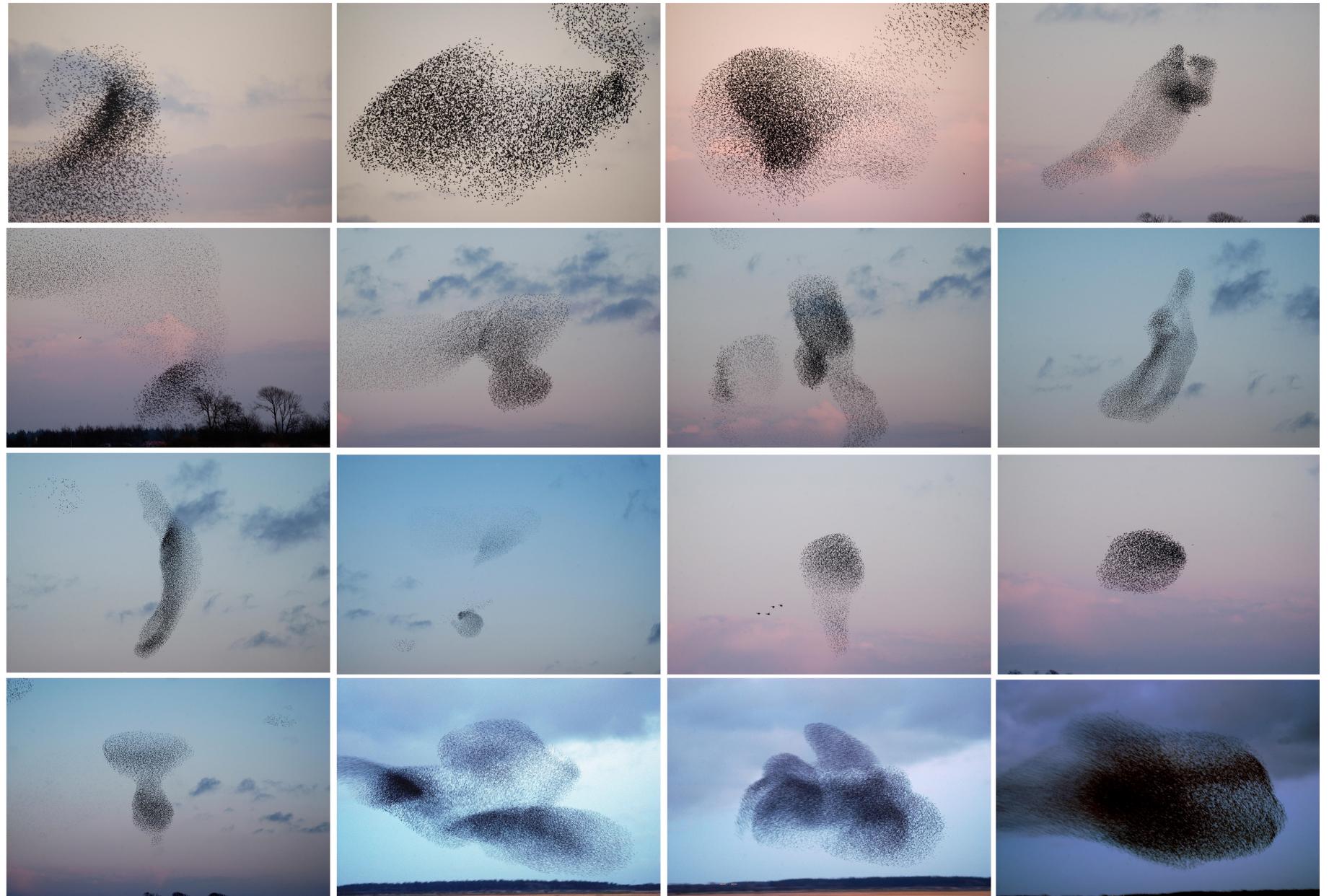


Robots for Emergency Response

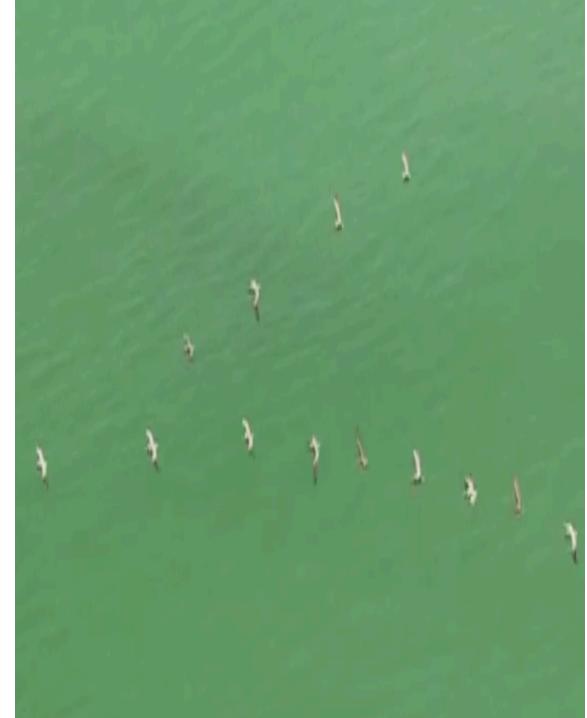
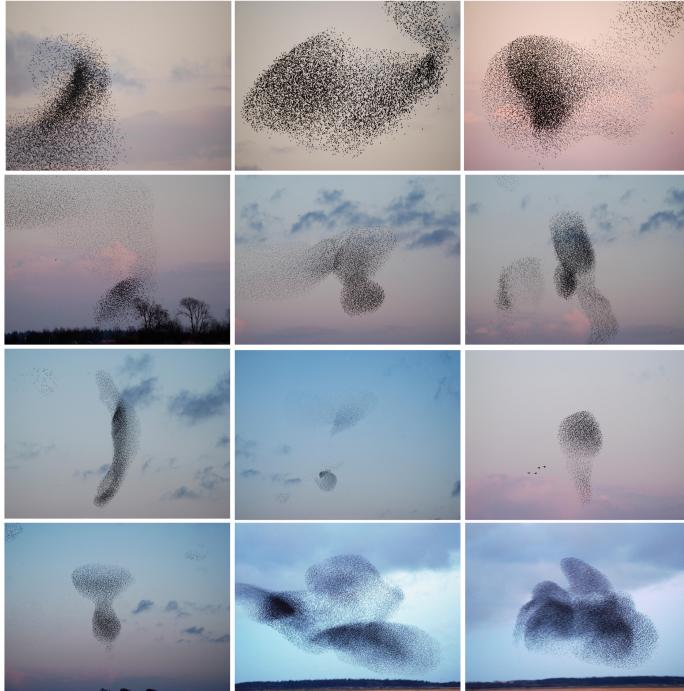
Swarms











