A Fast Rescheduling Algorithm for Real-Time Multi-Robot Coordination

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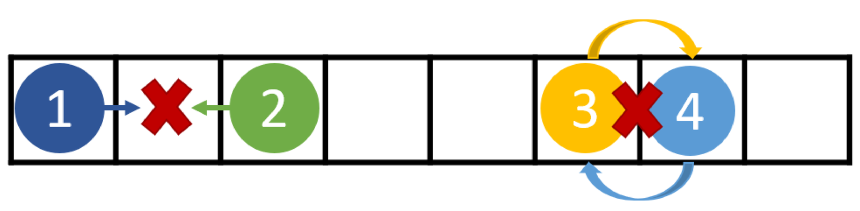
Abstract

- An important area of research in Multi-Agent Path Finding (MAPF) is to determine how re-planning can be efficiently achieved in the case of **the delay of an agent**.
- One option is to **determine a new precedence relationships between the agents** to find the most optimal new solution.
- We propose to use an Edge-Switchable Temporal Plan Graph and an augmented A* algorithm, called Switchable-Edge Search, to approach finding a new optimal precedence relationships between the agents.

1 Multi-Agent Path Finding (MAPF)

- Multi-Agent Path Finding is the problem of finding a set of collision-free paths for a team of agents on a given graph. The objective is to **minimize the sum of the costs of the paths**.



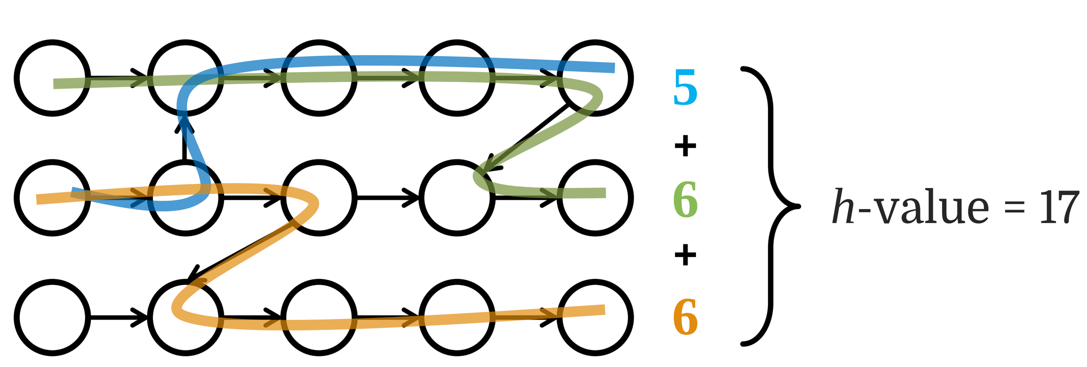
Examples of Agent Collisions [LBF+19]

☐ **Our goal**: After a delay happens, we **optimize the MAPF plan** by **keeping the agents to their pre-planned paths but <u>modifying their ordering of visiting at specific locations</u>** on the fly.

4 Heuristic Calculation

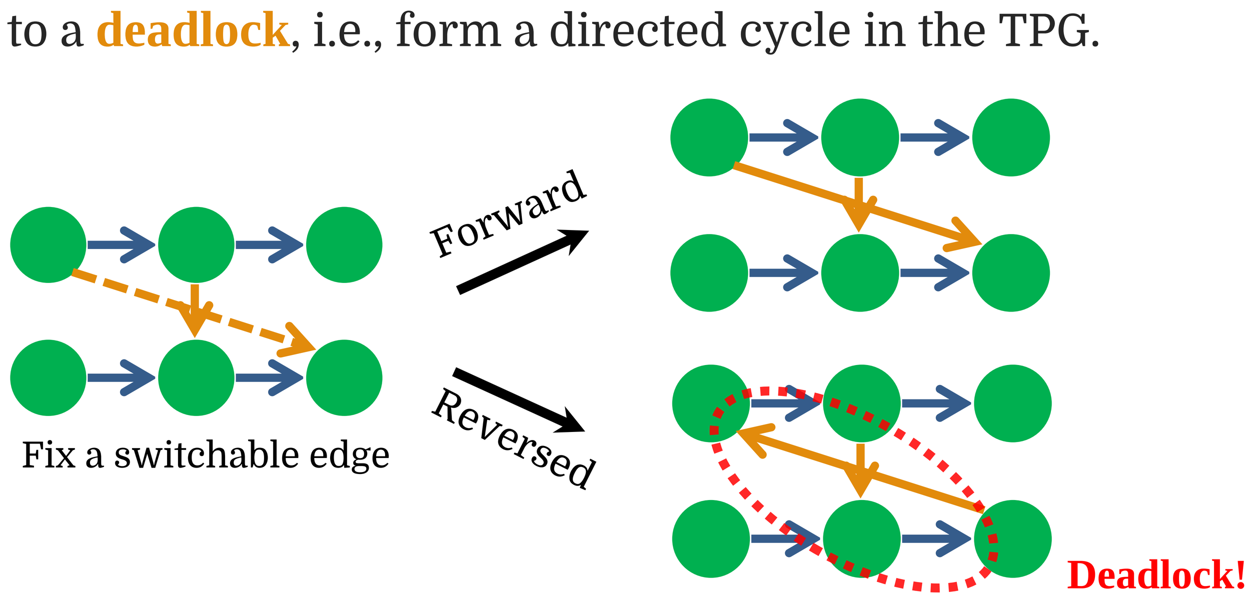
Defn. [*h*-value of a search tree node]
The sum of timesteps all agents take to reach their goals, following their planned paths specified by the TPG that ignores switchable Type 2 edges.

