# NRI: INT: COLLAB: Interactive and collaborative robot-assisted emergency evacuations

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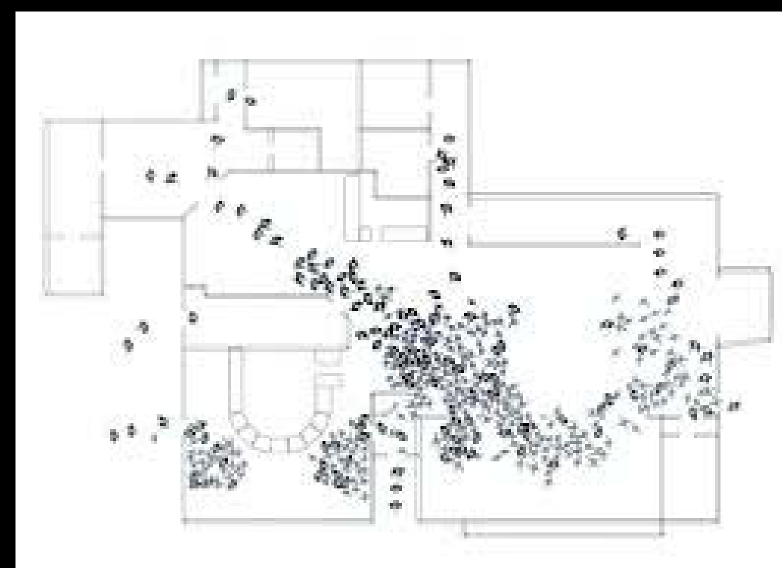
# Emergency Evacuations


Evacuees tend to exit through the same door they entered (NIST, 2005)



High casualties at choke points (100 dead in 2003 Station Nightclub Fire)

# Emergency Evacuation Robots

- Increase survivability
- Increase awareness
- Reduce response time
- Reduce distance to guidance signs
- Reduce number of emergency personnel

# How do we create Emergency Evacuation Robots?

1. Collect data to create models of evacuees (Wagner)
2. Develop control methods to shepherd evacuees to safety (Zhu)
3. Develop dispersion methods for initial placement of robots (Lin)