Three Organizing Principles for Collective Behavior

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

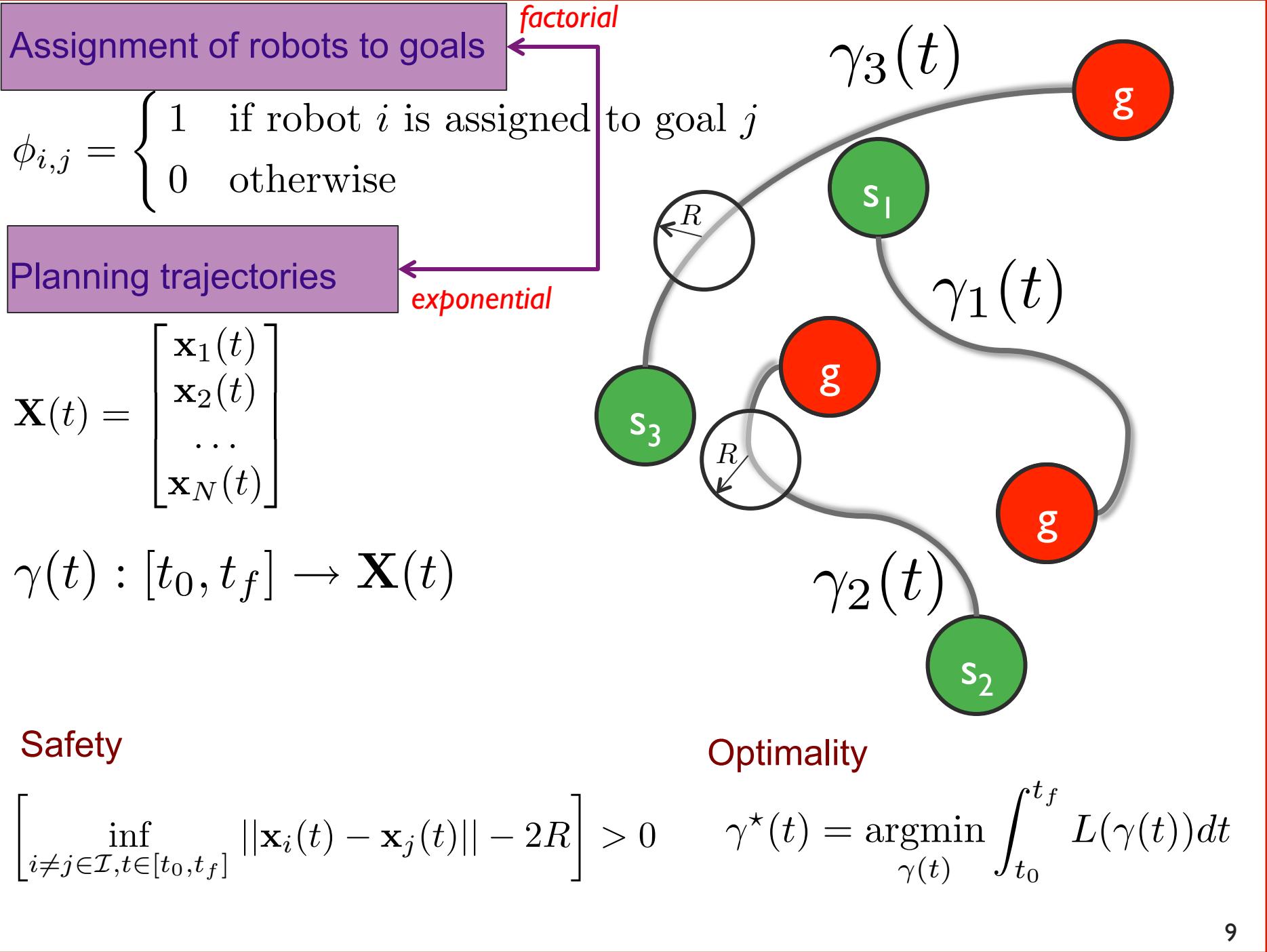
Example: Transportation and Construction



