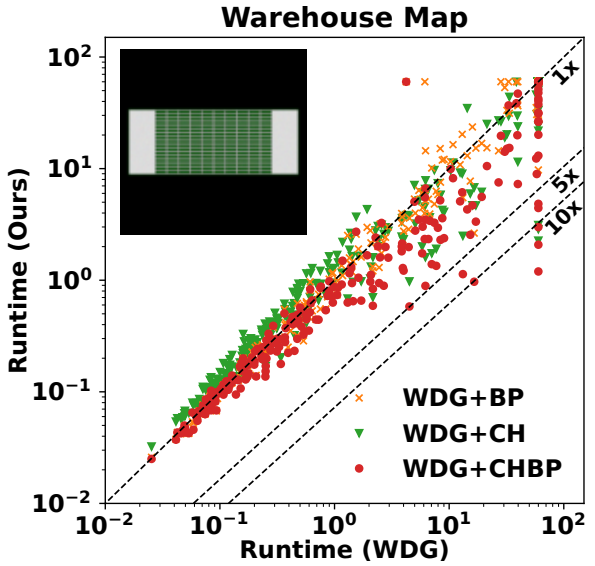




Our Contribution

- Conflict-Based Search [1]:
  - Two-level search algorithm:
    - Finds the optimal solution by reasoning the conflicts.
  - Recent enhancements:
    - Pairwise heuristics [2 - 3].
    - Pairwise symmetry reasoning [4 - 6].
    - Pairwise conflict prioritization [7].
  - Cluster Heuristic and Bypass (CHBP)
    - Reason a cluster of agents:
      - Generate stronger heuristics.
      - Find more feasible bypasses.
    - Improvement:
      - Solve 10 - 20% more instances within same runtime.
      - Up to 10x Speed up.