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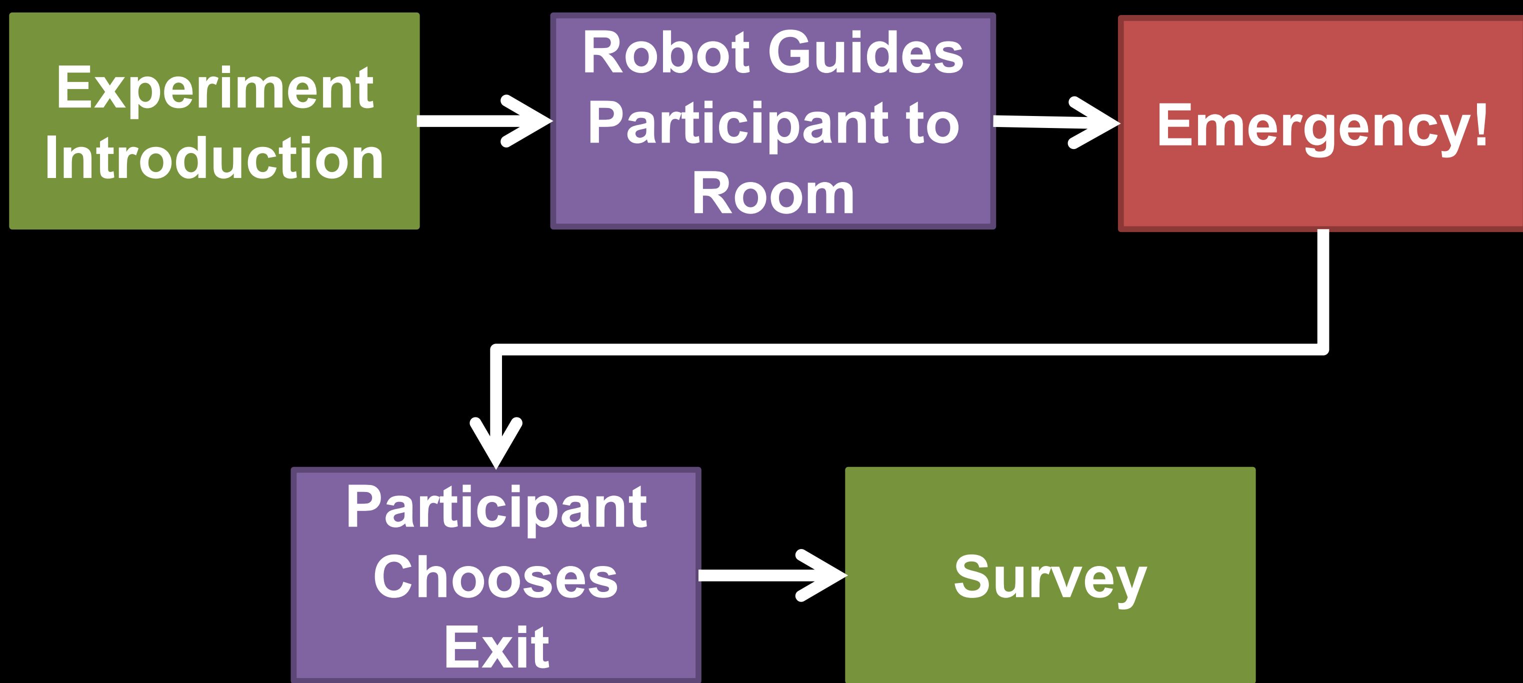
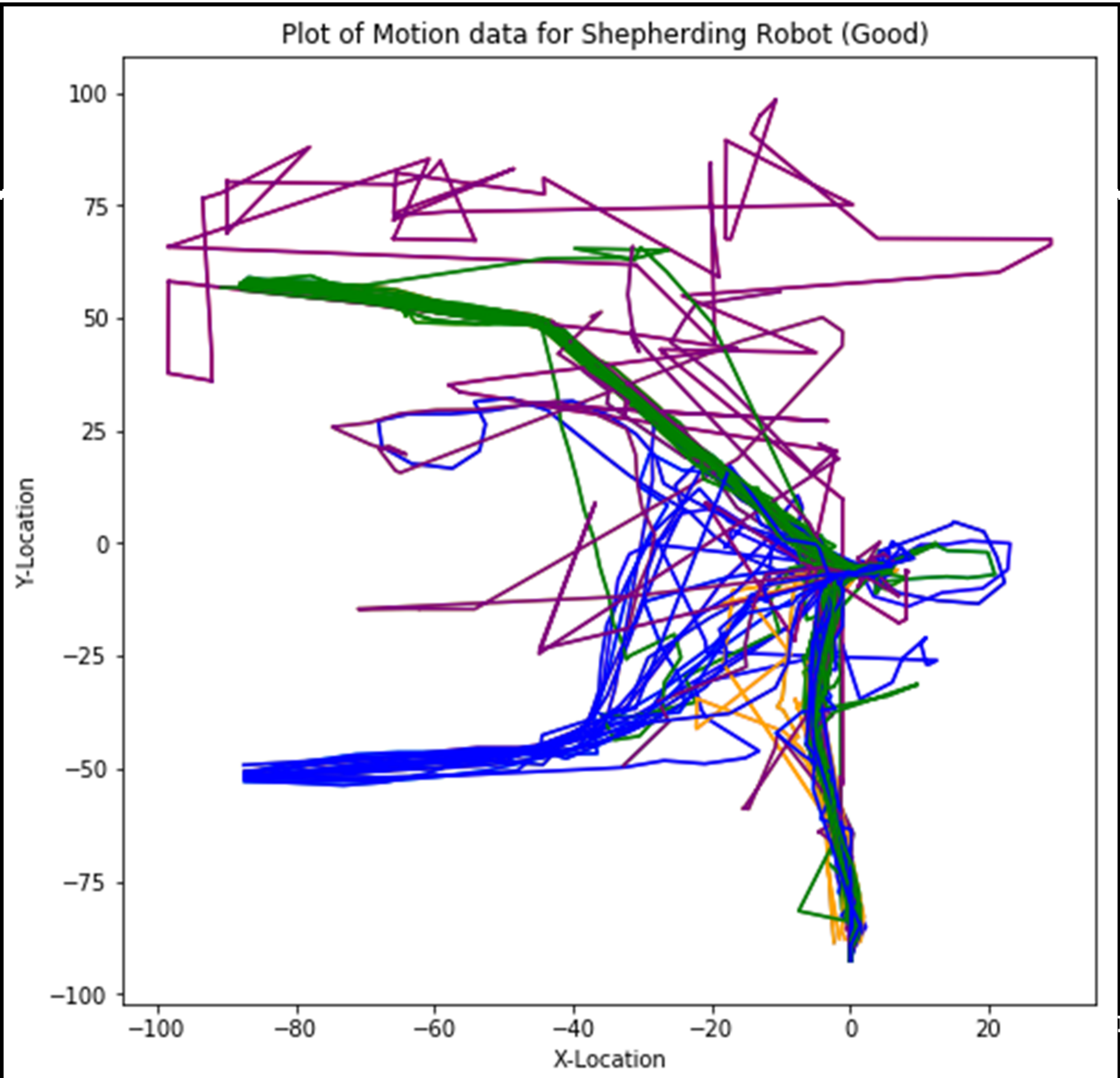
# Developing Practical Robot Evacuation Guides

