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Leading Multi-Agent Teams to Multiple Goals While Maintaining Communication

Robotics: Science and Systems 2020

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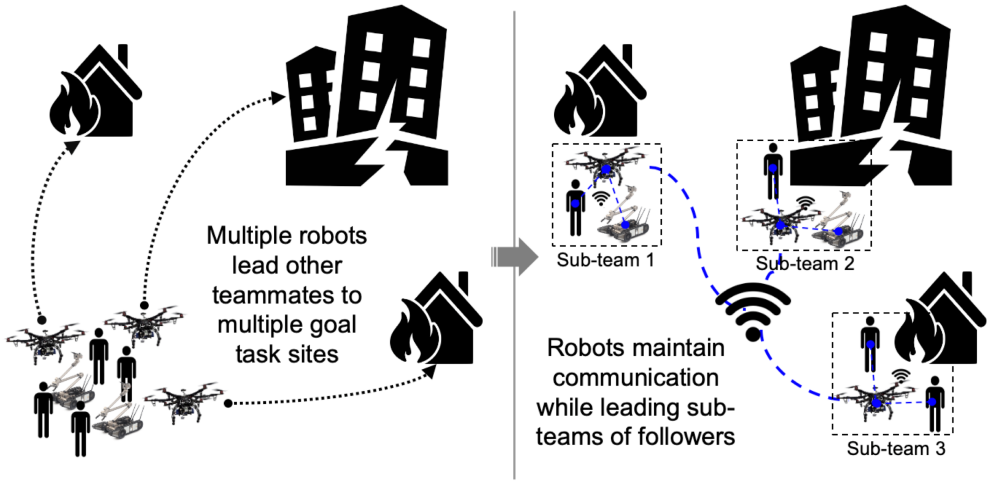
Overview

We address the problem of influencing a team such that its members can be guided to goal positions by leaders that maintain communication with their followers and other leaders.

Contributions

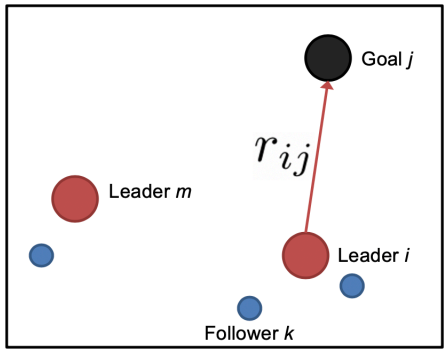
- We propose a principled approach to address the problem by optimizing the competing utilities to make progress towards goals while maintaining communication.
- We introduce an iterative solver for the formulated objective, which is theoretically guaranteed to converge to the optimal solution.



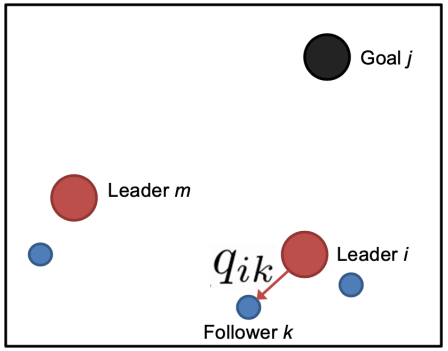
Approach: Problem Formulation

We formulate this problem as a regularized optimization task to find weight matrices ($\mathbf{W}$, $\mathbf{V}$, and $\mathbf{U}$) that optimally balance multiple competing utilities.

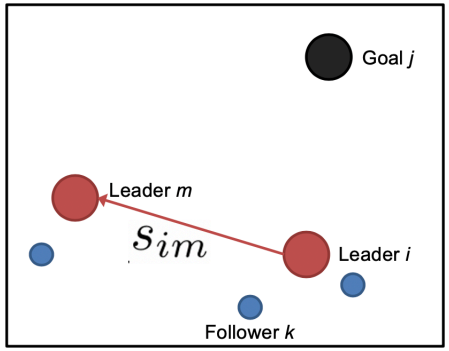
$$\max_{\mathbf{W},\mathbf{V},\mathbf{U}} \|\mathbf{W} \odot \mathbf{R}\|_1 + \|\mathbf{V} \odot \mathbf{Q}\|_1 + \|\mathbf{U} \odot \mathbf{S}\|_1$$



Utility of Leader *i* moving in the direction of Goal *j*, in order to make progress towards that goal.



