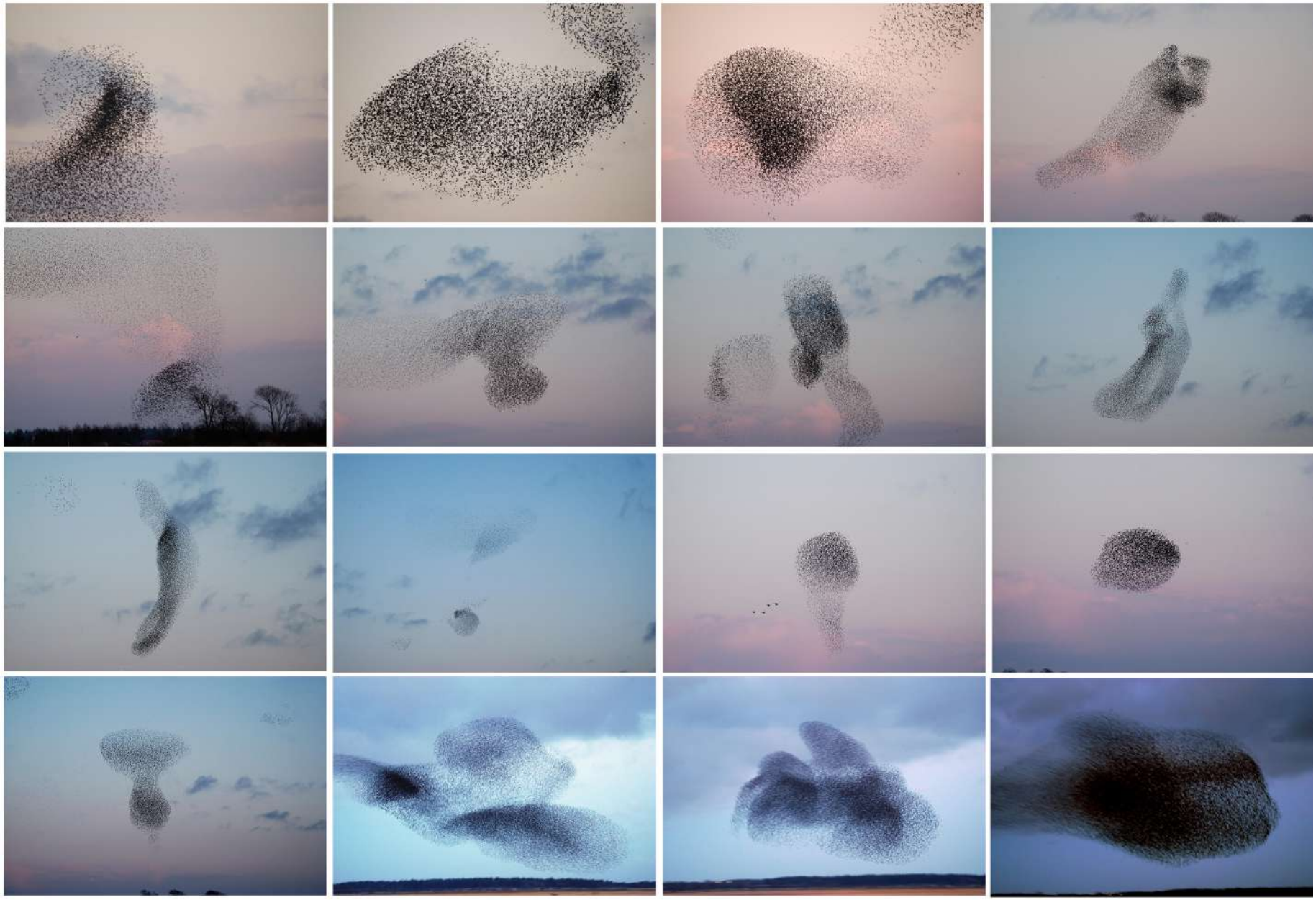
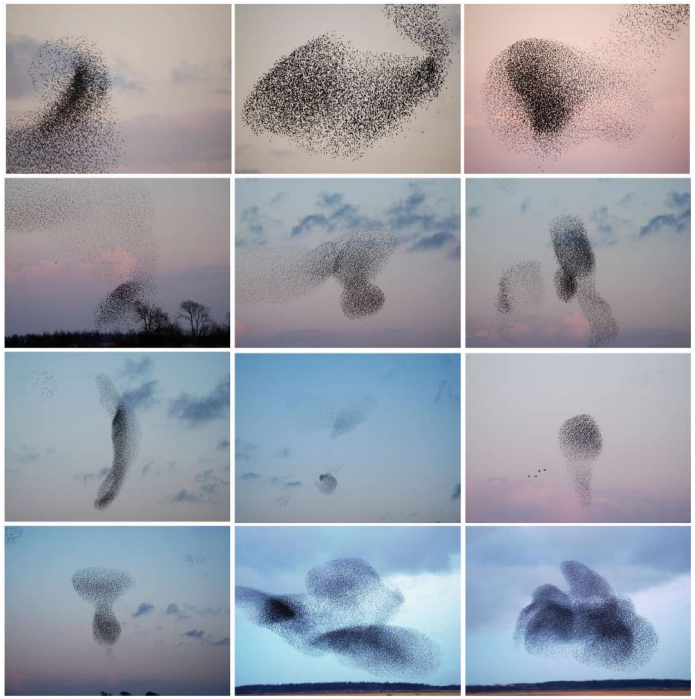
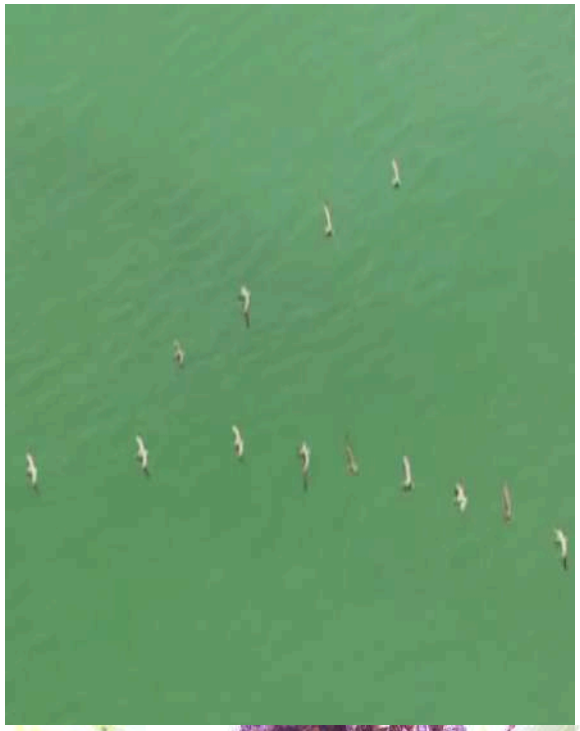
Robots for Emergency Response