- Influence of other people
  - Factor 1: Individuals vs. Groups
- Factor 2: Robot paradigm
  - Shepherding: single robot leads group to an exit
    - + Possible compliance advantage?
    - Difficult
  - Handoffs: robots at each decision point
    - + Easier
    - Compliance disadvantage?

# Experimental Setting



# Simulation Environment


Plot of Motion data for Shepherding Robot (Good)
Y-Location
X-Location
100
75
50
25
0
−25
−50
−75
−100
−100
−80
−60
−40
−20
0
20

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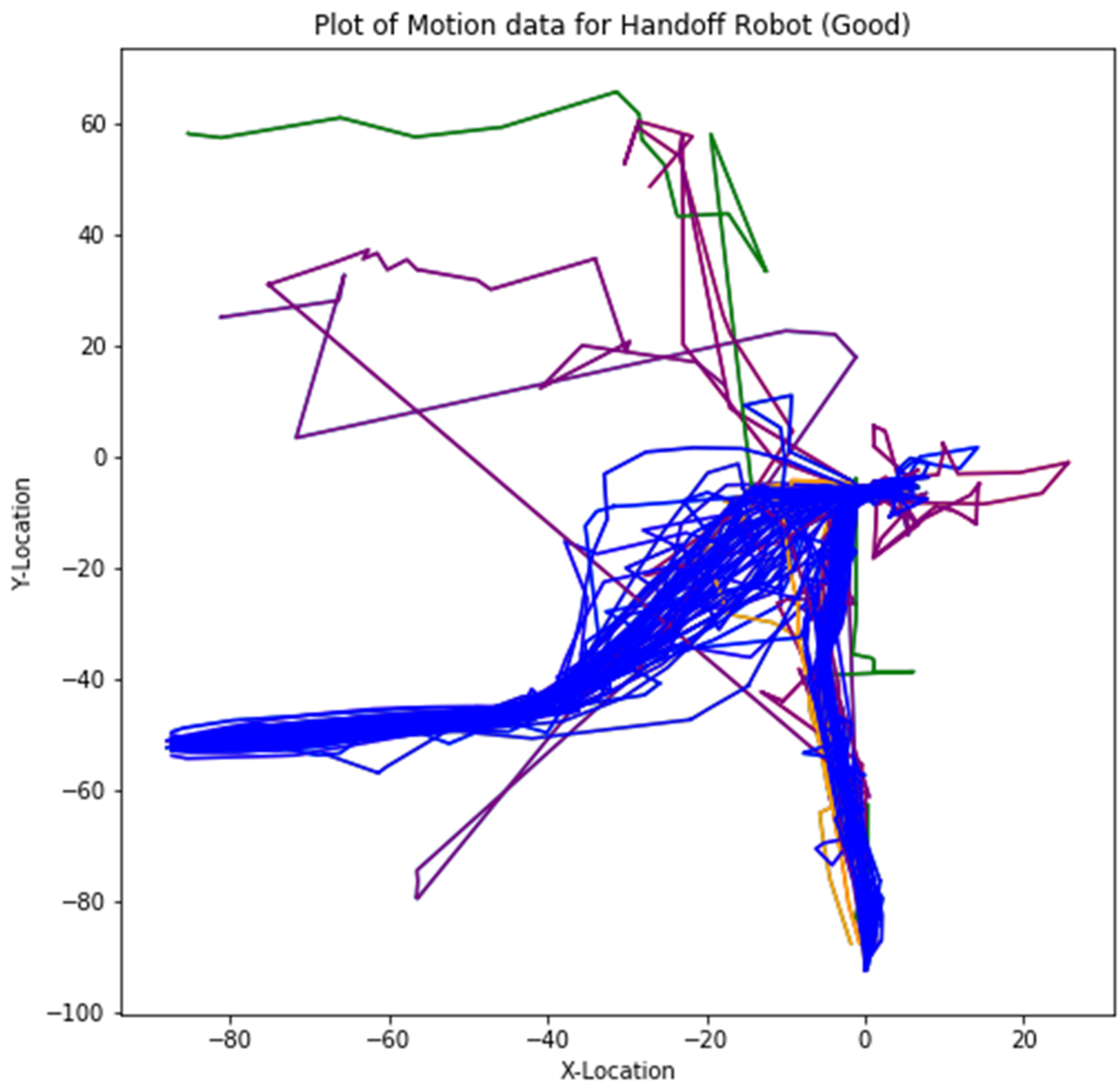
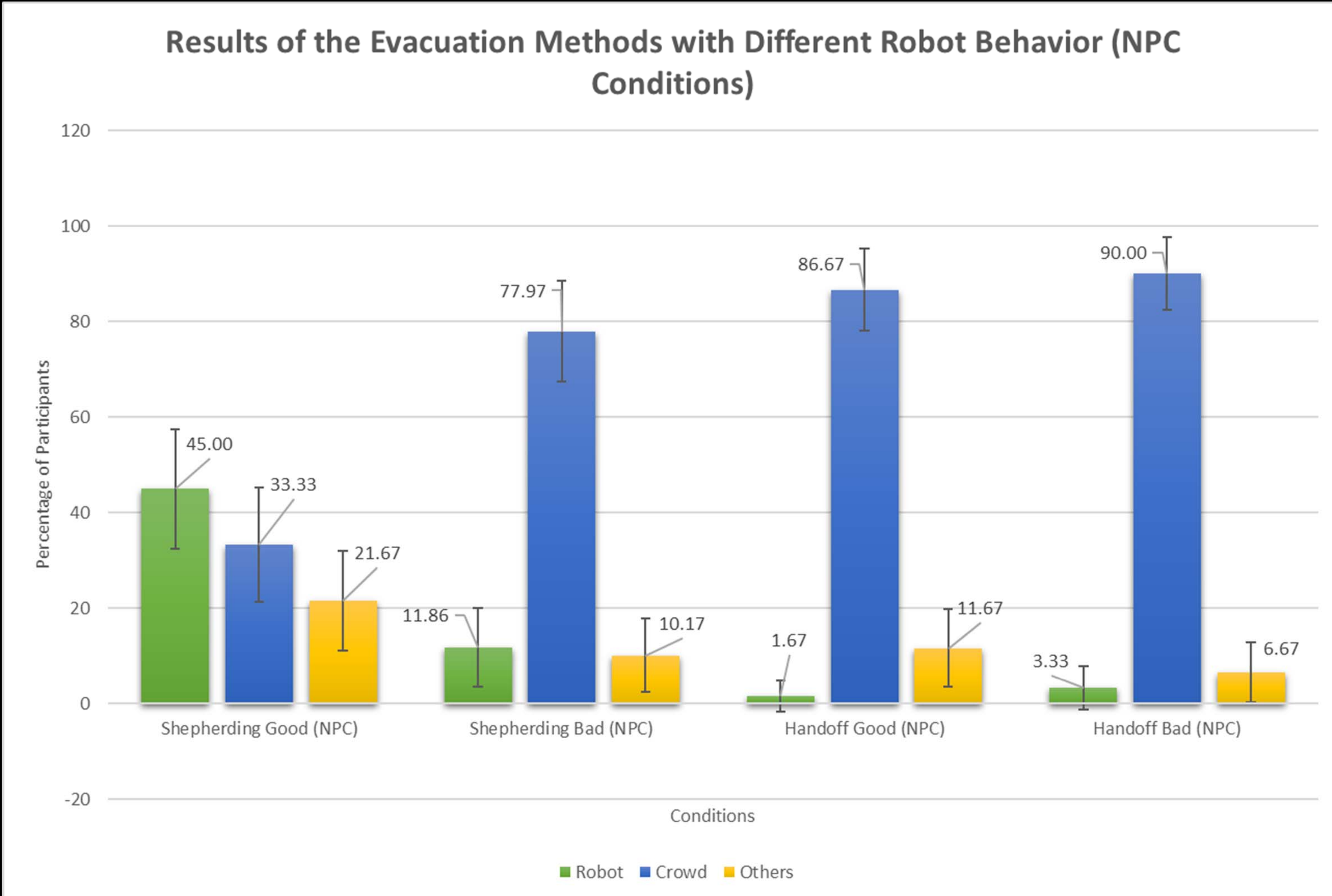

Plot of Motion data for Handoff Robot (Good)
Y-Location
X-Location
60
40
20
0
−20
−40
−60
−80
−100
−80
−60
−40
−20
0
20



