USC University of Southern California Ben-Gurion University of the Negev

Moving Agents in Formation in Congested Environments

Jiaoyang Li,[1] Kexuan Sun,[1] Hang Ma,[2] Ariel Felner,[3] T. K. Satish Kumar[1] and Sven Koenig[1]

[1] University of Southern California

[2] Simon Fraser University

[3] Ben-Gurion University of the Negev

AAMAS-20

Motivation

Figure sources:
[1] https://en.wikipedia.org/wiki/Cossacks:_European_Wars#/media/File:3_cossacks_european_wars.JPG
[2] https://futureoflife.org/wp-content/uploads/2019/04/Why-ban-lethal-AI-1030x595.jpg

Motivation

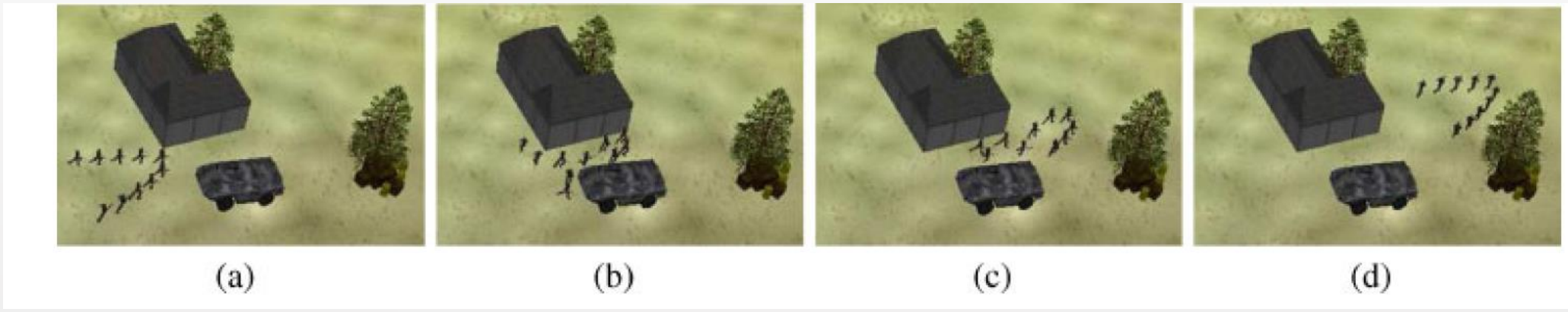


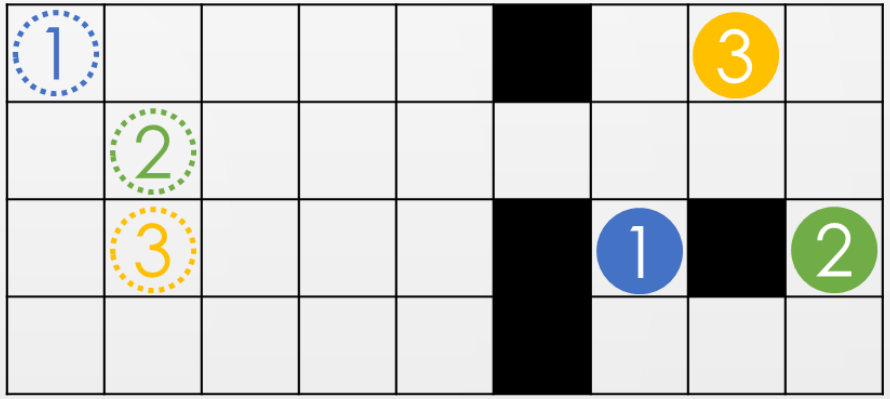
Figure source:
[1] Renato Silveira, Edson Prestes e Silva Jr., Luciana Porcher Nedel. Managing coherent groups. Journal of Visualization and Computer Animation 19(3-4): 295-305 (2008).