Complexity

n robots, m obstacles

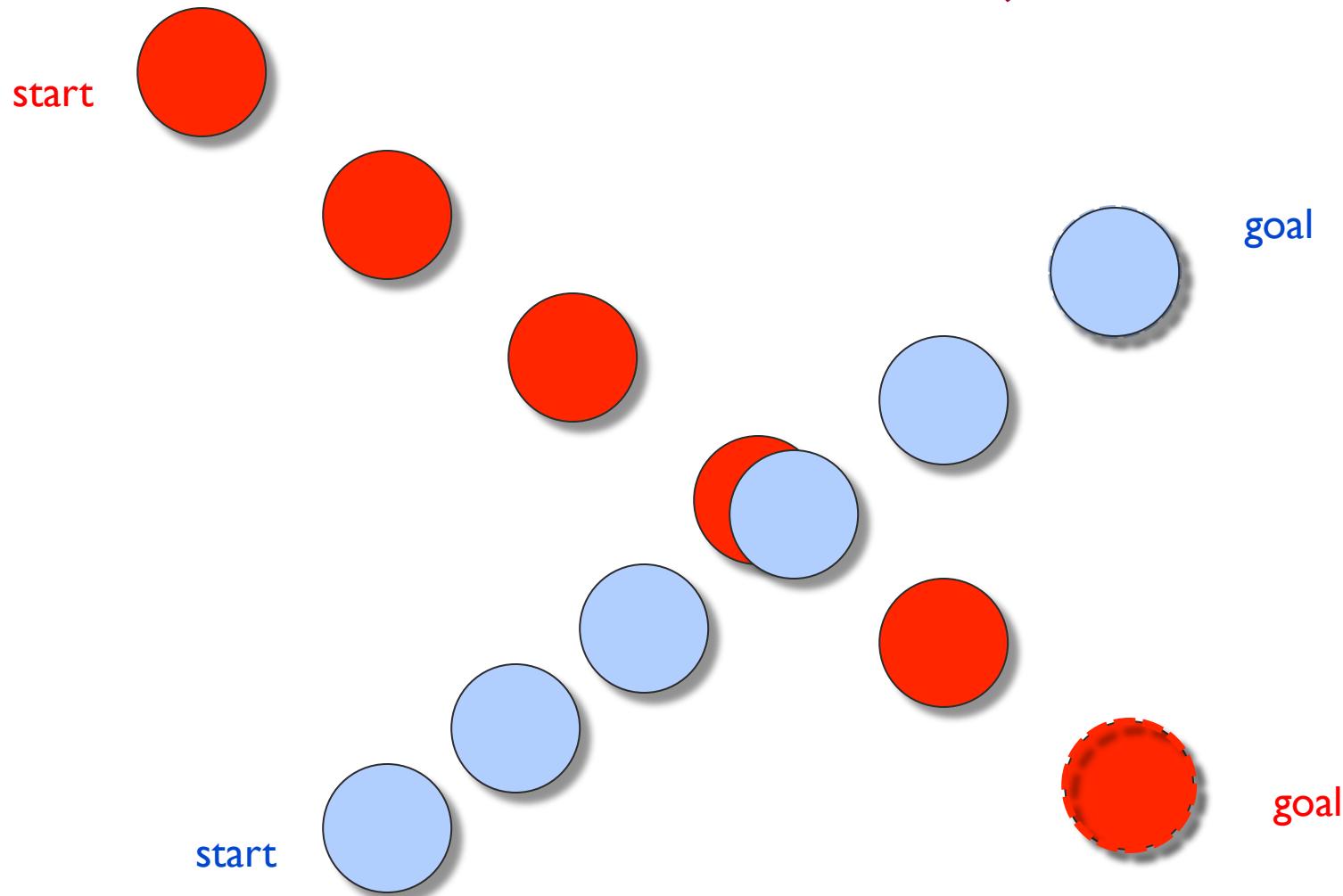
- Dimensionality of the state space increases linearly with n $O(n)$
- Number of potential interactions with neighbors increases as n^2 $O(mn+n^2)$
- Number of potential interactions with obstacles increases as mn
- Number of assignments of robots to goal positions $O(n!)$