Results of the Evacuation Methods with Different Robot Behavior (NPC Conditions)
120
100
80
60
40
20
0
-20
Percentage of Participants
45.00
33.33
21.67
11.86
77.97
10.17
1.67
86.67
11.67
3.33
90.00
6.67
Shepherding Good (NPC)
Shepherding Bad (NPC)
Handoff Good (NPC)
Handoff Bad (NPC)
Conditions
Robot
Crowd
Others

# Physical Experiments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# Short Video of Experiment

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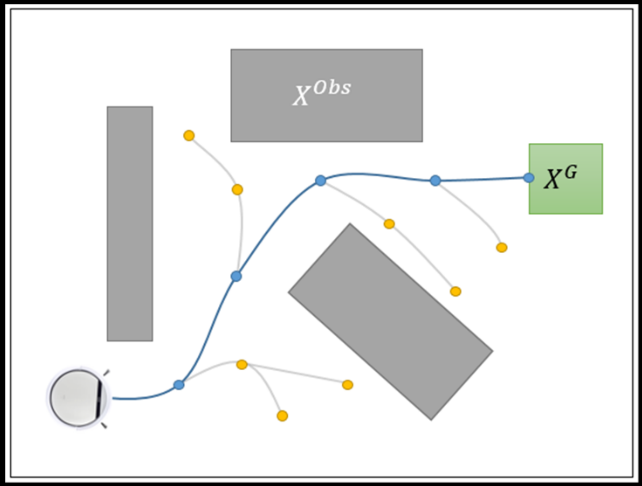
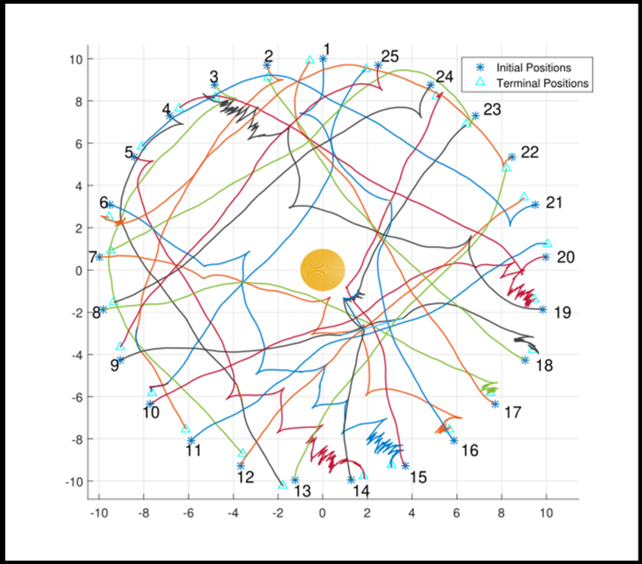
# Scalable multi-robot optimal motion planning – Computational challenge

- Generalized mover's problem is PSPACE-hard;
- Shortest path problem in 3D is NP-hard in the number of obstacles;
- Worst-case complexity of multi-robot motion planning grows exponentially in robot number.



# Scalable multi-robot optimal motion planning – Our solution

Key idea: decoupled optimal feedback planning (offline) + distributed conflict resolution (online)

- Offline: Robot i solves single-robot feedback optimal motion planning;
- Online: (i) If there is no conflict, robot i executes the controller synthesized offline. (ii) If there is a conflict with a high-ranked robot, robot i treats it as a moving obstacle and actively escapes from it.

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# Scalable multi-robot optimal motion planning – Performance guarantee

Key idea: decoupled optimal feedback planning (offline) + distributed conflict resolution (runtime)

Theoretic guarantee: All the unicycle robots safely reach their goals in finite time.

Computational complexity: (1) offline complexity is independent of robot number; (2) online execution is spatially distributed.