Swarms



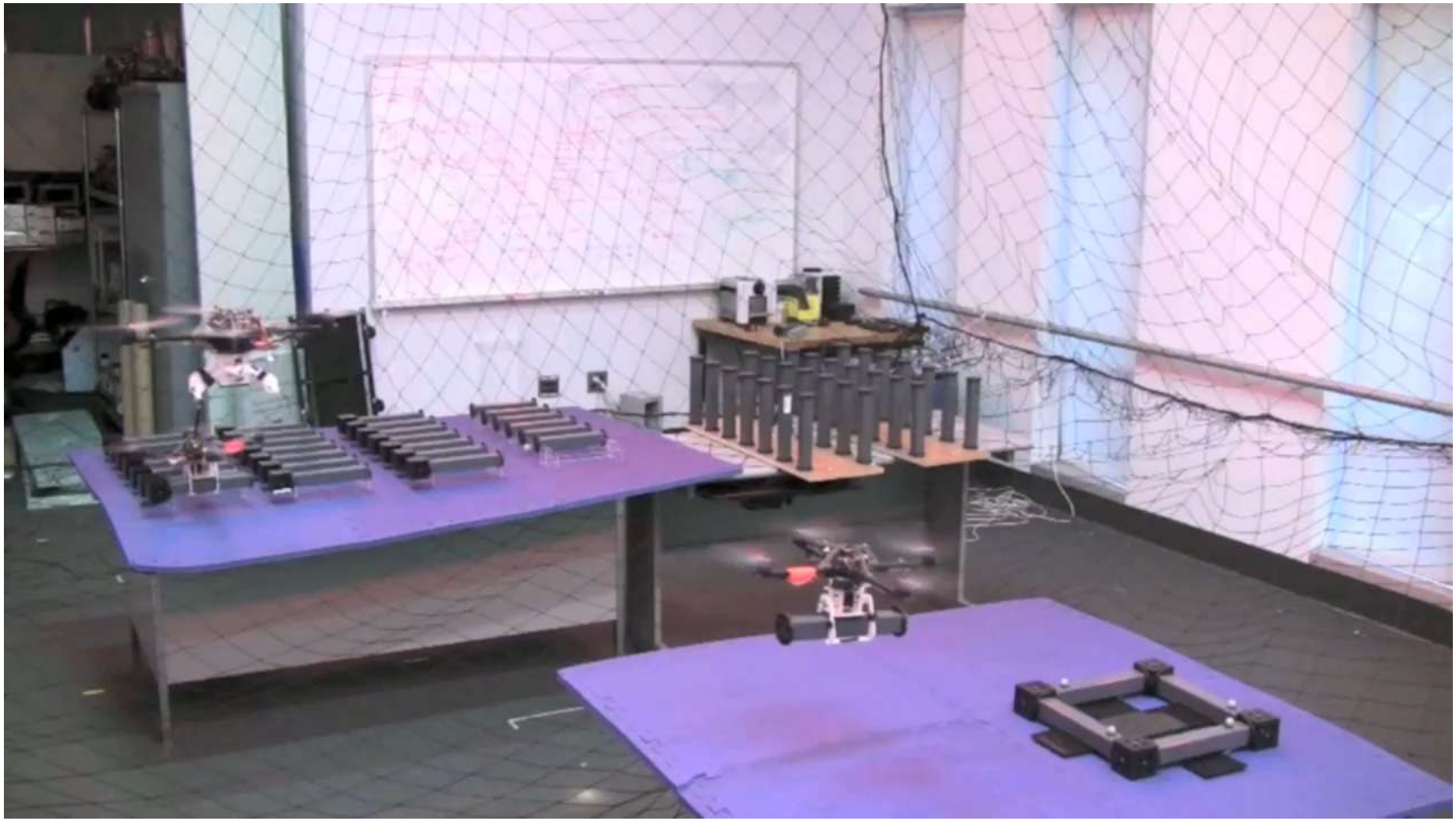




Three Organizing Principles for Collective Behavior

- Each individual acts independently
- Actions are based on local information
- Anonymity in coordination

Example: Transportation and Construction



Complexity

n robots, *m* obstacles

- Dimensionality of the state space increases linearly with *n* — $O(n)$
- Number of potential interactions with neighbors increases as n^2 — $O(mn+n^2)$
- Number of potential interactions with obstacles increases as *mn*
- Number of assignments of robots to goal positions — $O(n!)$

Assignment of robots to goals

factorial

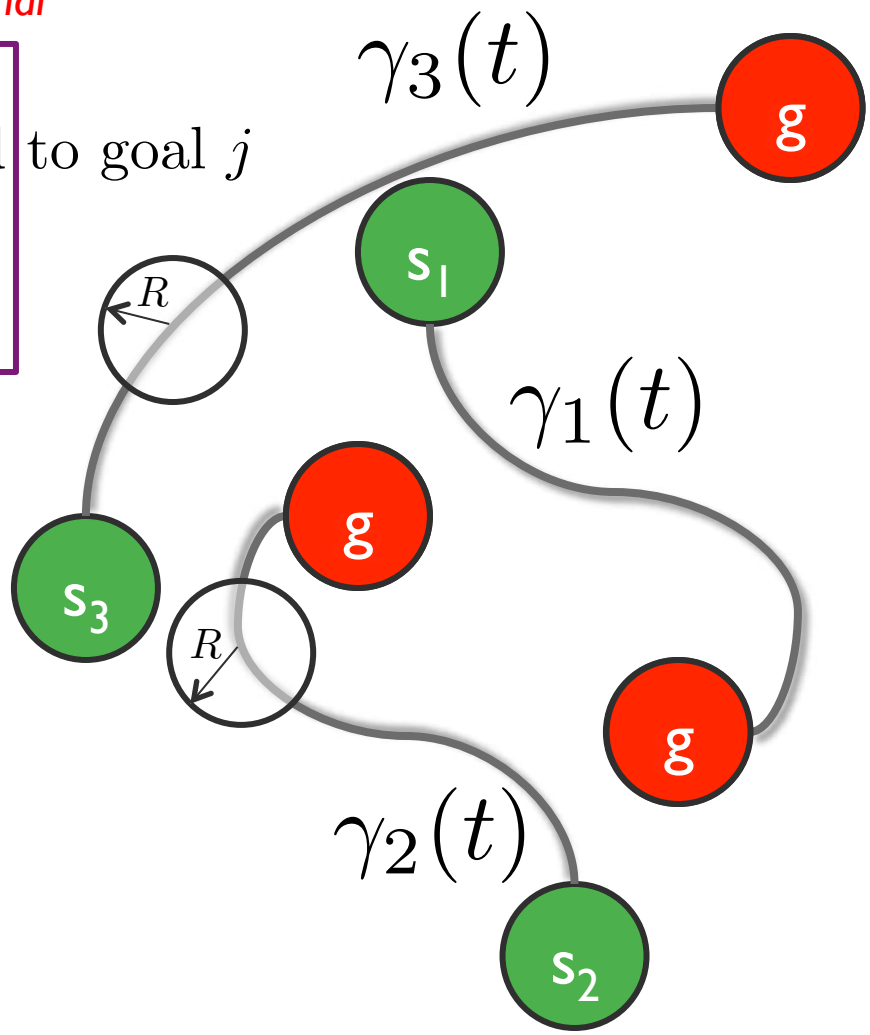
$$\phi_{i,j} = \begin{cases} 1 & \text{if robot } i \text{ is assigned to goal } j \\ 0 & \text{otherwise} \end{cases}$$

Planning trajectories

exponential

$$\mathbf{X}(t) = \begin{bmatrix} \mathbf{x}_1(t) \\ \mathbf{x}_2(t) \\ \dots \\ \mathbf{x}_N(t) \end{bmatrix}$$

$$\gamma(t) : [t_0, t_f] \rightarrow \mathbf{X}(t)$$



Safety

$$\left[\inf_{i \neq j \in \mathcal{I}, t \in [t_0, t_f]} ||\mathbf{x}_i(t) - \mathbf{x}_j(t)|| - 2R \right] > 0$$