- Naïve Approach: simulating the agents' movements
- Fast Approach: graph search for longest paths



5 Cycle Detection

- Once we fix the direction of a switchable edge, it can lead to a **deadlock**, i.e., form a directed cycle in the TPG.



- We implement a **deadlock-detection mechanism** to efficiently identify such deadlocks before computing the heuristic.

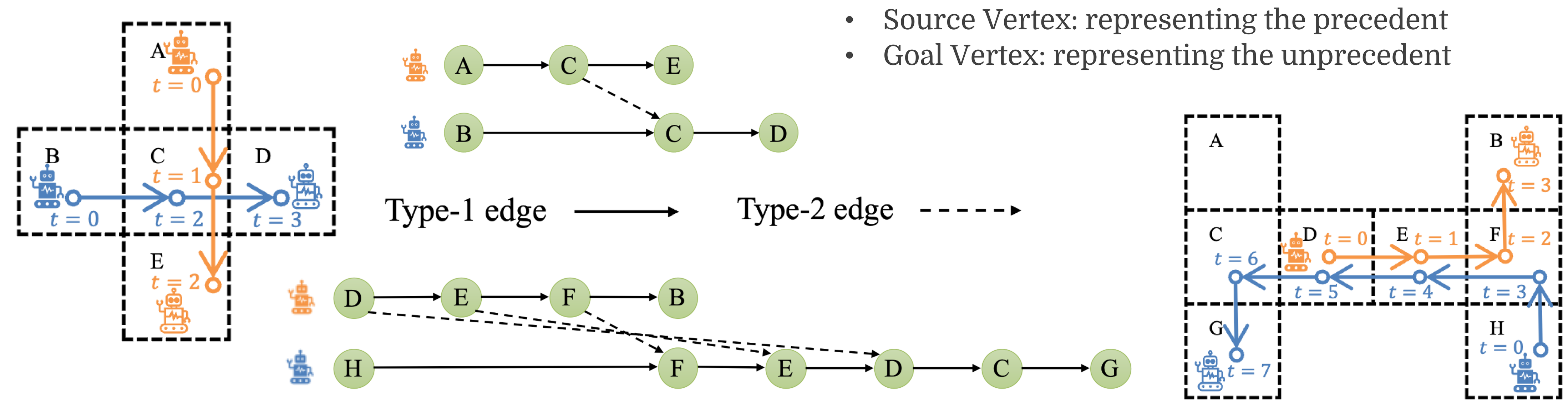
References

[HKC+16] Hönig, W.; Kumar, T. K. S.; Cohen, L.; Ma, H.; Xu, H.; Ayanian, N.; and Koenig, S. 2016. Multi-Agent Path Finding with Kinematic Constraints. In International Conference on Automated Planning and Scheduling.
[LBF+19] Li, J.; Felner, A.; Boyarski, E.; Ma, H.; and Koenig, S. 2019. Improved Heuristics for Multi-Agent Path Finding with Conflict-Based Search. In International Joint Conference on Artificial Intelligence.