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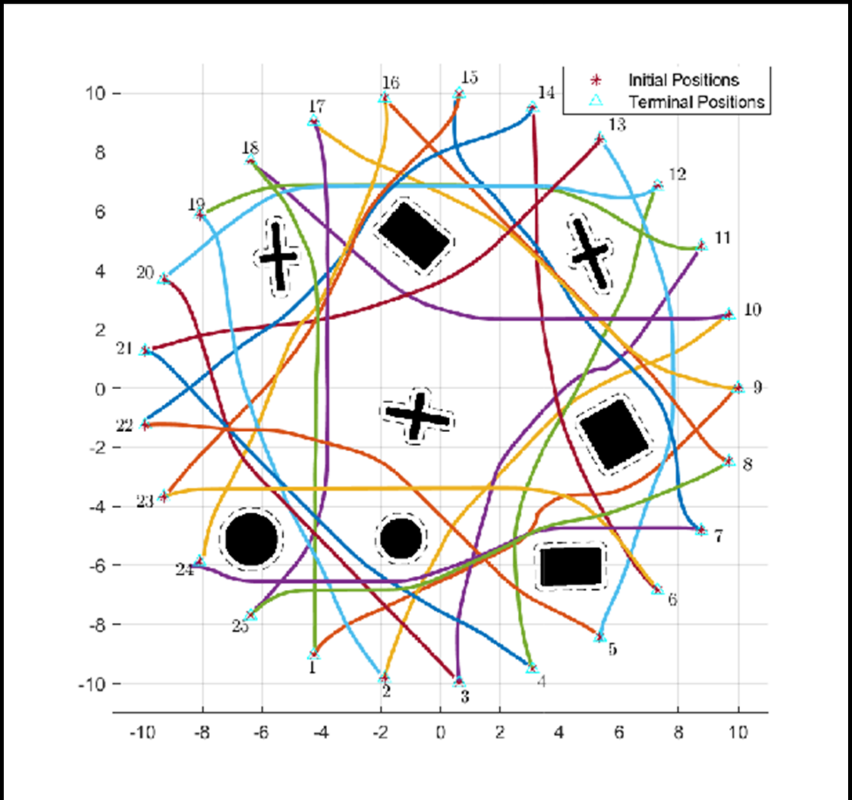
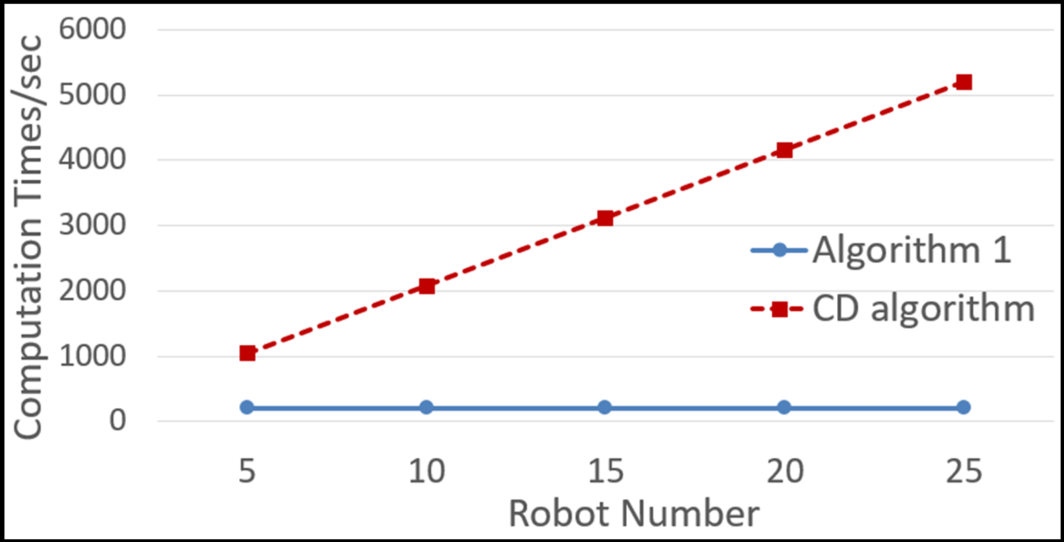
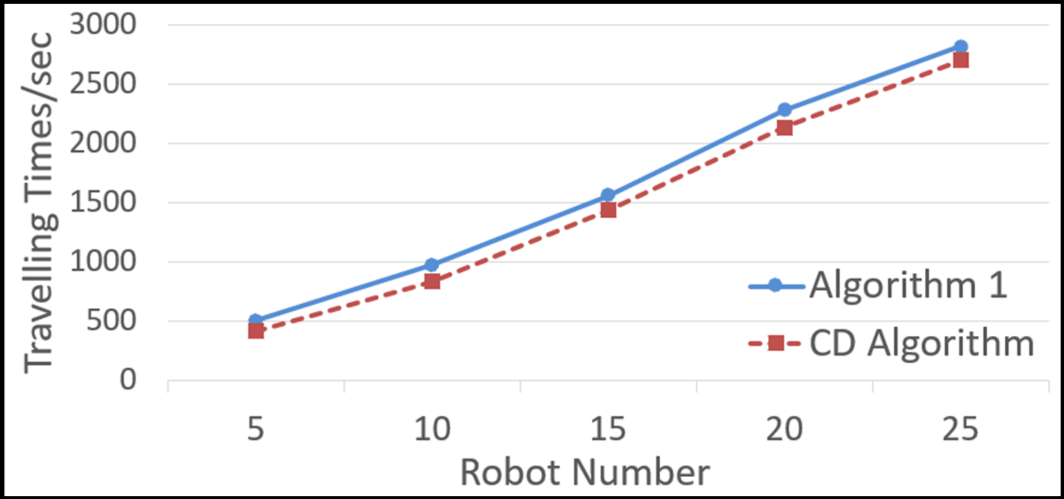
# Scalable multi-robot optimal motion planning – Simulation