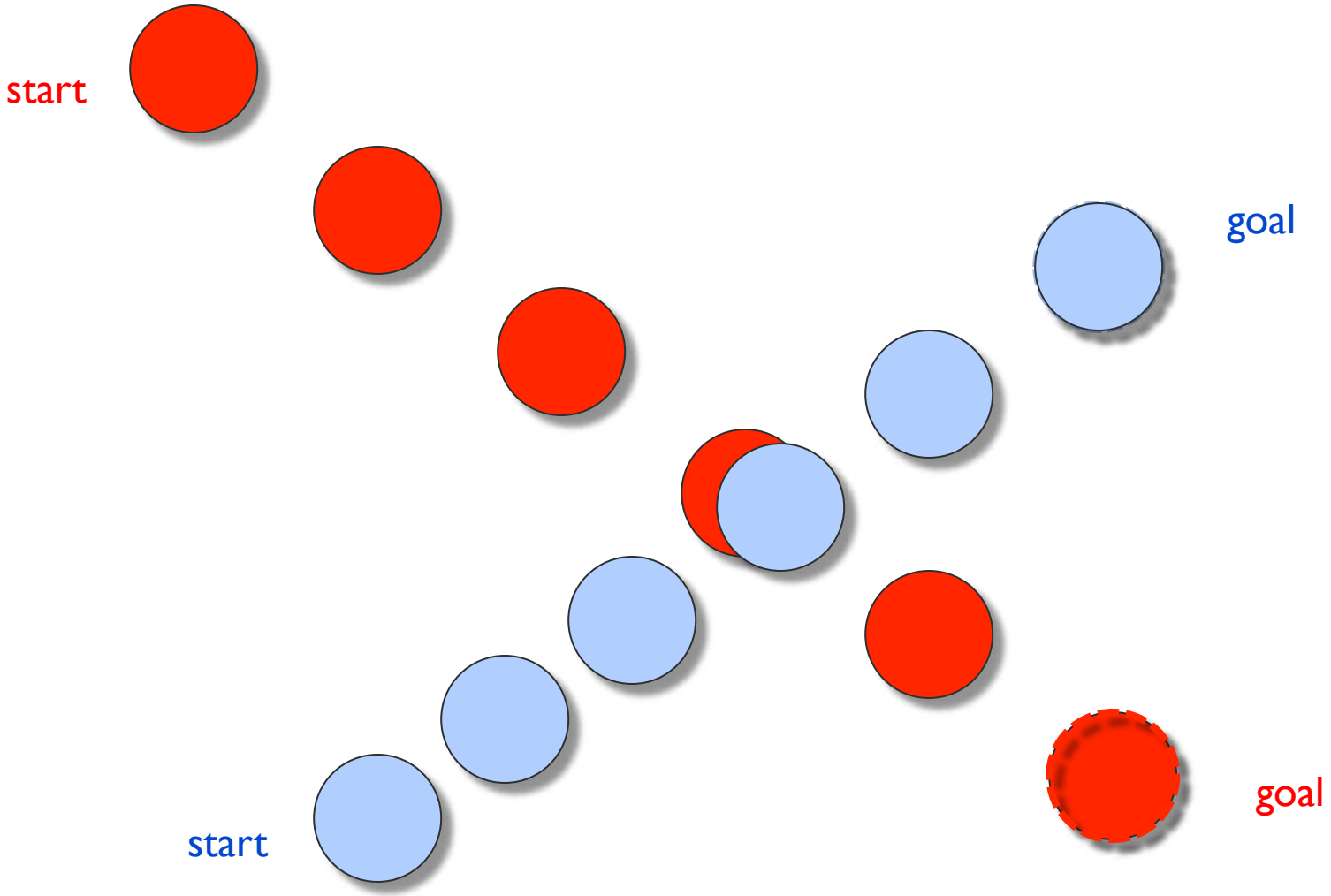
Optimality

$$\gamma^\star(t) = \underset{\gamma(t)}{\operatorname{argmin}} \int_{t_0}^{t_f} L(\gamma(t)) dt$$

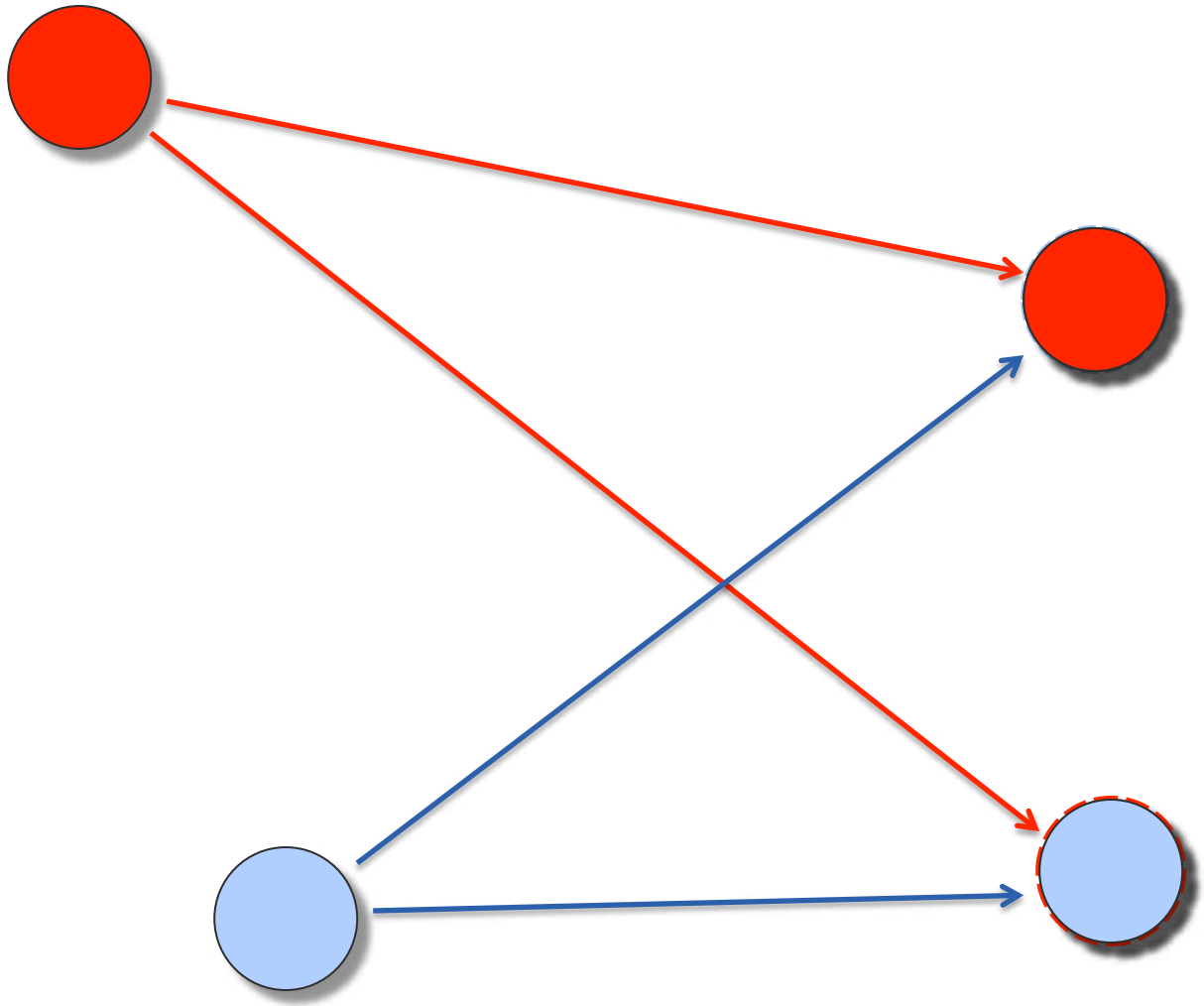
Four Key Ideas

- Concurrent assignment of goals and trajectories
- Leader-follower networks
- Anonymity
- Sharing information

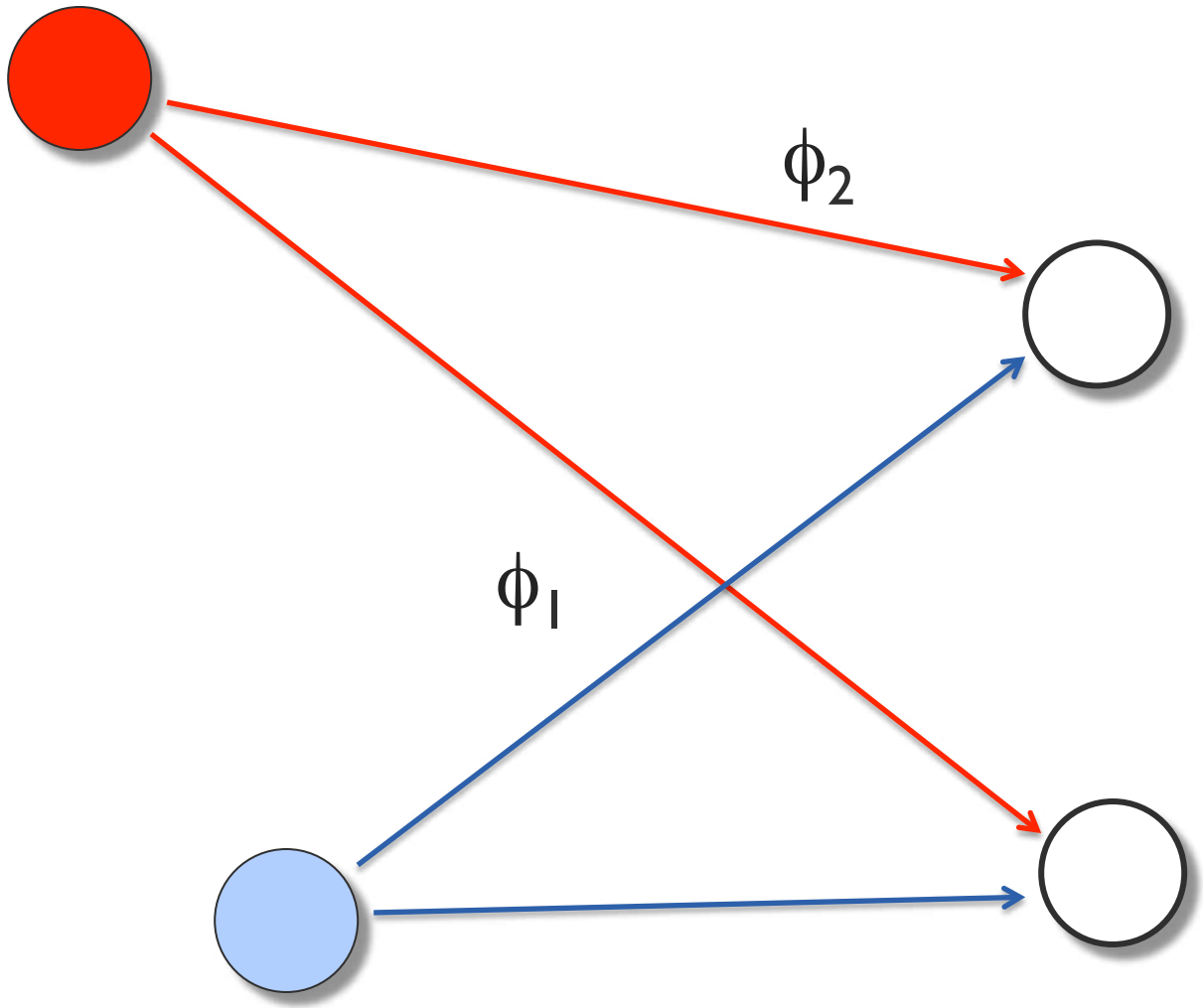
1. Assignment of Goals and Collision Free Trajectories