Utility of Leader *i* moving in the direction of Follower *k*, in order to maintain communication with that follower.



Utility of Leader *i* moving in the direction of Leader *m*, in order to maintain communication with fellow leaders.

Approach: Optimizing Competing Utilities

We introduce constraints and regularization terms to integrate expert knowledge and control the weights assigned to different utilities.

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- Weights must be nonnegative and the weights for each leader must sum to 1.

$$\begin{aligned} \mathbf{W}\mathbf{1}_G &= \mathbf{1}_N & \mathbf{W} &\geq 0 \\ \mathbf{V}\mathbf{1}_F &= \mathbf{1}_N & \mathbf{V} &\geq 0 \\ \mathbf{U}\mathbf{1}_N &= \mathbf{1}_N & \mathbf{U} &\geq 0 \end{aligned}$$

Approach: Optimizing Competing Utilities

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- Weights must be nonnegative and the weights for each leader must sum to 1.
- Leaders should value advancing towards only a single goal.

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$$\|\mathbf{W}\|_G = \sum_{n=1}^{N} \|\mathbf{w}^n\|_2$$

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- No more than one leader should value maintaining communication with an individual follower.

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$$\|\mathbf{W}\|_G = \sum_{n=1}^{N} \|\mathbf{w}^n\|_2$$

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- Weights must be nonnegative and the weights for each leader must sum to 1.
- Leaders should value advancing towards only a single goal.
- No more than one leader should value maintaining communication with an individual follower.
- Weights should be similar to weights at the last time step.

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$$\mathbf{U}\mathbf{1}_N = \mathbf{1}_N \qquad \mathbf{U} \geq 0$$

$$\|\mathbf{W}\|_G = \sum_{n=1}^{N} \|\mathbf{w}^n\|_2$$

$$\|\mathbf{V}\|_L = \sum_{f=1}^{F} \|\mathbf{v}_f\|_2$$

$$\mathcal{T}(\mathbf{W}, \mathbf{V}, \mathbf{U}) = \|\mathbf{W} - \hat{\mathbf{W}}\|_F^2 + \|\mathbf{V} - \hat{\mathbf{V}}\|_F^2 + \|\mathbf{U} - \hat{\mathbf{U}}\|_F^2$$

Approach: Regularized Optimization

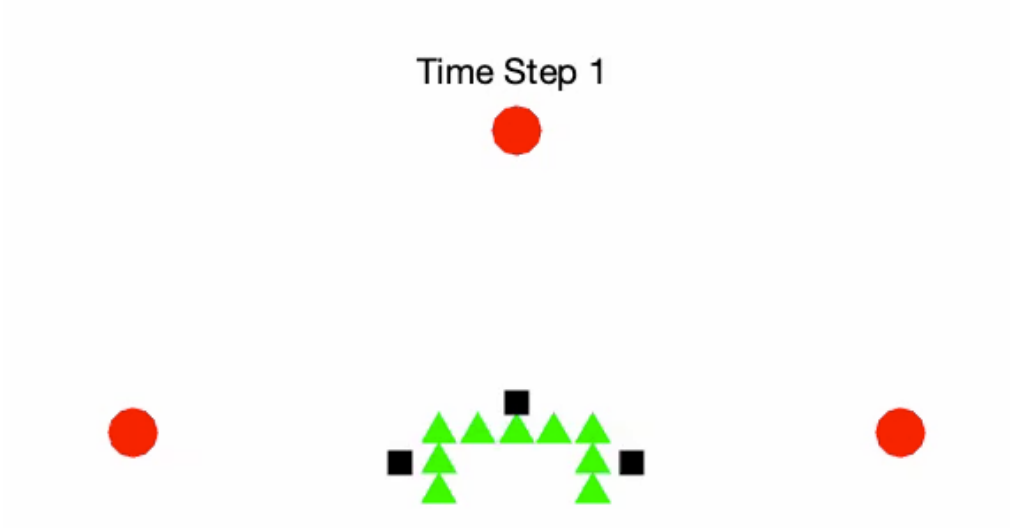
Final regularized constrained optimization formulation:

$$\max_{\mathbf{W},\mathbf{V},\mathbf{U}} \|\mathbf{W} \odot \mathbf{R}\|_1 + \|\mathbf{V} \odot \mathbf{Q}\|_1 + \|\mathbf{U} \odot \mathbf{S}\|_1 + \gamma_1 \|\mathbf{W}\|_G + \gamma_2 \|\mathbf{V}\|_L - \gamma_3 \mathcal{T}(\mathbf{W}, \mathbf{V}, \mathbf{U})$$
$$\text{s.t. } \mathbf{W}\mathbf{1}_G = \mathbf{1}_N, \mathbf{V}\mathbf{1}_F = \mathbf{1}_N, \mathbf{U}\mathbf{1}_N = \mathbf{1}_N, \mathbf{W} \geq 0, \mathbf{V} \geq 0, \mathbf{U} \geq 0.$$