Overview

- Moving agents in formation
  - Definition
  - Related work
- SWARM-MAPF
  - Choose a leader
  - Partition the leader's path into segments and plan paths for each segment
- Experiments

Problem Definition

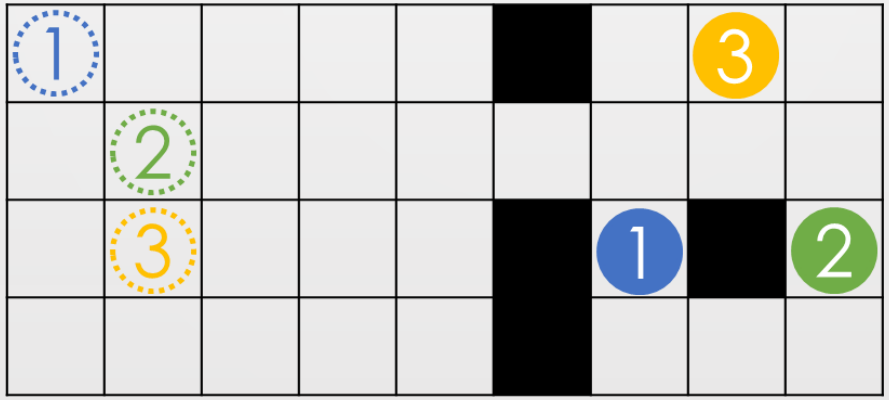
- Inputs
  - An undirected graph
  - M agents, each with
    - a start location,
    - a goal location.



- Output
  - A set of *collision-free* paths, one for each agent.

Problem Definition

- Formation
  - The **formation** of the agents at timestep t is specified by the coordinates of the locations of all agents at timestep t.
  - The **desired formation** is specified by the coordinates of the goal locations.



Formation Deviation

- The **formation deviation** $\mathcal{F}(t)$ captures the *least effort* required for the agents to move from their current formation to their desired formation when ignoring obstacles on the map and collisions between agents.

$$\mathcal{F}(t) = \min_{\mathbf{\Delta x}} \sum_{i=1}^{M} \|\mathbf{u_i} - (\mathbf{v_i} + \mathbf{\Delta x})\|_1$$

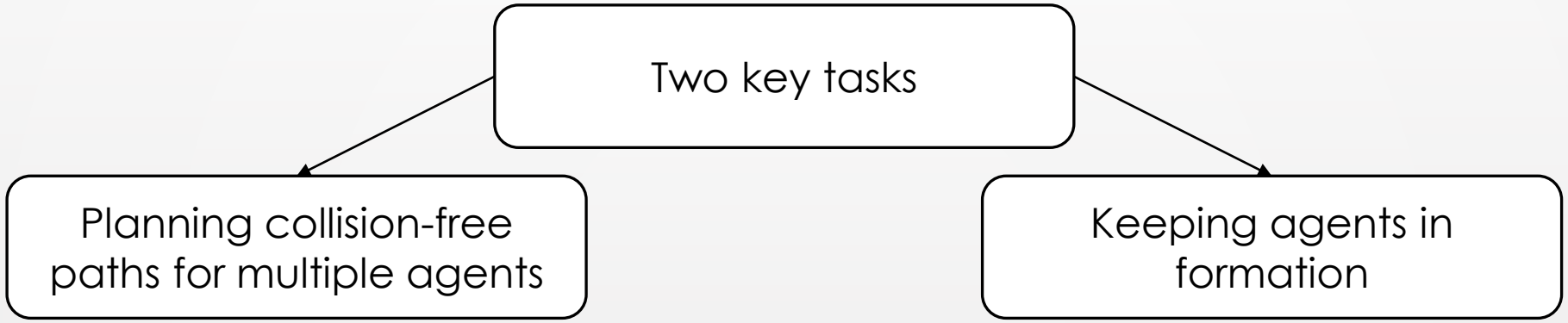
where

- $\mathbf{u_i}$ = the coordinate of the location of agent a_i in the current formation,
- $\mathbf{v_i}$ = the coordinate of the location of agent a_i in the desired formation.