Concurrent **A**ssignment and **P**lanning of **T**rajectories: CAPT



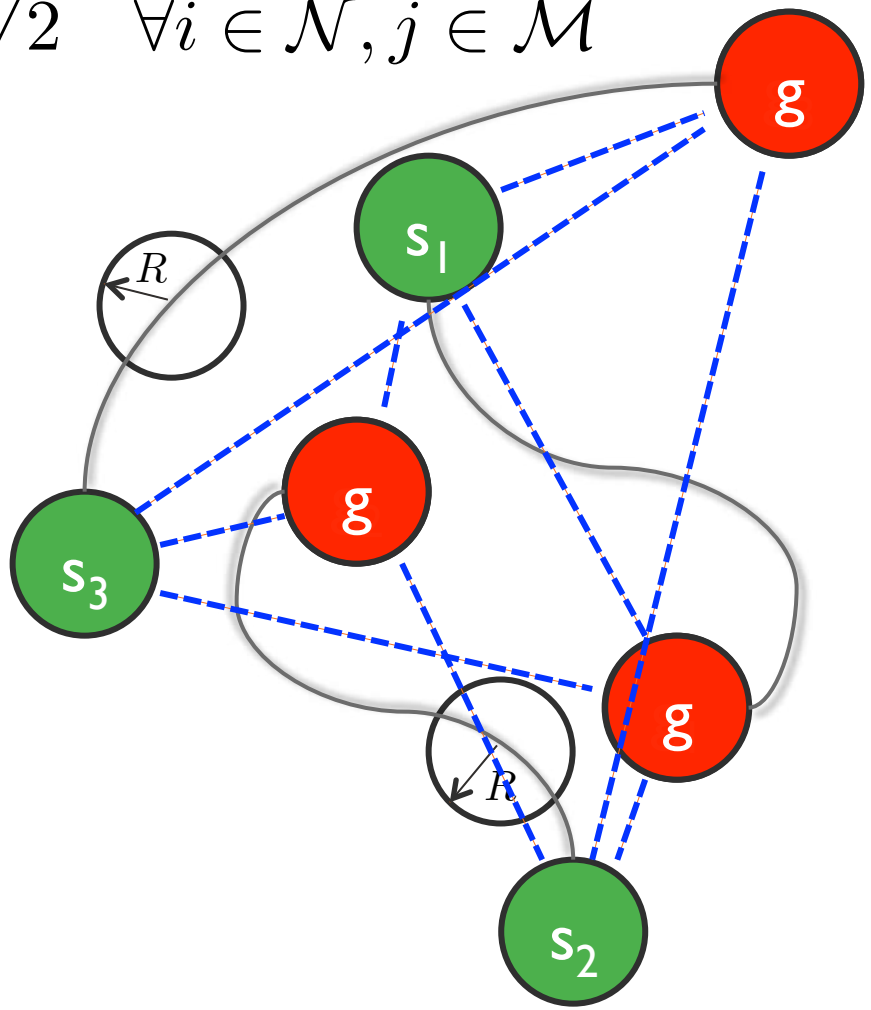
CAPT



Concurrent Assignment and Planning

Assumption

$$||\mathbf{s}_i - \mathbf{g}_j|| > 2R\sqrt{2} \quad \forall i \in \mathcal{N}, j \in \mathcal{M}$$



Theorem

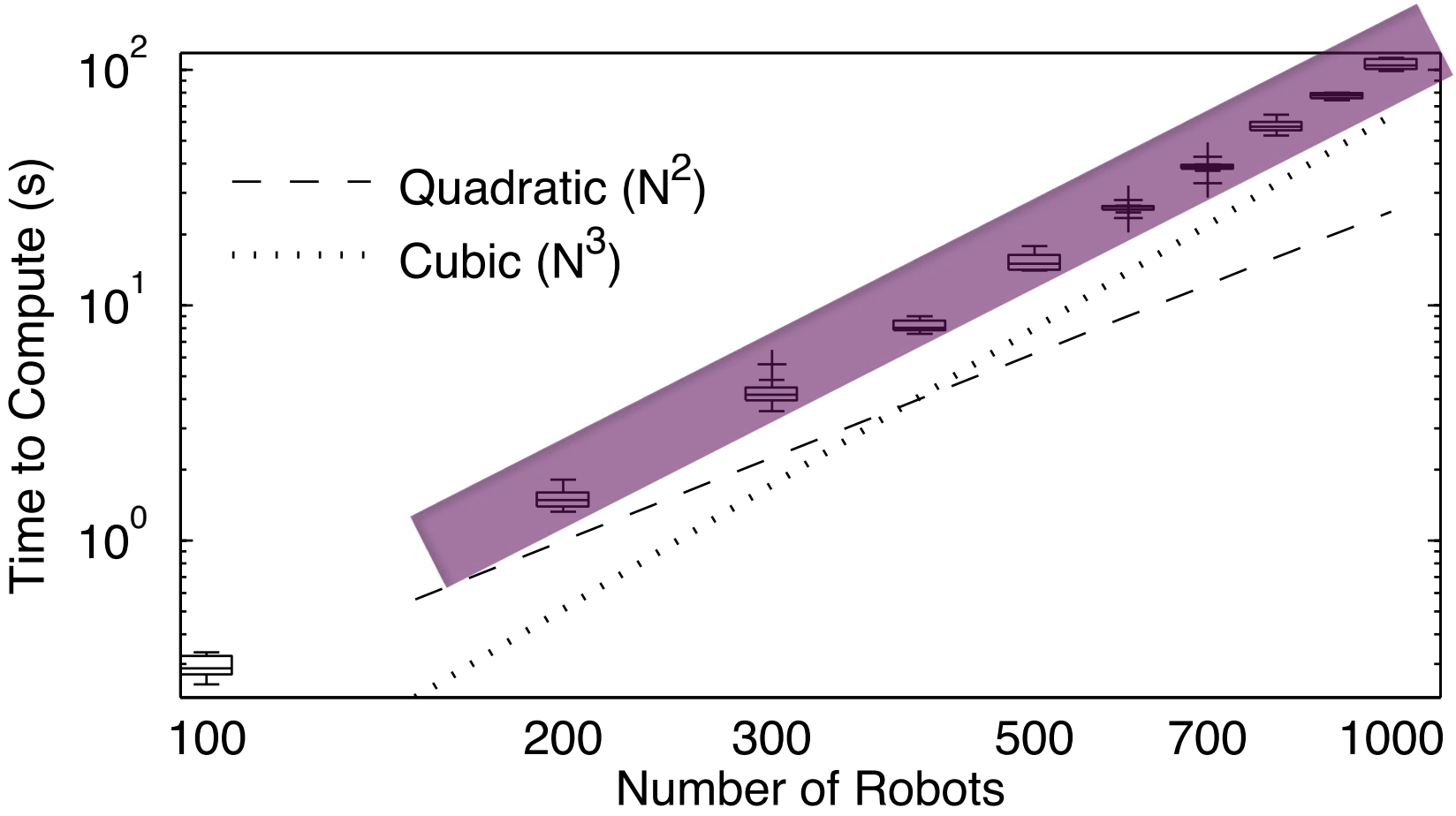
Assignments and trajectories that minimize the sum of square of distances

$$\underset{\phi,\gamma(t)}{\text{minimize}} \int_{t_0}^{t_f} \dot{X}(t)^T \dot{X}(t) dt$$