2 Temporal Plan Graph (TPG)

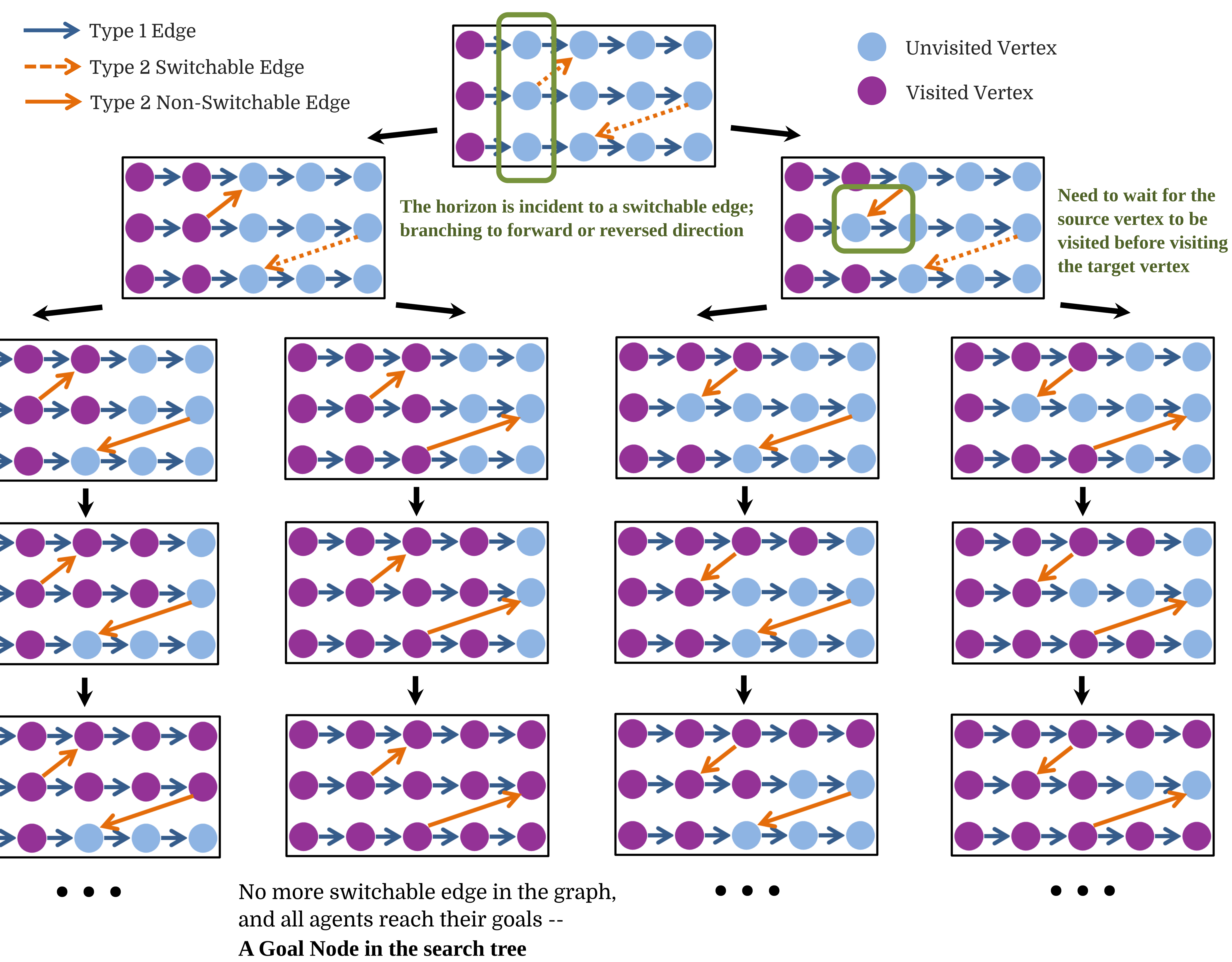
A directed graph that represents the **precedence relationships** of a given MAPF plan [HKC+16]

- ➢ Type 1 Edges: denoting the same agent moving from one location to the next location on its paths.
- ➢ Type 2 Edges: denoting two different agents planning to visit the same location.
  - Source Vertex: representing the precedent
  - Goal Vertex: representing the unprecedent



- We execute the plan by asking the agents to follow the TPG: at each time step, an agent moves to its next vertex **if and only if all the in-neighbors of that vertex have already been visited.**
- When a delay happens, we optimize the TPG by:
  1. Marking all Type 2 edges with unvisited endpoints to be **switchable**
  2. **Reversing the directions** of some switchable edges to get new precedence relationships
- Our algorithm search for the set of modifications (reversing) to the TPG that results in the optimal ordering given the delay.