Objective

- The quality of a solution is evaluated by
  - Its **makespan** and
  - Its **total formation deviation** $\sum_t \mathcal{F}(t)$.

Related Work



Multi-Agent Path Finding (MAPF) in AI:
- Conflict-Based Search
- A* in joint-state space
- Reduction-based methods
- Priority-based methods
- Rule-based methods
- …

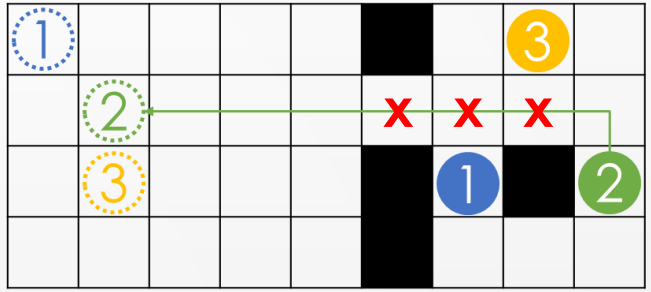
Formation control in Robotics:
- Leader-follower methods
- Potential-field methods
- Behavior-based methods
- Virtual-structure methods
- …

SWARM-MAPF

1. Choose a leader among the agents.
2. Partition the leader's path into **open** and **congested** segments.
   - For each open segment, plan paths by a leader-follower method.
   - For each congested segment, plan paths by a MAPF method.

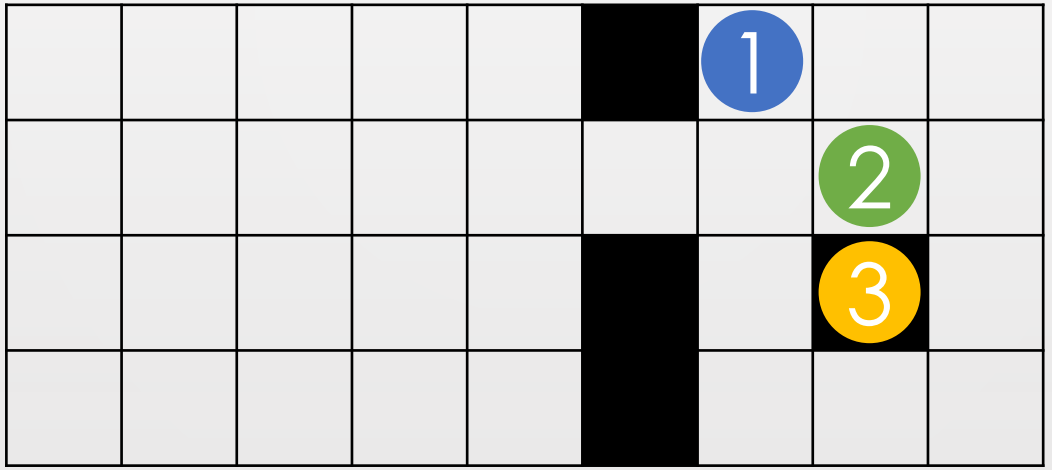
SWARM-MAPF

1. **Choose a leader**



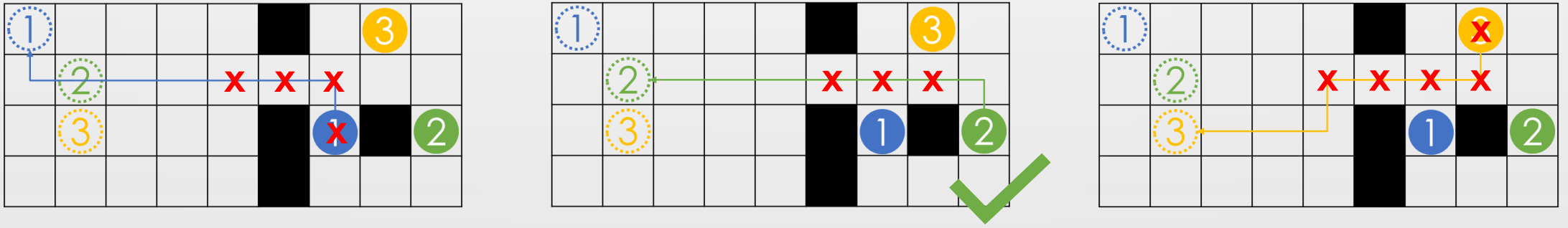
formation-blocking location!