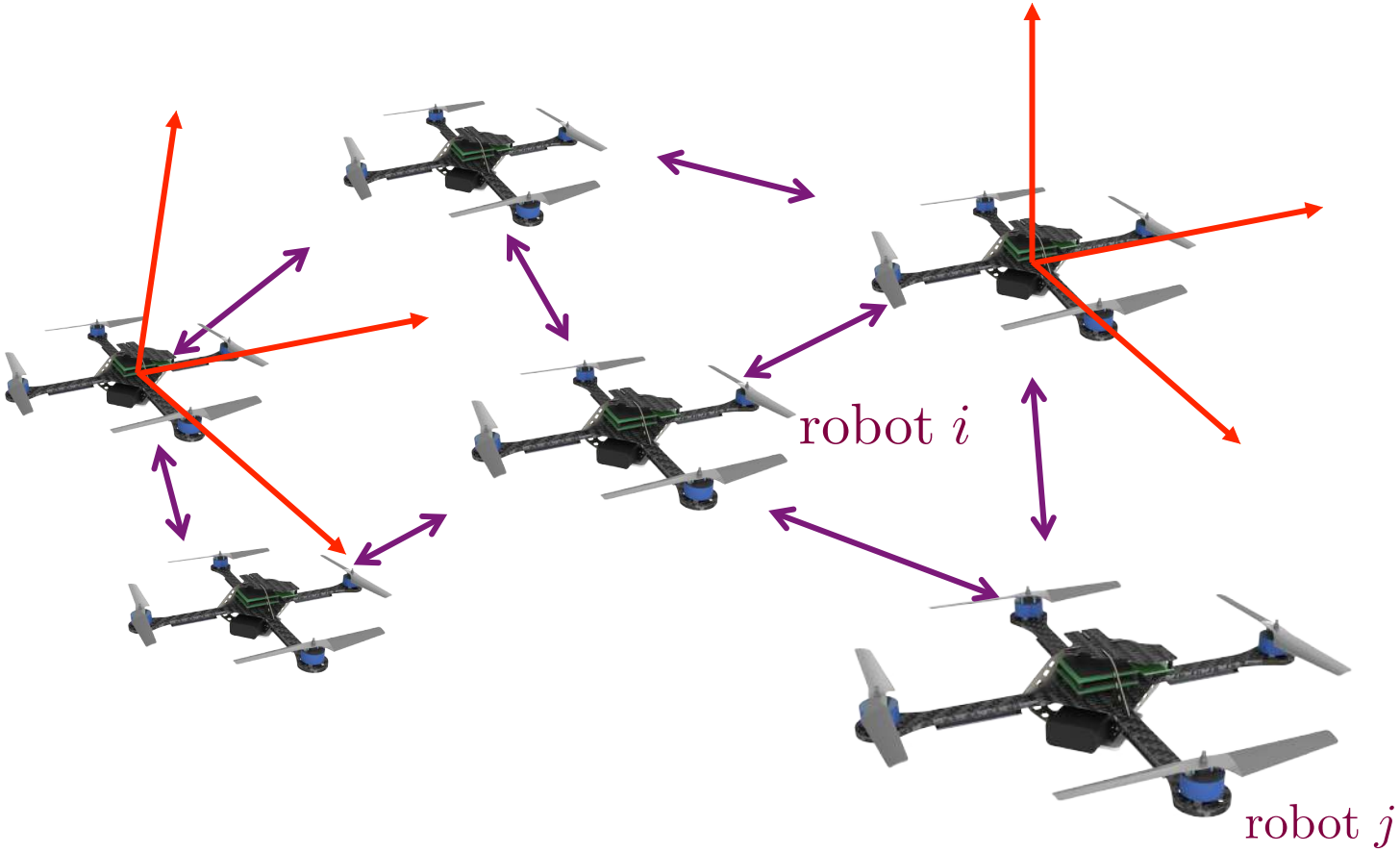
will be safe (no collisions)

$$||\mathbf{x}_i(t) - \mathbf{x}_j(t)|| > 2R$$

CAPT


10^2
10^1
10^0
Time to Compute (s)
Quadratic (N^2)
Cubic (N^3)
100
200
300
500
700
1000
Number of Robots

2. Leader-Follower Networks



$$\mathbf{s}_{i,j}(t) = \mathbf{x}_j(t) - \mathbf{x}_i(t)$$

Leader-Follower Networks

PBS NOVA: Making Stuff Wilder (Hosted by David Pogue)

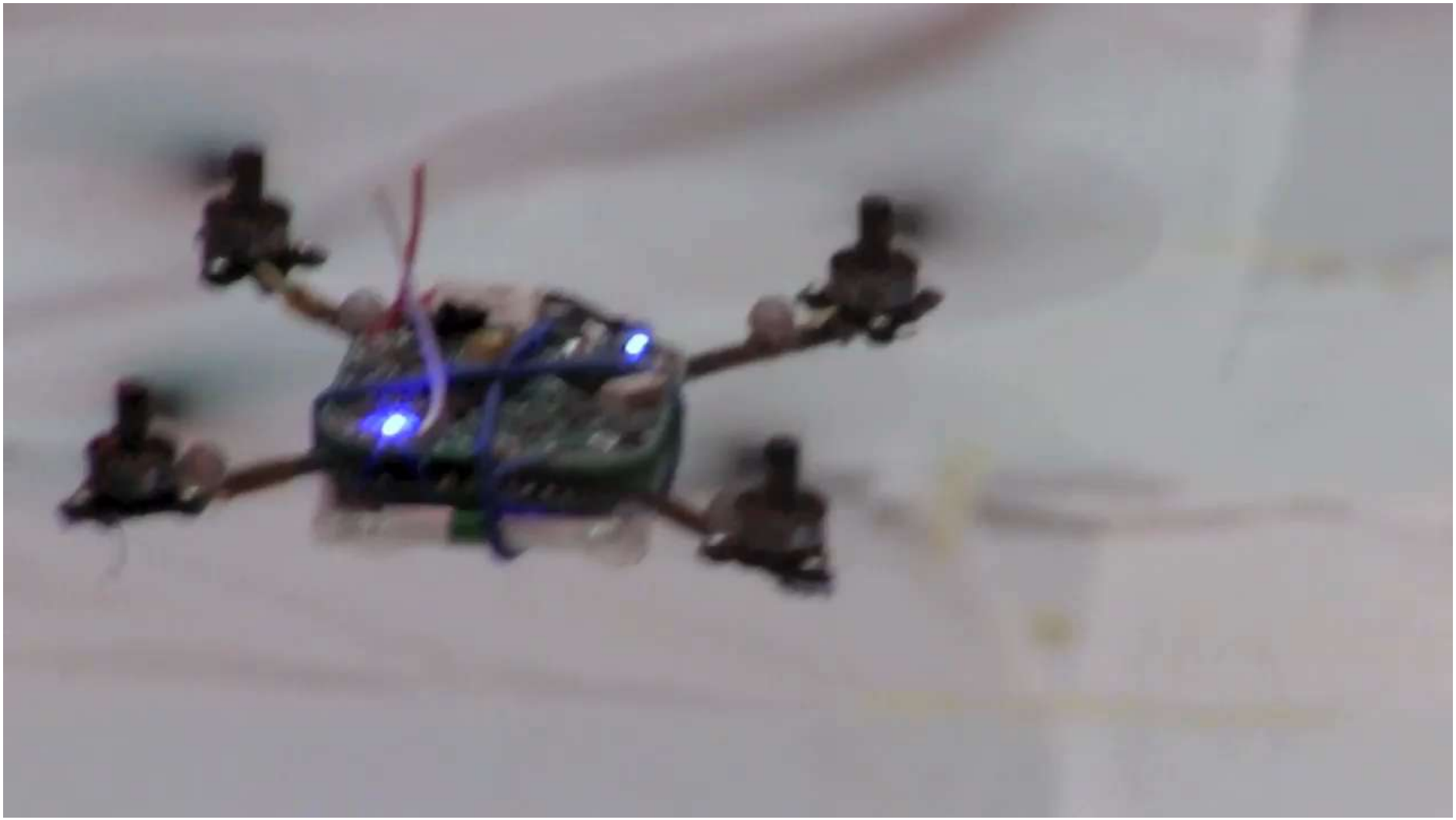
3. Anonymity

PBS NOVA: Making Stuff Wilder (Hosted by David Pogue)