Research Resource

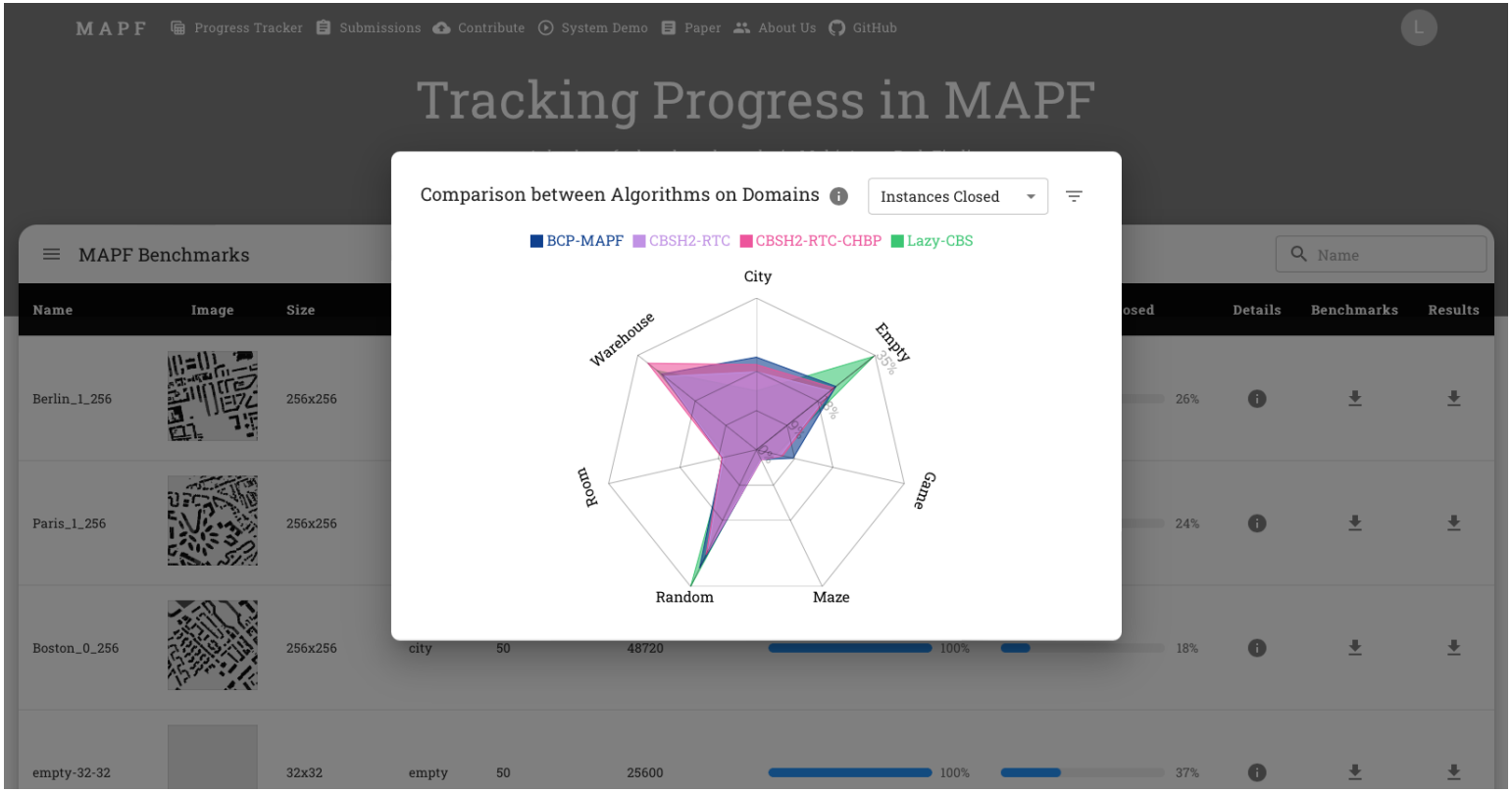
MONASH University

- Benchmarks:
  - Website: https://movingai.com/benchmarks/mapf/index.html
  - Paper: https://arxiv.org/abs/1906.08291

Preview	Download Image	Map	Dimensions	# states	Scenarios	Max number of problem in a scenario
	png svg pdf	Berlin_1_256.map	256x256	47,540	Berlin_1_256-even.scen (25 even scenarios) Berlin_1_256-random.scen (25 random scenarios)	1010 (even) 1000 (random)
	png svg pdf	Boston_0_256.map	256x256	47,768	Boston_0_256-even.scen (25 even scenarios) Boston_0_256-random.scen (25 random scenarios)	980 (even) 1000 (random)
	png svg pdf	Paris_1_256.map	256x256	47,240	Paris_1_256-even.scen (25 even scenarios) Paris_1_256-random.scen (25 random scenarios)	1100 (even) 1000 (random)
	png svg pdf	brc202d.map	530x481	43,151	brc202d-even.scen (25 even scenarios) brc202d-random.scen (25 random scenarios)	2580 (even) 1000 (random)
	png svg pdf	den312d.map	65x81	2,445	den312d-even.scen (25 even scenarios) den312d-random.scen (25 random scenarios)	310 (even) 1000 (random)
	png svg pdf	den520d.map	256x257	28,178	den520d-even.scen (25 even scenarios) den520d-random.scen (25 random scenarios)	890 (even) 1000 (random)
	png svg pdf	empty-16-16.map	16x16	256	empty-16-16-even.scen (25 even scenarios) empty-16-16-random.scen (25 random scenarios)	128 (even) 128 (random)