Number of formation-blocking locations = 3



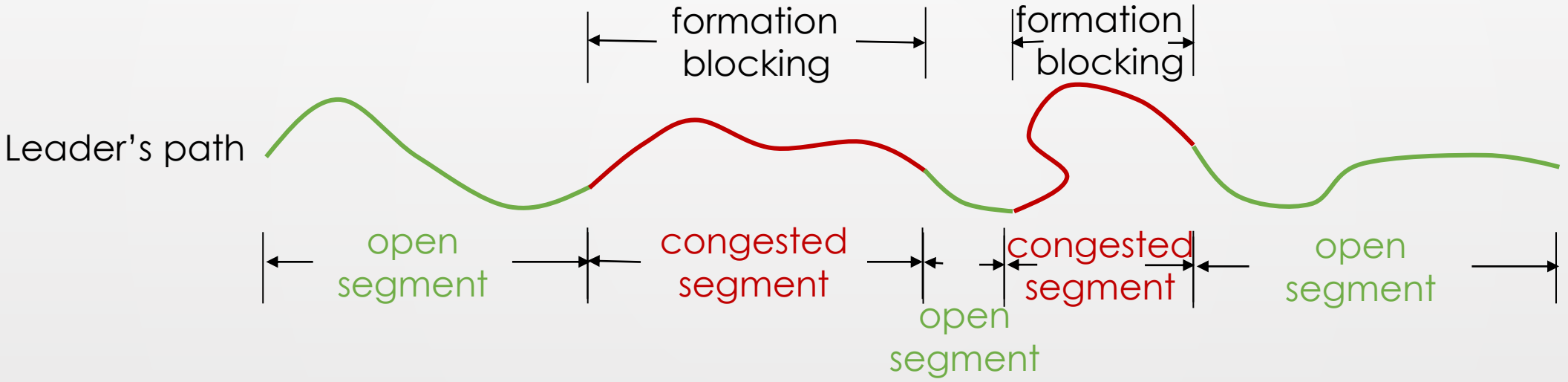
SWARM-MAPF

1. **Choose a leader**
   a. For each agent, find a *short* path that minimizes the number of formation-blocking locations.
   b. Choose the agent as the leader whose path has the minimum number of formation-blocking locations.



SWARM-MAPF

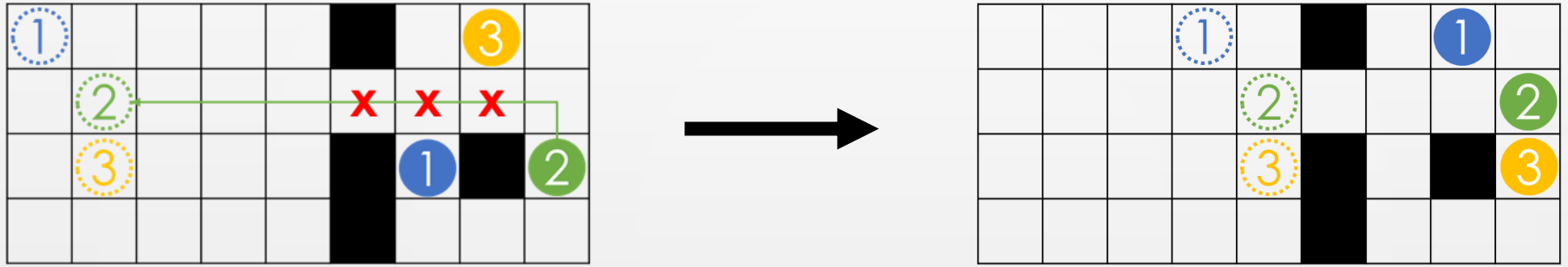
2. Partition the leader's path into segments



- Open segment: Ask all agents to follow the leader's path in the desired formation.
- Congested segment: Call a (modified) MAPF solver to plan collision-free paths.