Control of Formation Shape and Group Motion

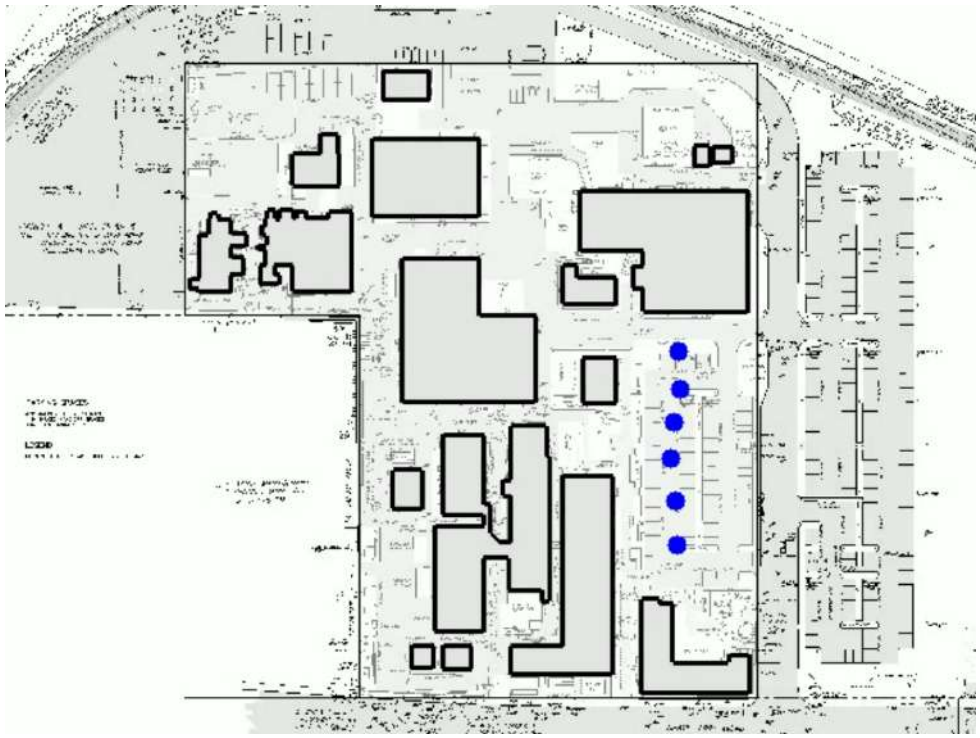
(Turpin, Michael, and Kumar, 2013)

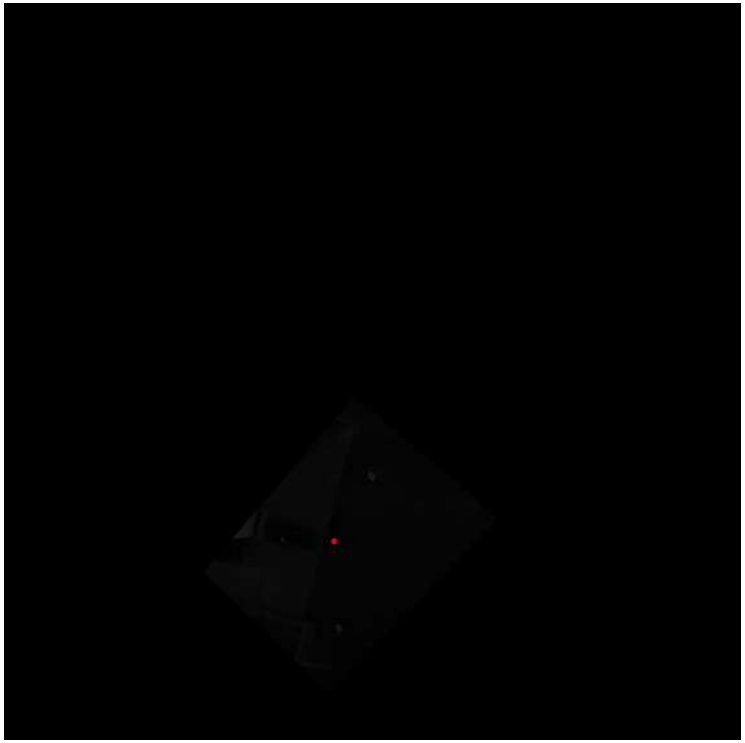
Control of Formation Shape and Group Motion

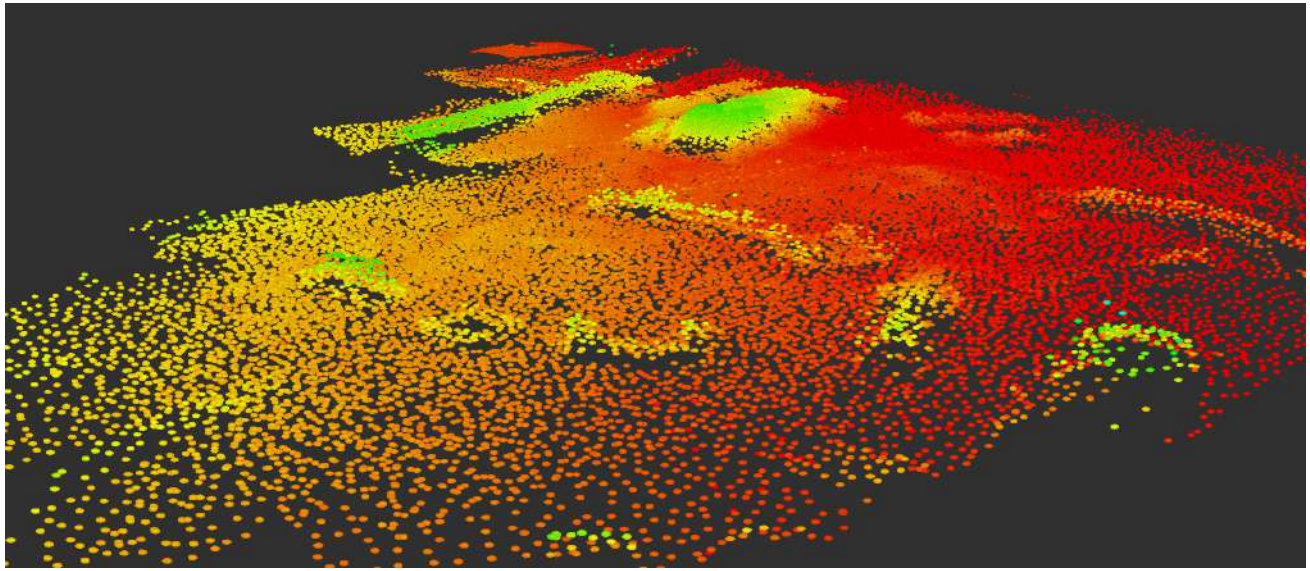


Robot First Responders

Kartik Mohta, Matthew Turpin, Alex Kushleyev, Daniel Mellinger, Nathan Michael, and Vijay Kumar, "QuadCloud: A Rapid Response Force with Quadrotor Teams," *Int. Symp. on Experimental Robotics* (ISER), 2014.