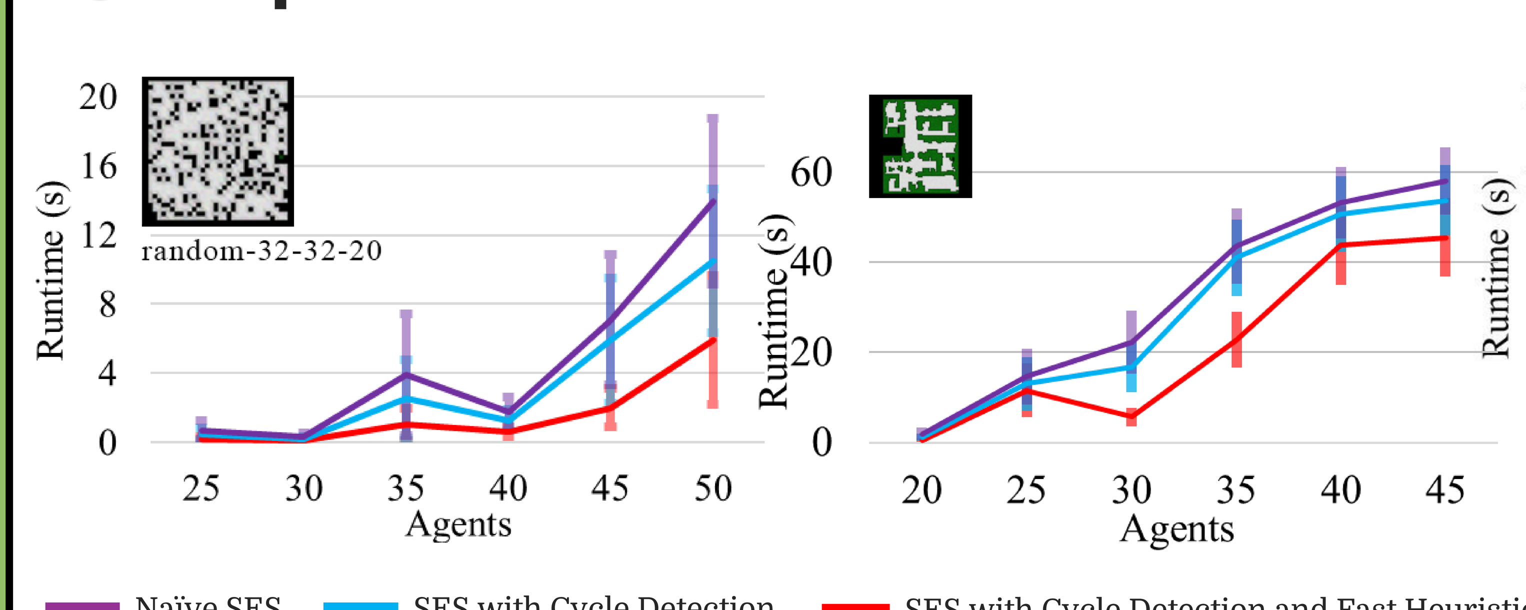
3 Switchable-Edge Search (SES): An Augmented A* Algorithm



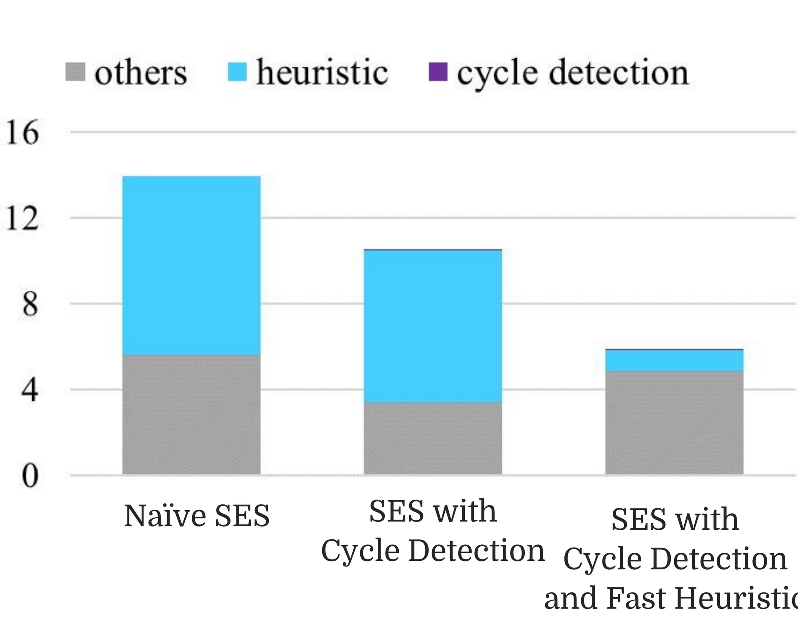
Given a switchable TPG, we **pick the direction of the switchable edges** to result in a most optimal* solution.

[*] Our algorithm guarantees the optimality of the solution

6 Experiments



The figures show average runtimes (indicated by lines) with standard error (indicated by vertical bars) over 25 trials on two different maps, with a runtime limit of 90 seconds.



The figure shows the runtime breakdown for 50 agents over 25 trials on a 32 × 32 random map.