SWARM-MAPF

Congested segment:

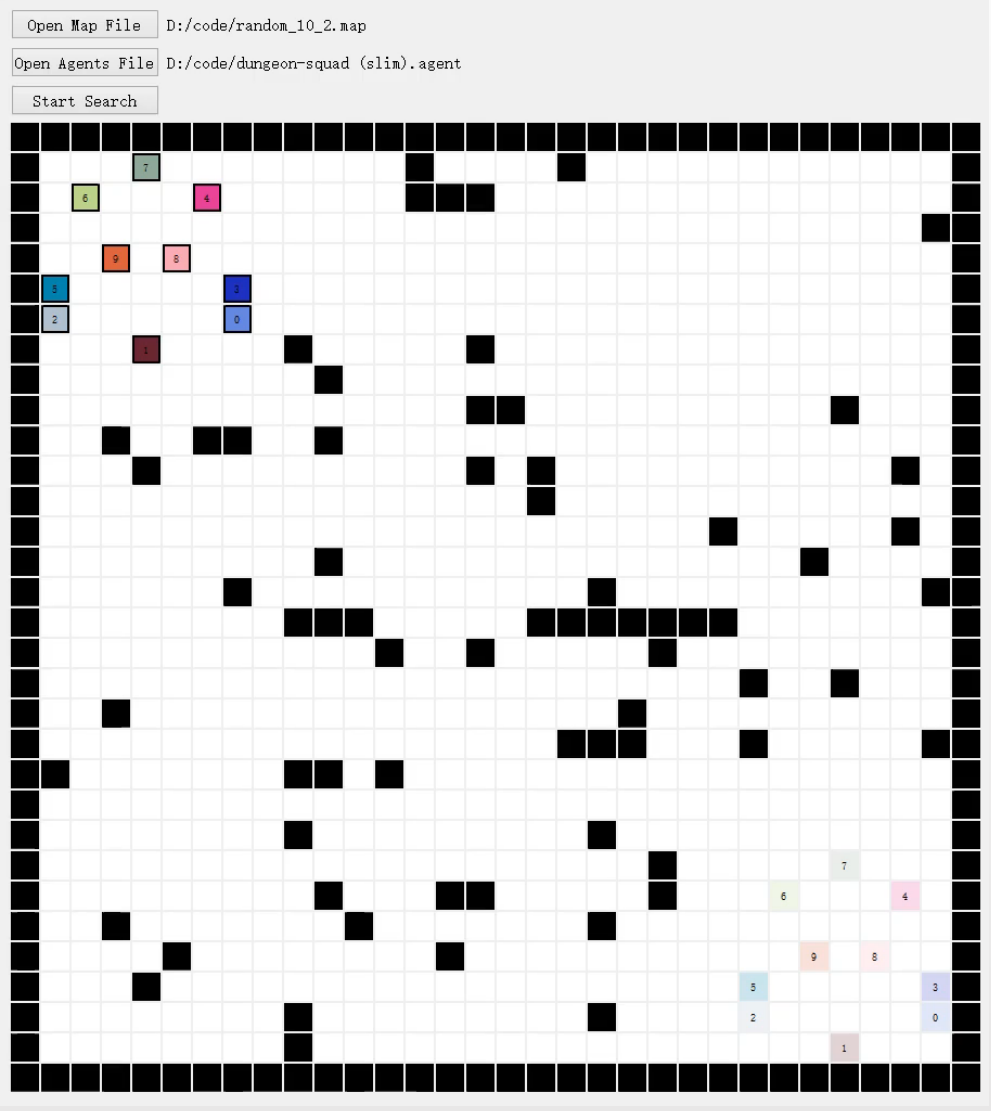


- We use CBS-M, a modified CBS [Sharon et al., 2015], to solve the sub-instance:
  - CBS-M is guaranteed to find collision-free paths with the minimum makespan.
  - CBS-M break ties by preferring paths with smaller total formation deviations in both its high- and low-level searches.