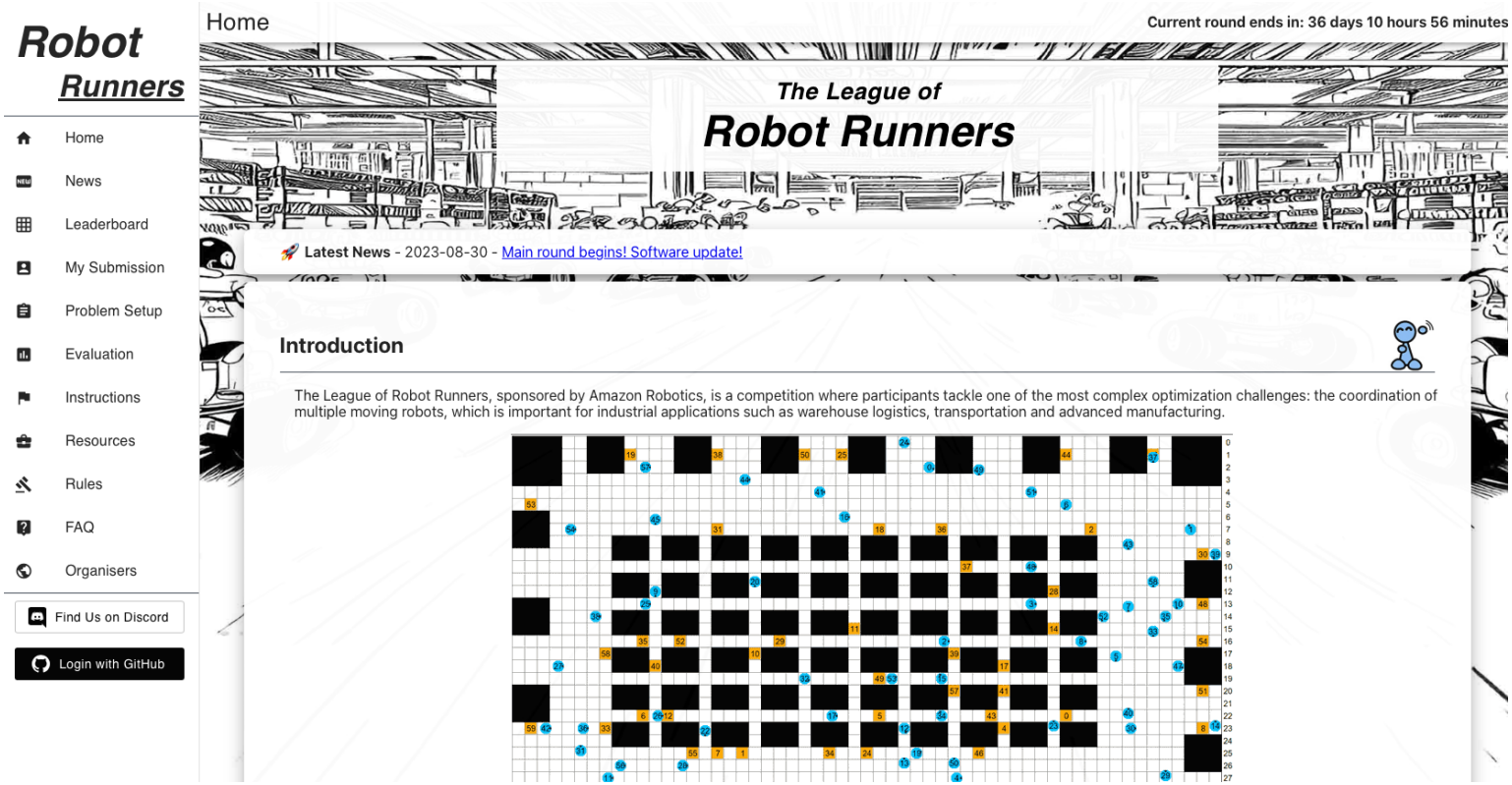
Research Resource

- Progress Tracker:
  - Website: http://tracker.pathfinding.ai
  - Paper: https://arxiv.org/abs/2305.08446



Research Resource

- Competition (Funded by Amazon):
  - Website: https://www.leagueofrobotrunners.org
  - Deadline: 30th November (ongoing)



Reference

MONASH University

[1] Sharon, G., Stern, R., Felner, A., & Sturtevant, N. R. (2015). Conflict-based search for optimal multi-agent pathfinding. Artificial Intelligence, 219, 40-66.

[2] Felner, A., Li, J., Boyarski, E., Ma, H., Cohen, L., Kumar, T. S., & Koenig, S. (2018). Adding heuristics to conflict-based search for multi-agent path finding. In *ICAPS* (Vol. 28, pp. 83-87).

[3] Li, J., Felner, A., Boyarski, E., Ma, H., & Koenig, S. (2019). Improved Heuristics for Multi-Agent Path Finding with Conflict-Based Search. In *IJCAI* (Vol. 2019, pp. 442-449).

[4] Li, J., Harabor, D., Stuckey, P. J., Ma, H., & Koenig, S. (2019). Symmetry-breaking constraints for grid-based multi-agent path finding. In *Proceedings of the AAAI Conference on Artificial Intelligence* (Vol. 33, No. 01, pp. 6087-6095).

[5] Li, J., Gange, G., Harabor, D., Stuckey, P. J., Ma, H., & Koenig, S. (2020). New techniques for pairwise symmetry breaking in multi-agent path finding. In *ICAPS* (Vol. 30, pp. 193-201).

[6] Zhang, H., Li, J., Surynek, P., Kumar, T. S., & Koenig, S. (2022). Multi-agent path finding with mutex propagation. *Artificial Intelligence*, *311*, 103766.

[7] Boyarski, E., Felner, A., Le Bodic, P., Harabor, D. D., Stuckey, P. J., & Koenig, S. (2021). f-Aware Conflict Prioritization & Improved Heuristics For Conflict-Based Search. In *AAAI* (Vol. 35, No. 14, pp. 12241-12248).

Thank you for listening