- This final formulation maximizes the overall utility at each time step in order to enable leaders to make progress towards goals while maintaining communication with followers and fellow leaders.
- An iterative algorithm is proposed to solve this regularized optimization problem, which is hard to solve due to equality constraints and non-smooth terms.
- After obtaining optimal $\mathbf{W}$, $\mathbf{V}$, and $\mathbf{U}$, by combining the weights with the movement vectors, we generate an overall position update for each leader.

Experiments: Synthetic Simulations

- Qualitative results on synthetic simulations.



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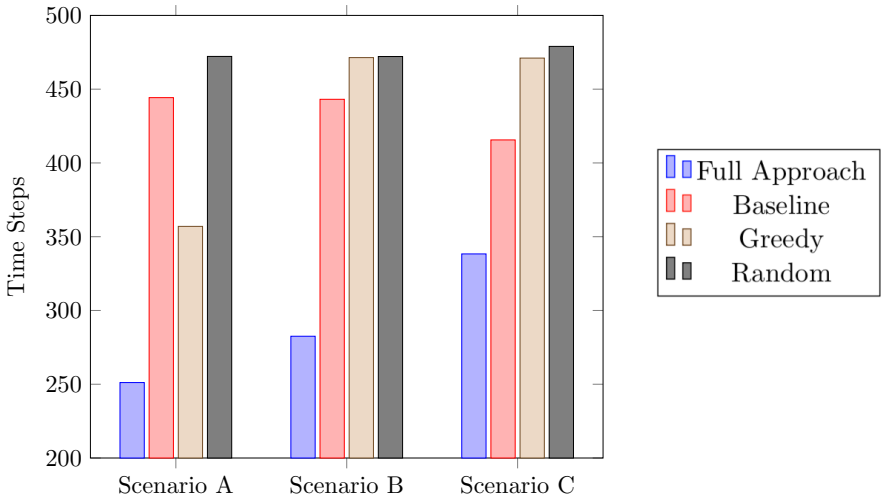
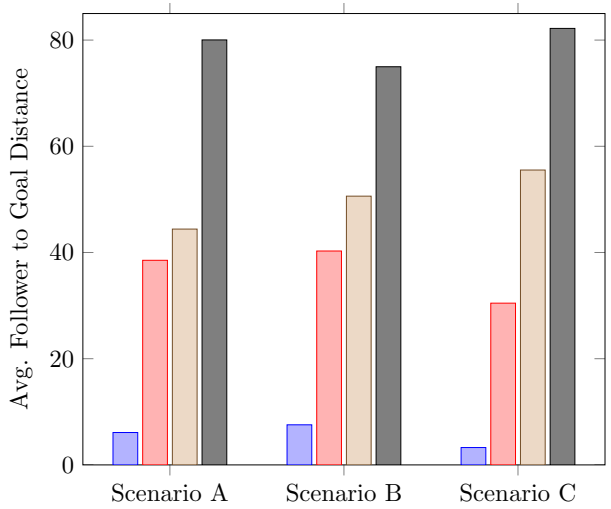


Our approach led followers to goals significantly faster than compared approaches.



The average distance from each follower to the nearest goal was significantly less than compared approaches.

Experiments: High-Fidelity Simulations

- Qualitative results on high-fidelity simulations.

Initial state, with two leaders (drones) and six followers.

Leaders have begun moving to separate goals, with three followers each.

Each team has arrived at a goal position.

Thanks!

- We introduce the problem of multiple agents leading a group of followers to multiple goals, where leaders maintain communication with each other as well as their followers.
- We introduce a novel mathematical formulation to optimize the competing utilities of progress towards goals and communication maintenance, which integrates regularization terms to focus leader attention on select goals and followers while maintaining temporal consistency.

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