[1] Guni Sharon, Roni Stern, Ariel Felner, and Nathan R. Sturtevant. 2015. Conflict-Based Search for Optimal Multi-Agent Pathfinding. Artificial Intelligence 219(2015), 40–66.

Random Map

Runtime = 0.34 seconds.



Random Map

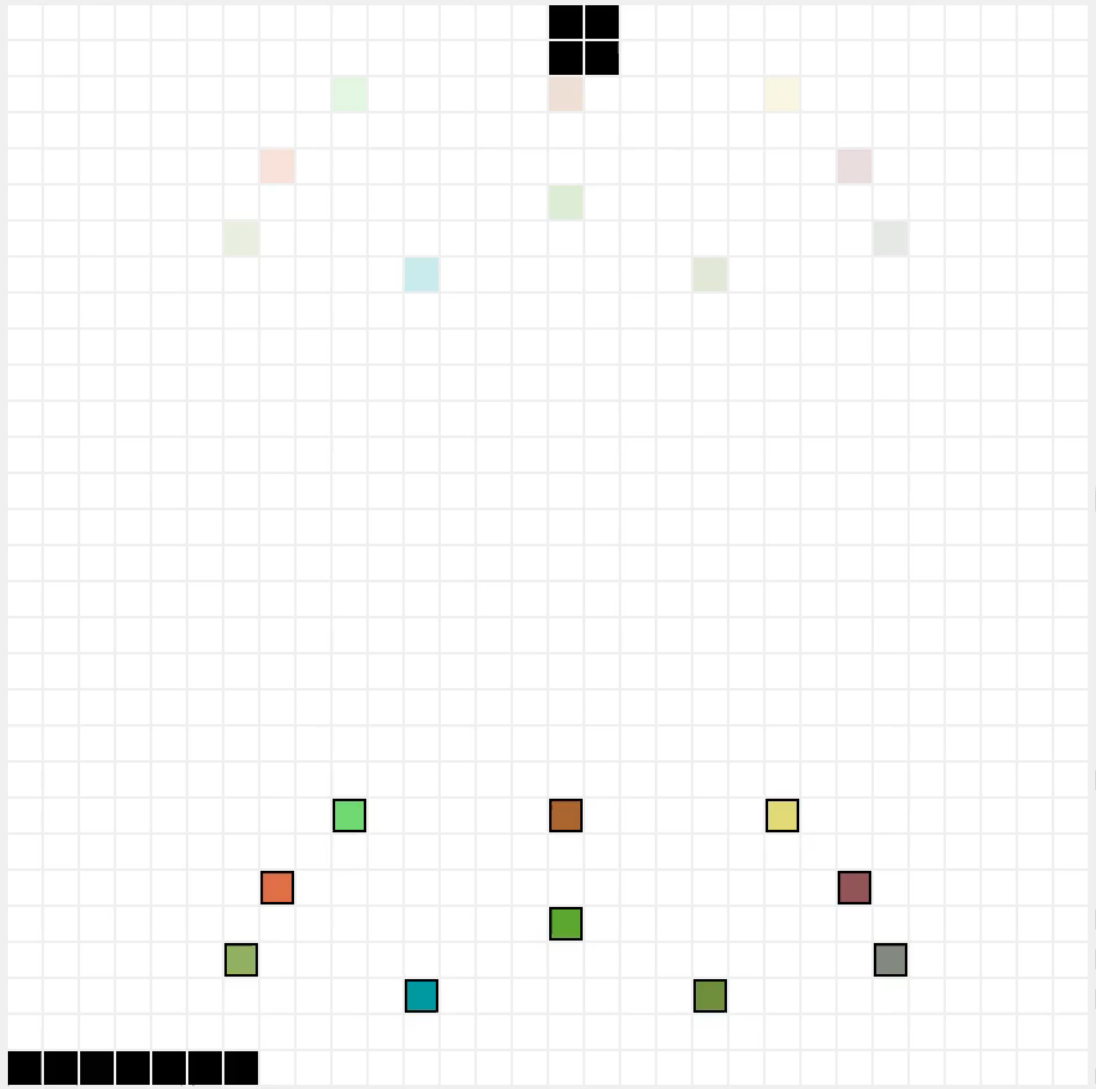
Agents	Makespan		Total formation deviation		Runtime (s)	
	CBS-M	SWARM-MAPF	CBS-M	SWARM-MAPF	CBS-M	SWARM-MAPF
5	44	48	64	9	0.02	0.03
10	44	56	162	57	0.04	0.16
15	44	59	523	144	0.16	0.29
20	44	59	681	267	0.44	0.42
25	44	58	1,190	448	1.96	0.69
30	44	55	1,798	696	0.50	0.75
35	44	53	2,212	1,044	2.84	2.30
40	44	52	3,331	1,572	10.62	10.43