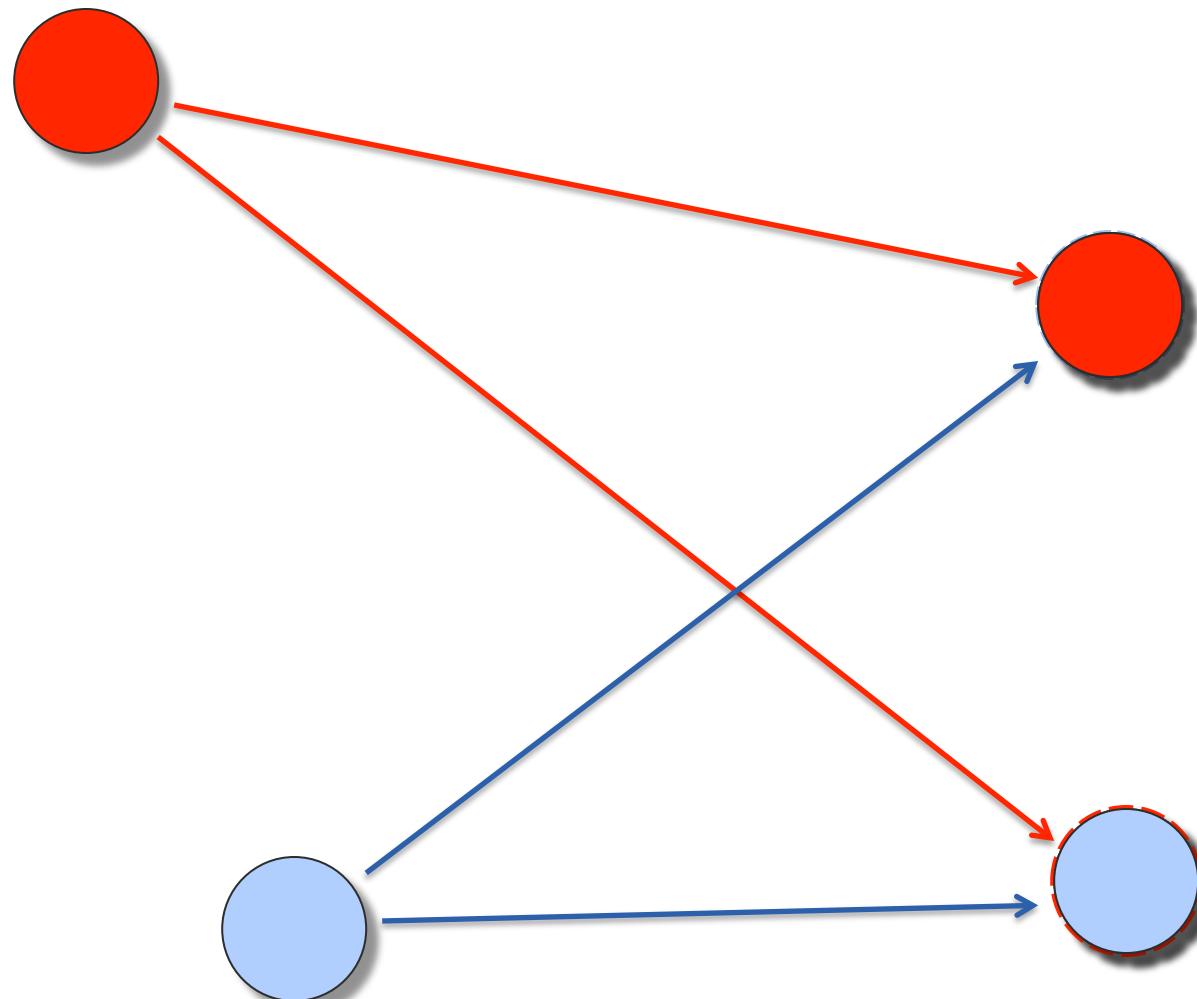
Four Key Ideas

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

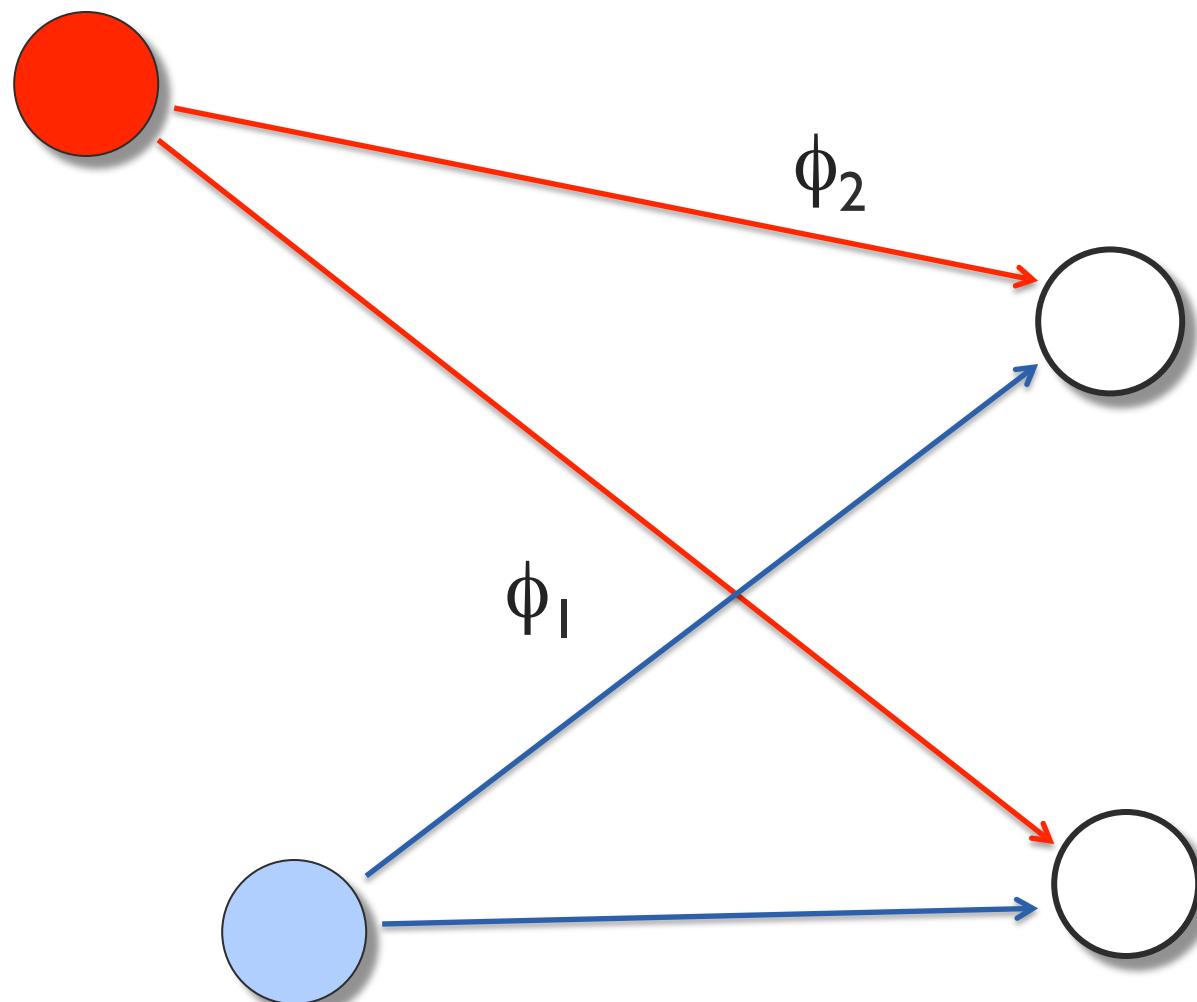
I. Assignment of Goals and Collision Free Trajectories