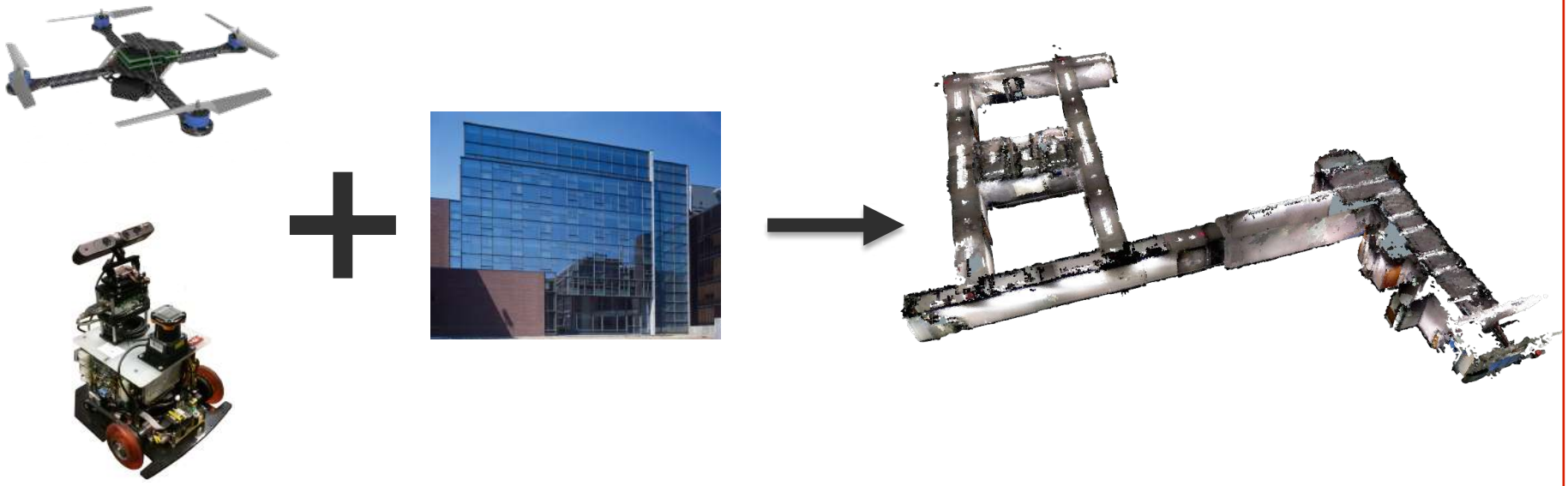


Kartik Mohta, Matthew Turpin, Alex Kushleyev, Daniel Mellinger, Nathan Michael, and Vijay Kumar, "QuadCloud: A Rapid Response Force with Quadrotor Teams," *Int. Symp. on Experimental Robotics* (ISER), 2014.

Enabling Cooperation

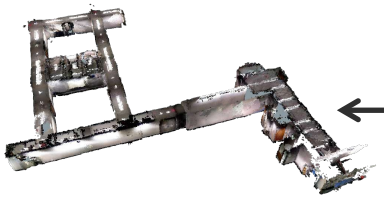
Active Mapping

Autonomously create 3D map of an unknown environment with ground and aerial robots



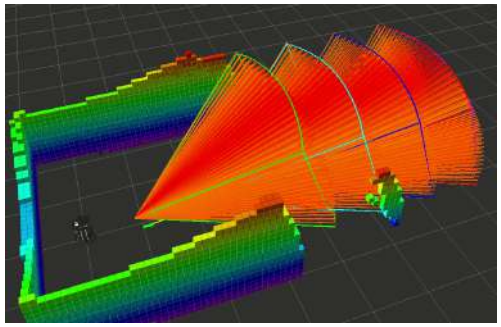
Control Policy

Reduce uncertainty of map by maximizing information gain



Map

Measurements

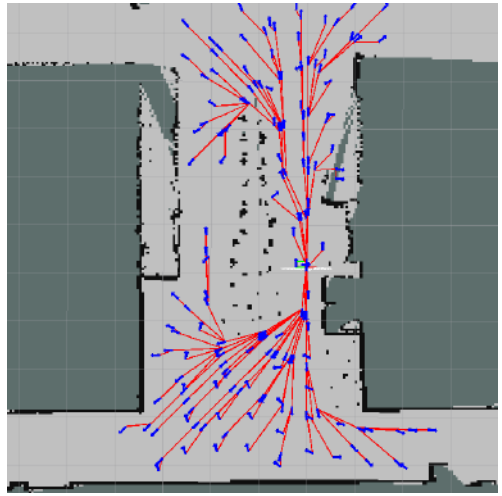


$$x_{\tau}^{*} = \arg\max_{x_{\tau} \in \mathcal{X}} \frac{\mathrm{I}_{\mathrm{CS}}[m; z_{\tau} \mid x_{\tau}]}{D(x_{\tau})}$$

Information

Duration

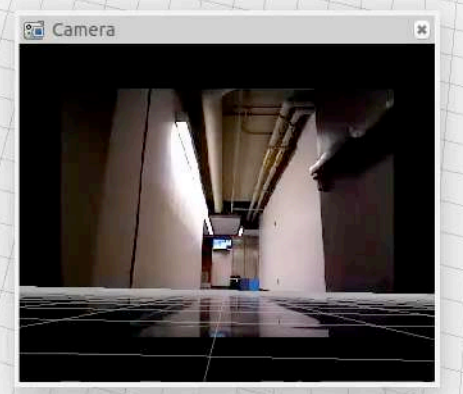
Paths



Change I_CS to IG (information gain)