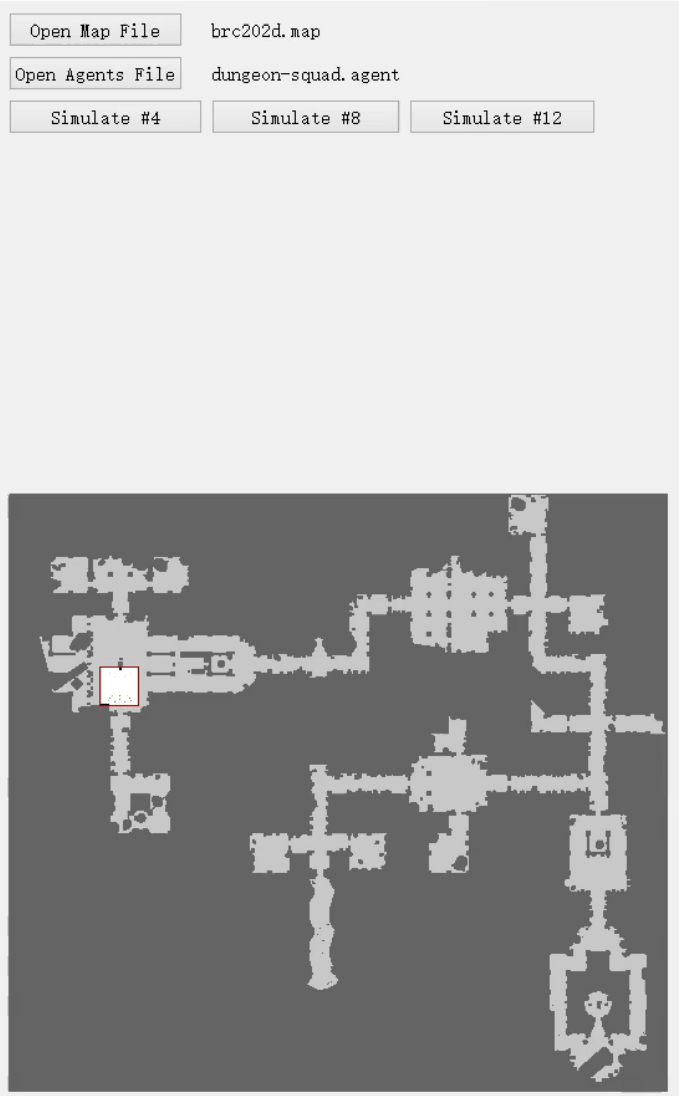
Game Map

The desired formation is specified by the initial goal locations.

The goal locations are updated every 12 timesteps.

Total runtime = 1.13 seconds.





Summary

- **Moving agents in formation**
  - Planning collision-free paths for multiple agents.
  - Keeping agents in formation.
- **SWARM-MAPF**
  - Complete.
  - Produces solutions that keep agents in formation better than CBS-M with only a small loss of optimality in makespan.
  - Scales up to 40 agents.