Concurrent Assignment and Planning of Trajectories: CAPT



CAPT



Concurrent Assignment and Planning

Assumption

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

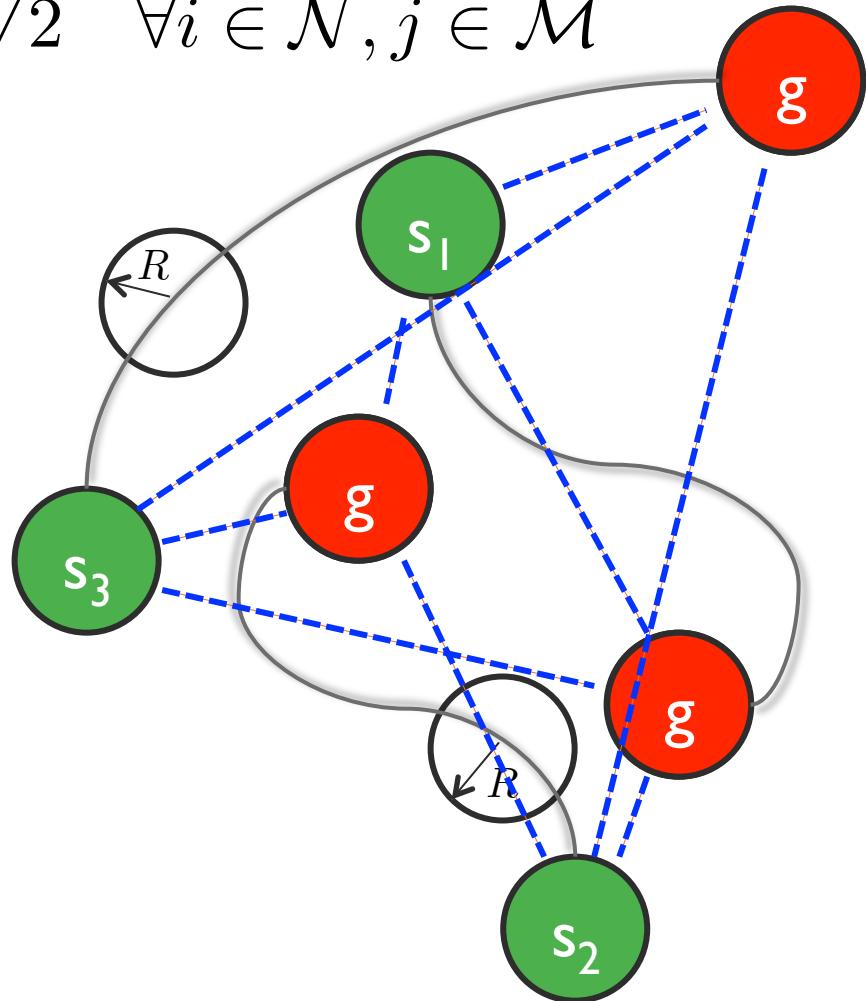
Theorem

Assignments and trajectories that minimize the sum of square of distances

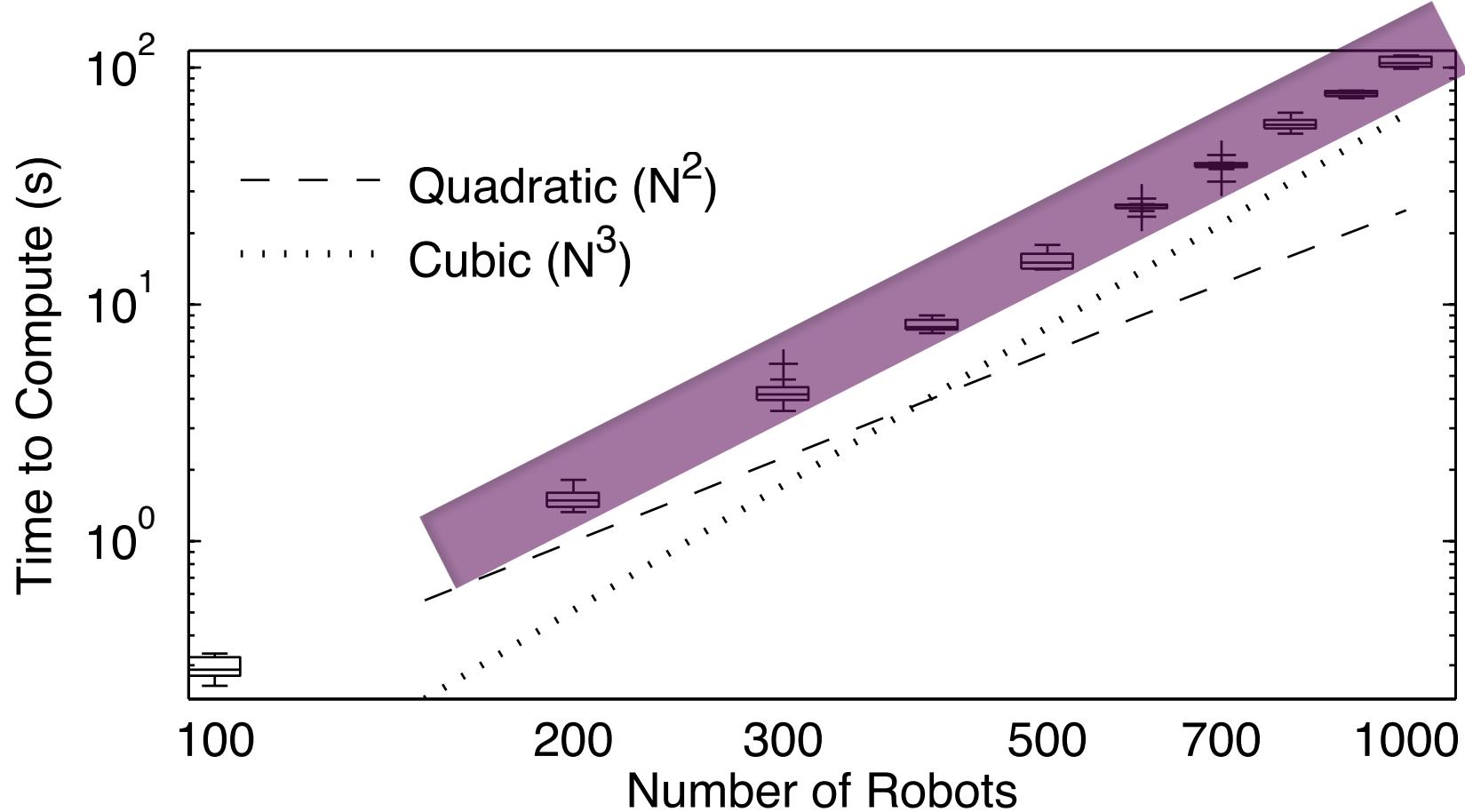
$$\underset{\phi, \gamma(t)}{\text{minimize}} \int_{t_0}^{t_f} \dot{\mathbf{X}}(t)^T \dot{\mathbf{X}}(t) dt$$

will be safe (no collisions)