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# Evacuation by density control

- Idea: robots generate navigation fields to guide the crowd to a safe location
- Micro-level: explicit modeling of human-robot interaction
- Macro-level: crowd density controlled by navigation fields
- Feedback design: dynamically control robot states based on real-time crowd density
- Result: crowd density convergence guaranteed

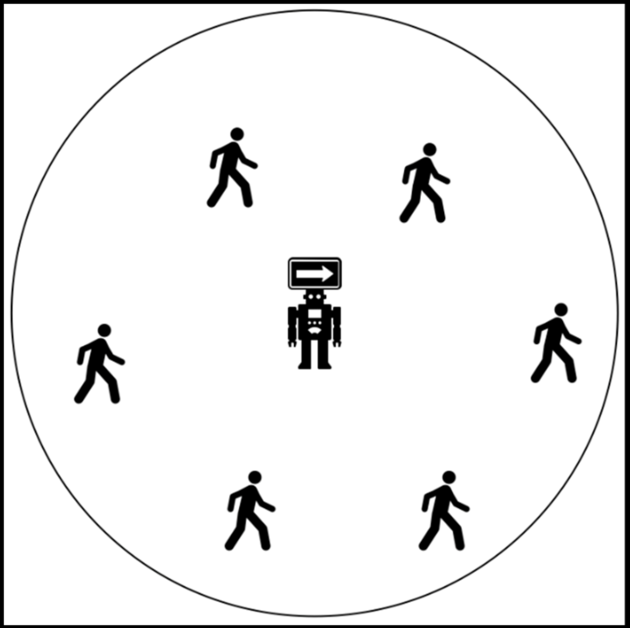

Fig. Robot generating navigation fields by providing directed signs.

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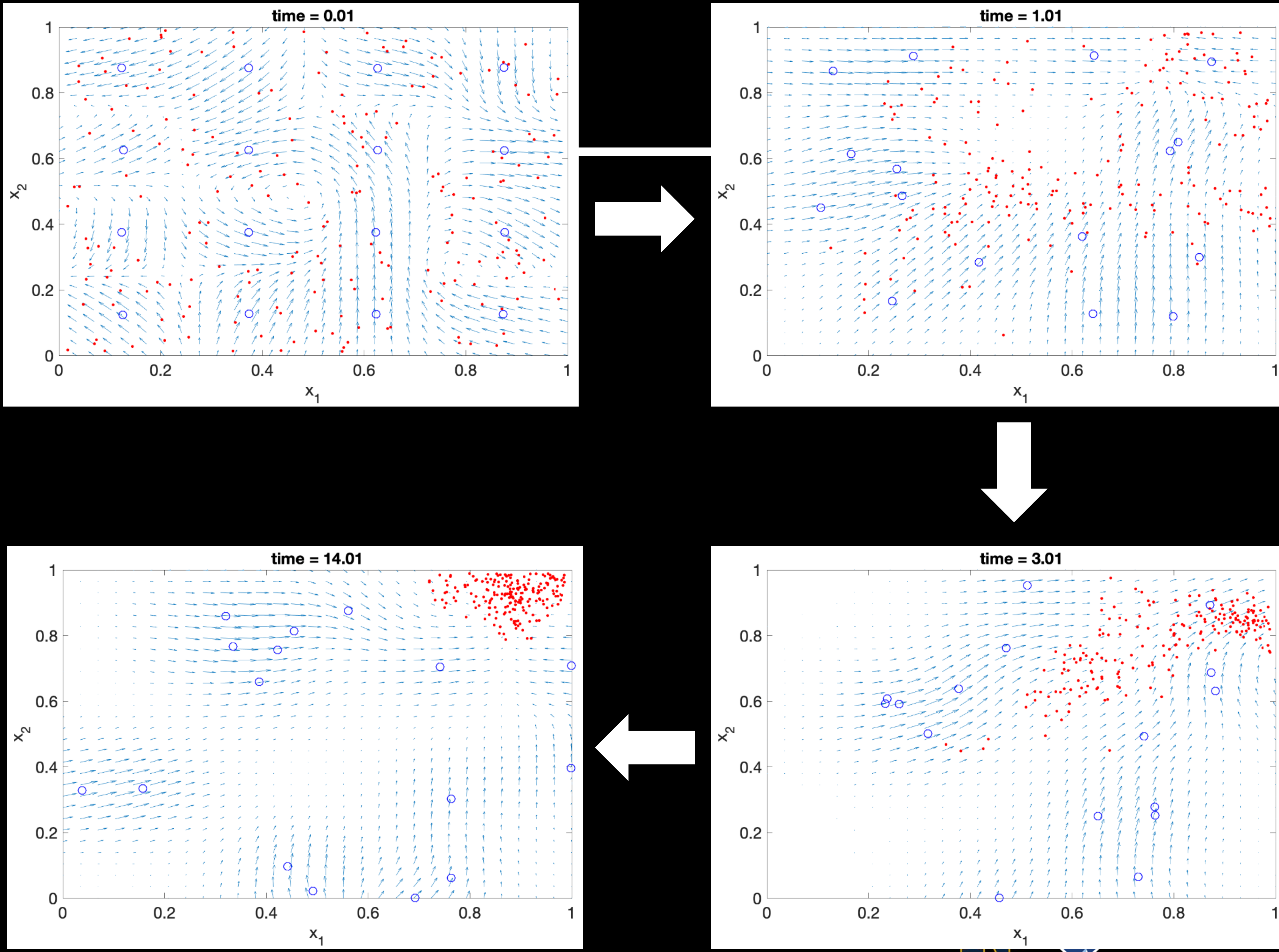
time = 0.01
time = 1.01
time = 3.01
time = 14.01
x1
x2
0
0.2
0.4
0.6
0.8
1