Active Mapping

Robot's location



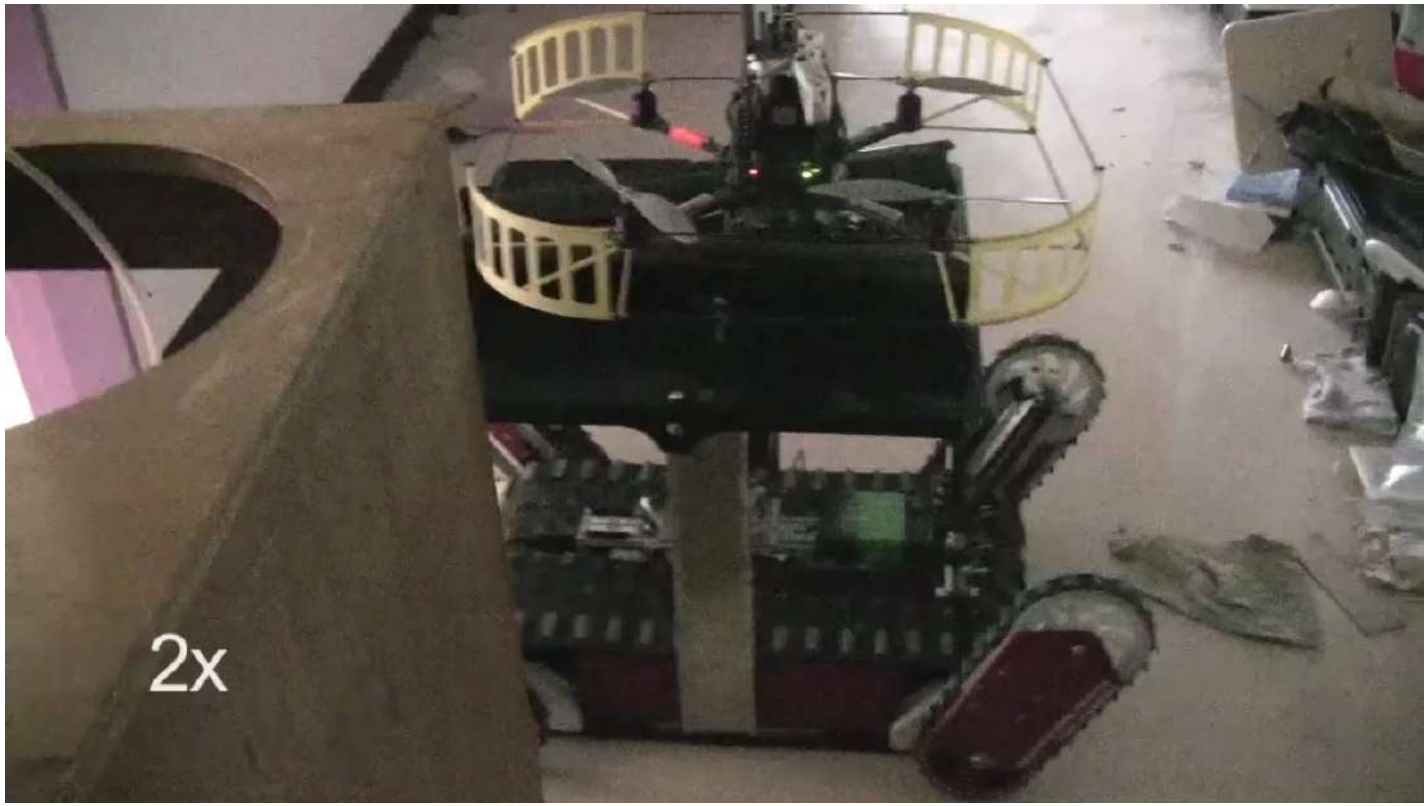
Robot's view

20x

Active Mapping

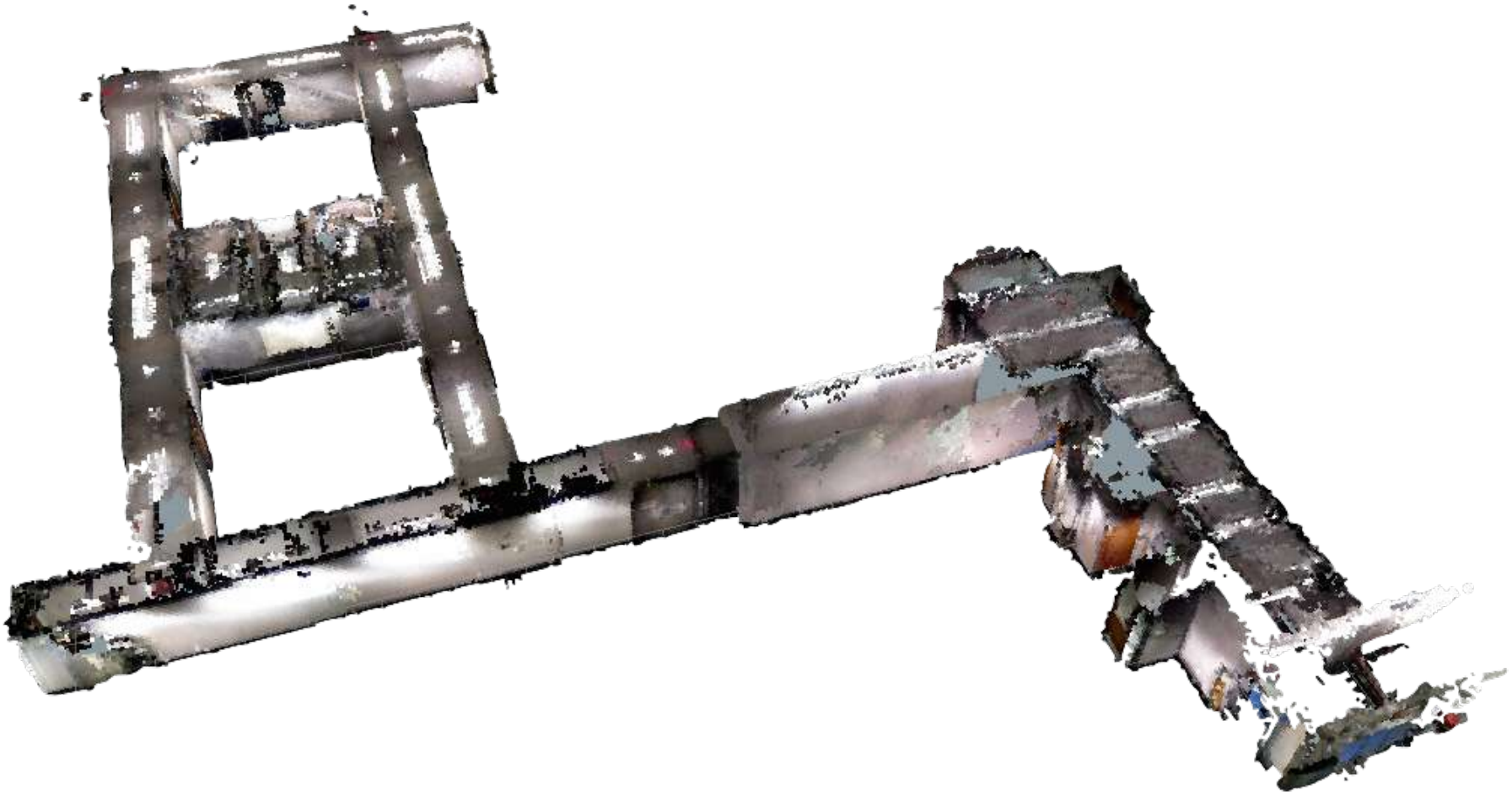
Search and Rescue

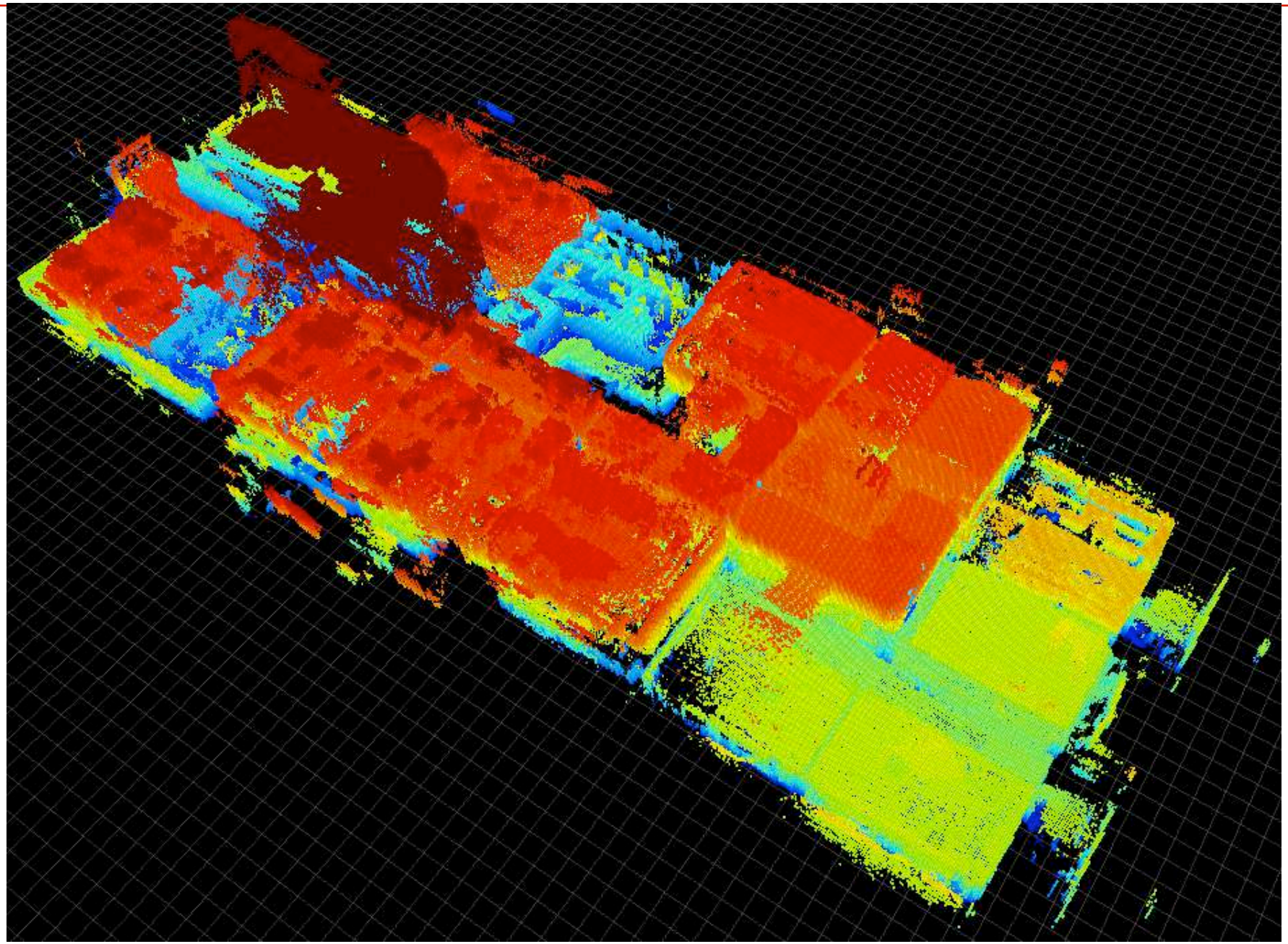
N. Michael, S. Shen, K. Mohta, Y. Mulgaonkar, V. Kumar, K. Nagatani, Y. Okada, S. Kiribayashi, K. Otake, K. Yoshida, K. Ohno, E. Takeuchi, and S. Tadokoro, "Collaborative mapping of an earthquake-damaged building via ground and aerial robots," J. Field Robotics, vol. 29, no. 5, pp. 832–841, 2012.



[*Michael et al*, 2012]

Final Map





3 floors of a 9 story building


Swarms!