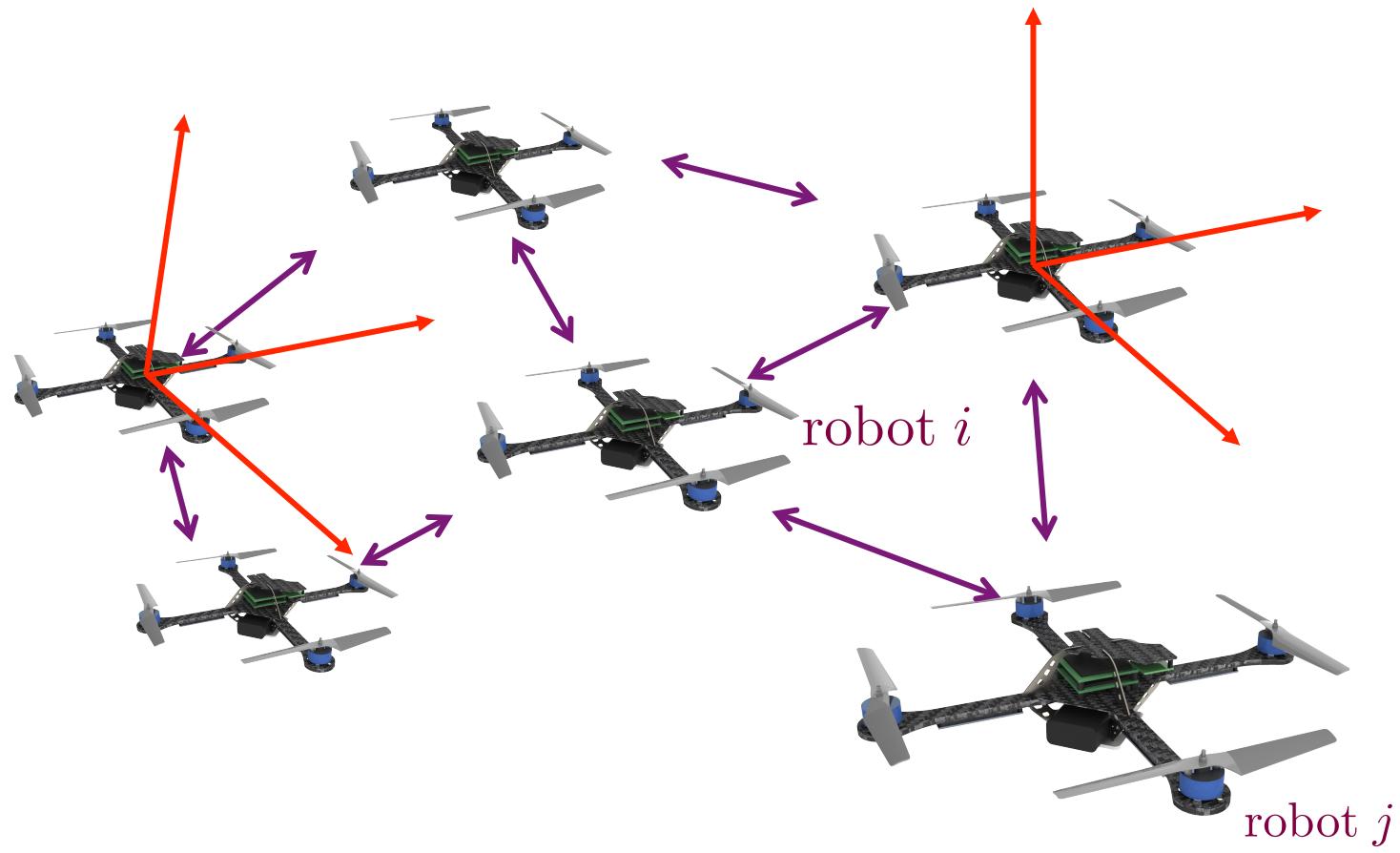
$$\|\mathbf{x}_i(t) - \mathbf{x}_j(t)\| > 2R$$