# Thank You

## Journal articles:


- Zheng, Tongjia, Qing Han, and Hai Lin. "Transporting robotic swarms via mean-field feedback control." IEEE Transactions on Automatic Control (2021).
- Zheng, Tongjia, Qing Han, and Hai Lin. "Distributed Mean-Field Density Estimation for Large-Scale Systems." IEEE Transactions on Automatic Control (2021).
- Zheng, Tongjia, Qing Han, and Hai Lin. "Pde-based dynamic density estimation for large-scale agent systems." IEEE Control Systems Letters 5.2 (2020): 541-546.
- G. Zhao and M. Zhu. Scalable distributed algorithms for multi-robot near-optimal motion planning. Automatica, 2022. To appear.
- G. Zhao and M. Zhu. Pareto optimal multi-robot motion planning. IEEE Transactions on Automatic Control, 66(9):3984-3999, 2021.


## Conferences:


- Zheng, Tongjia, and Hai Lin. "Field estimation using robotic swarms through Bayesian regression and mean-field feedback." 2021 American Control Conference (ACC). IEEE, 2021.
- Zheng, Tongjia, and Hai Lin. "Distributed density filtering for large-scale systems using mean-filed models." 2021 American Control Conference (ACC). IEEE, 2021.
- Zheng, Tongjia, Zhiyu Liu, and Hai Lin. "Complex pattern generation for swarm robotic systems using spatial-temporal logic and density feedback control." 2020 American Control Conference (ACC). IEEE, 2020.
- Nayyar, M., Zoloty, Z., McFarland, C., & Wagner, A. R. (2020, November). Exploring the effect of explanations during robot-guided emergency evacuation. In International Conference on Social Robotics (pp. 13-22). Springer, Cham.
- Nayyar, M., & Wagner, A. R. (2019, October). Effective robot evacuation strategies in emergencies. In 2019 28th IEEE International Conference on Robot and Human Interactive Communication (RO-MAN) (pp. 1-6). IEEE.
- Y. Lu, Y. Guo, G. Zhao and M. Zhu. Distributed safe reinforcement learning for multi-robot formation control. 2021 Mediterranean Conference on Control and Automation, Puglia, Italy, pages:1209-1214, June 2021.
- R. Yu, Z. Yuan, M. Zhu and Z. Zhou. Data-driven distributed state estimation and behavior modeling in sensor networks. 2020 IEEE/RSJ International Conference on Intelligent Robots and Systems, Las Vegas, NV, pages:8192-8199, October 2020.
- G. Zhao and M. Zhu. Scalable distributed algorithms for multi-robot near-optimal motion planning. 2019 IEEE Conference on Decision and Control, Nice, France, pages:226-231, Dec 2019.


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# Five Principles of Evacuation Robotics

1. Do no harm
2. Communicate understandably with as wide a variety of people as possible
3. Be authoritative
4. Attract attention, but also keep interactions minimal
5. When the situation demands it, evacuate as many people as possible, as quickly as possible

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