CAPT



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

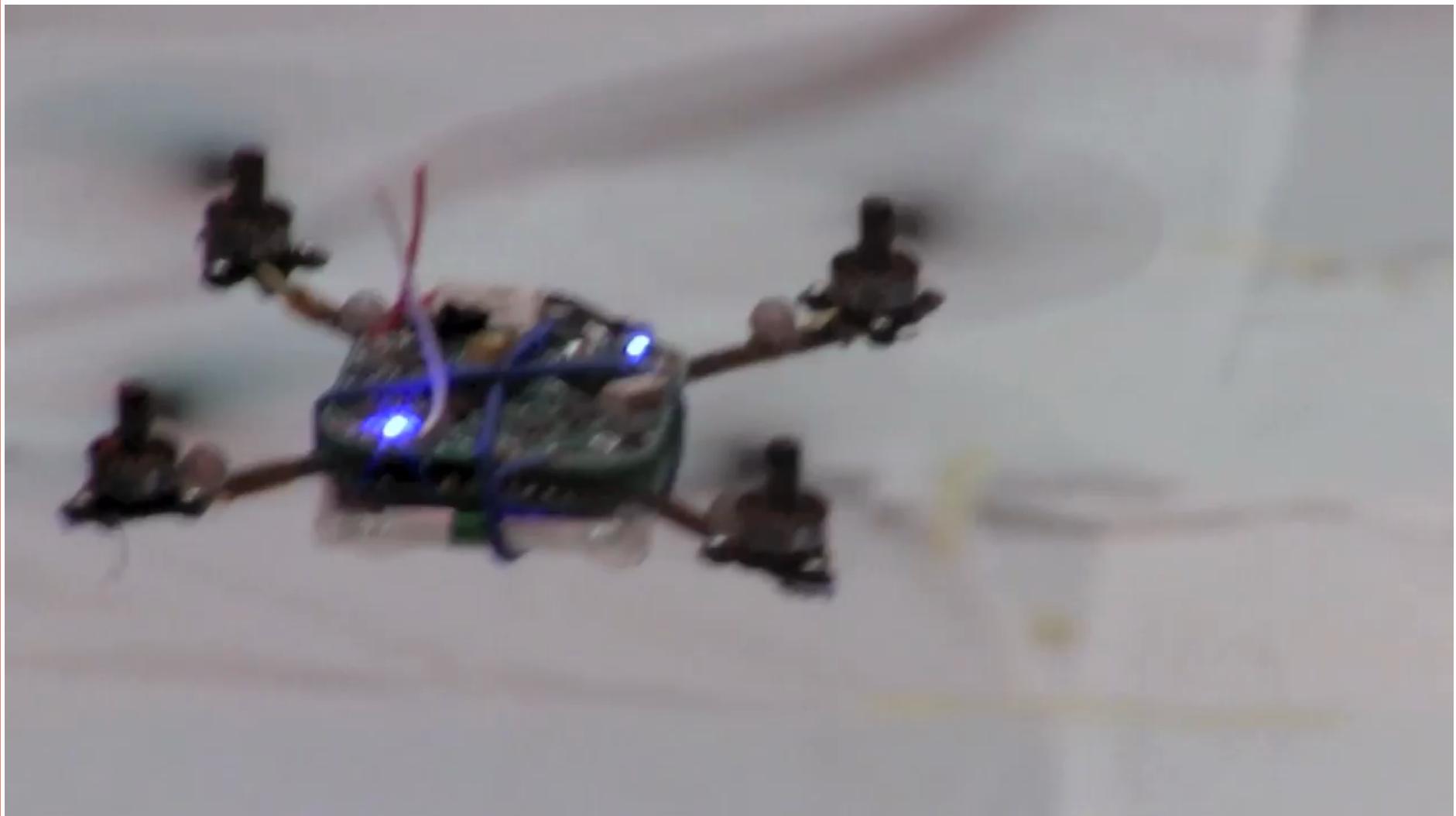


Control of Formation Shape and Group Motion



(Turpin, Michael, and Kumar, 2013)

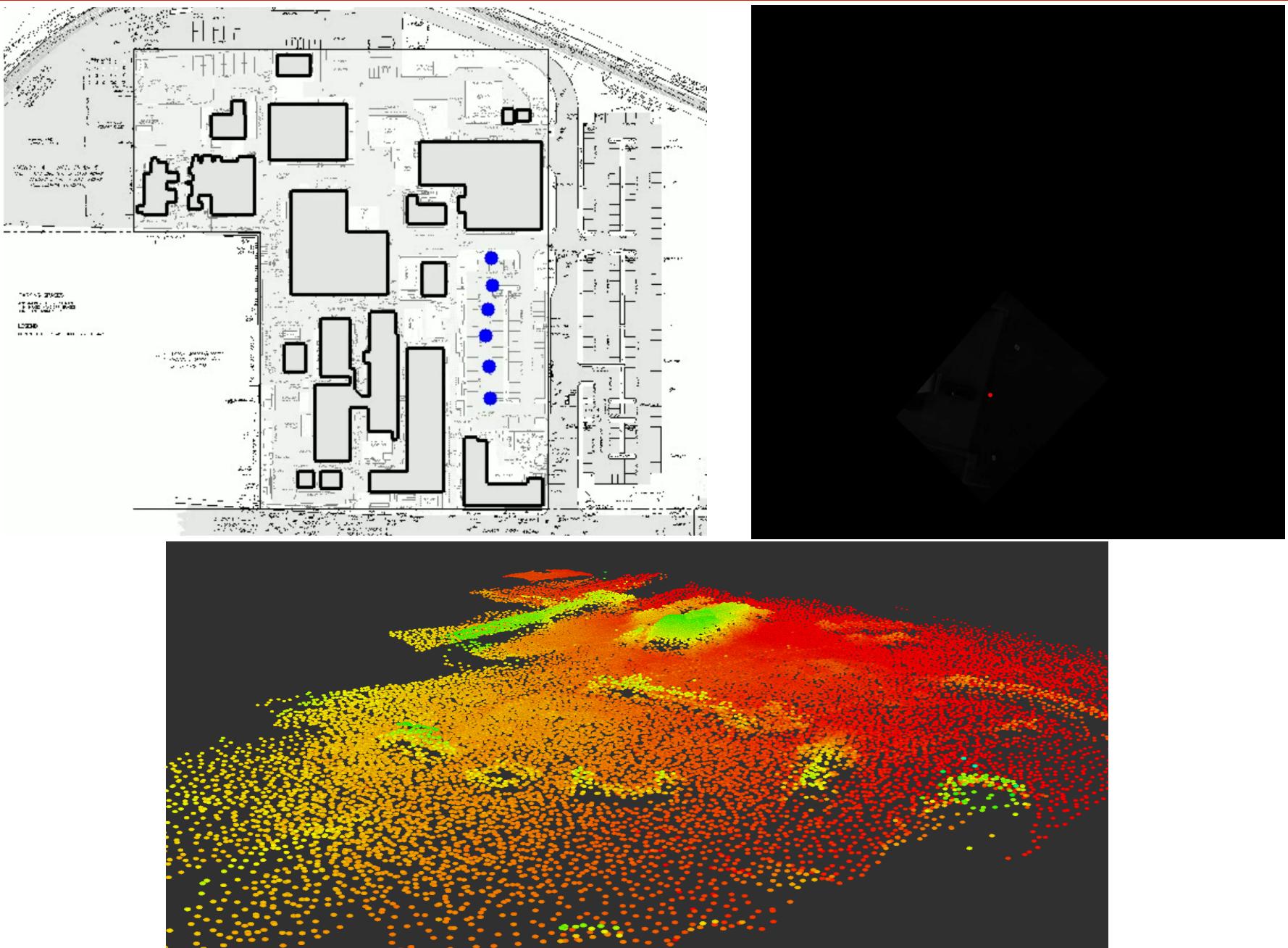
Control of Formation Shape and Group Motion



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.



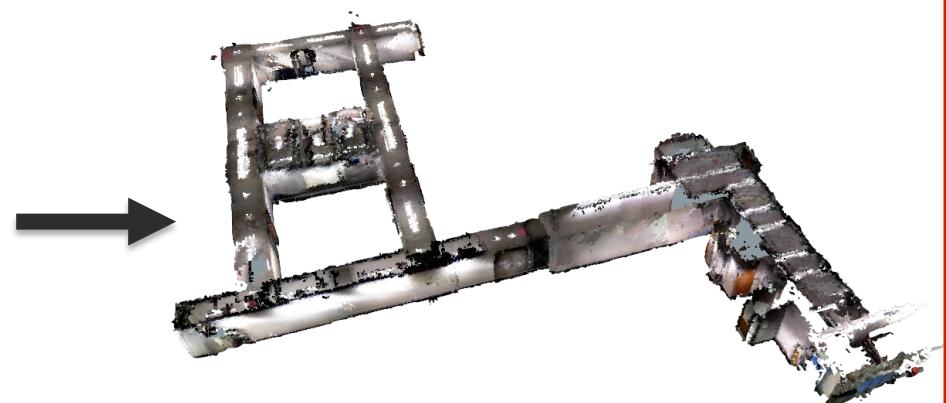
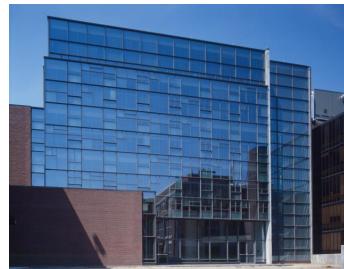
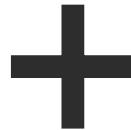
Kartik Mohta, Matthew Turpin, Alex Kushleyev, Daniel Mellinger, Nathan Michael, and Vijay Kumar, “QuadCloud: A Rapid Response Force with Quadrotor Teams,” *Int. Symp. on Experimental Robotics (ISER)*, 2014.

Enabling Cooperation



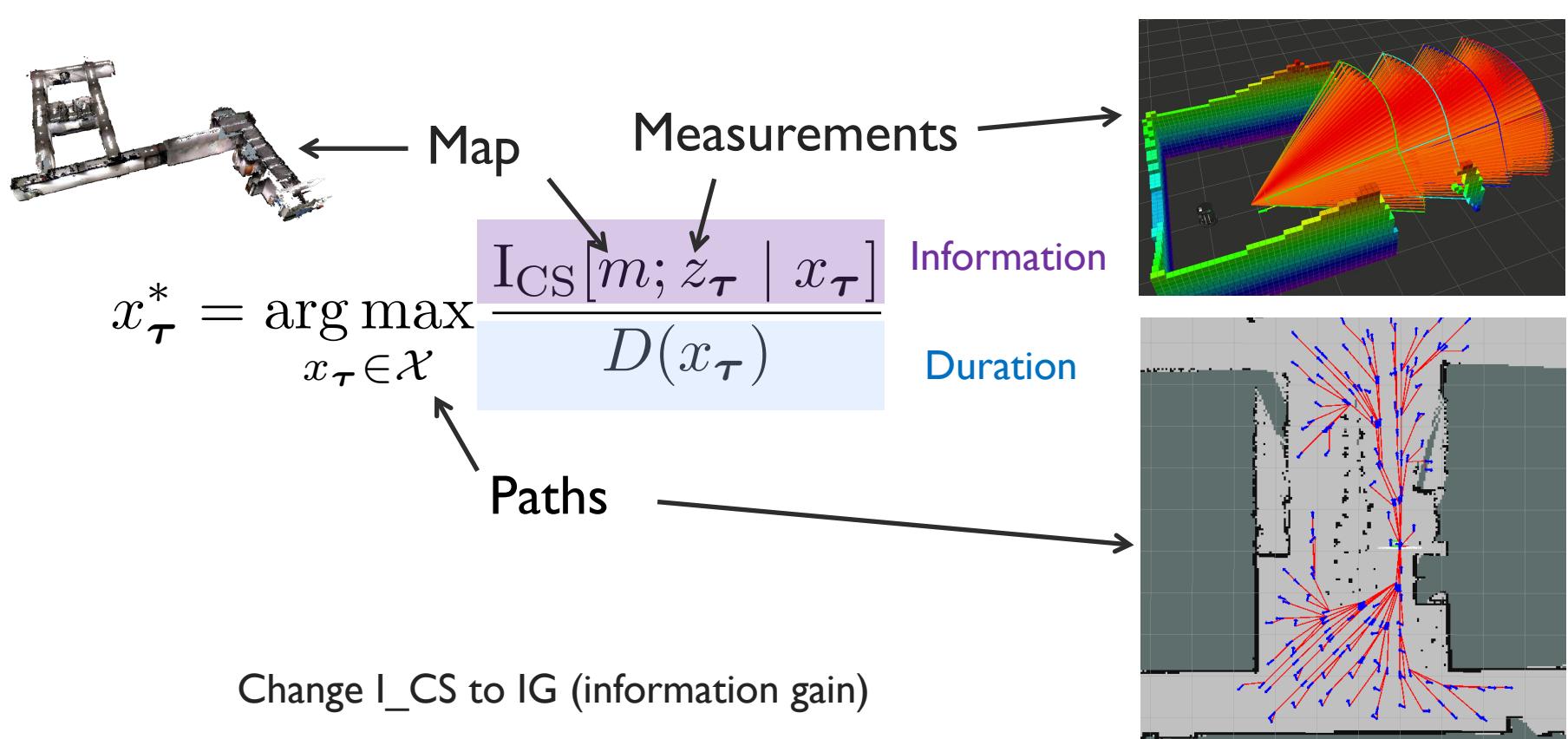
Active Mapping

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

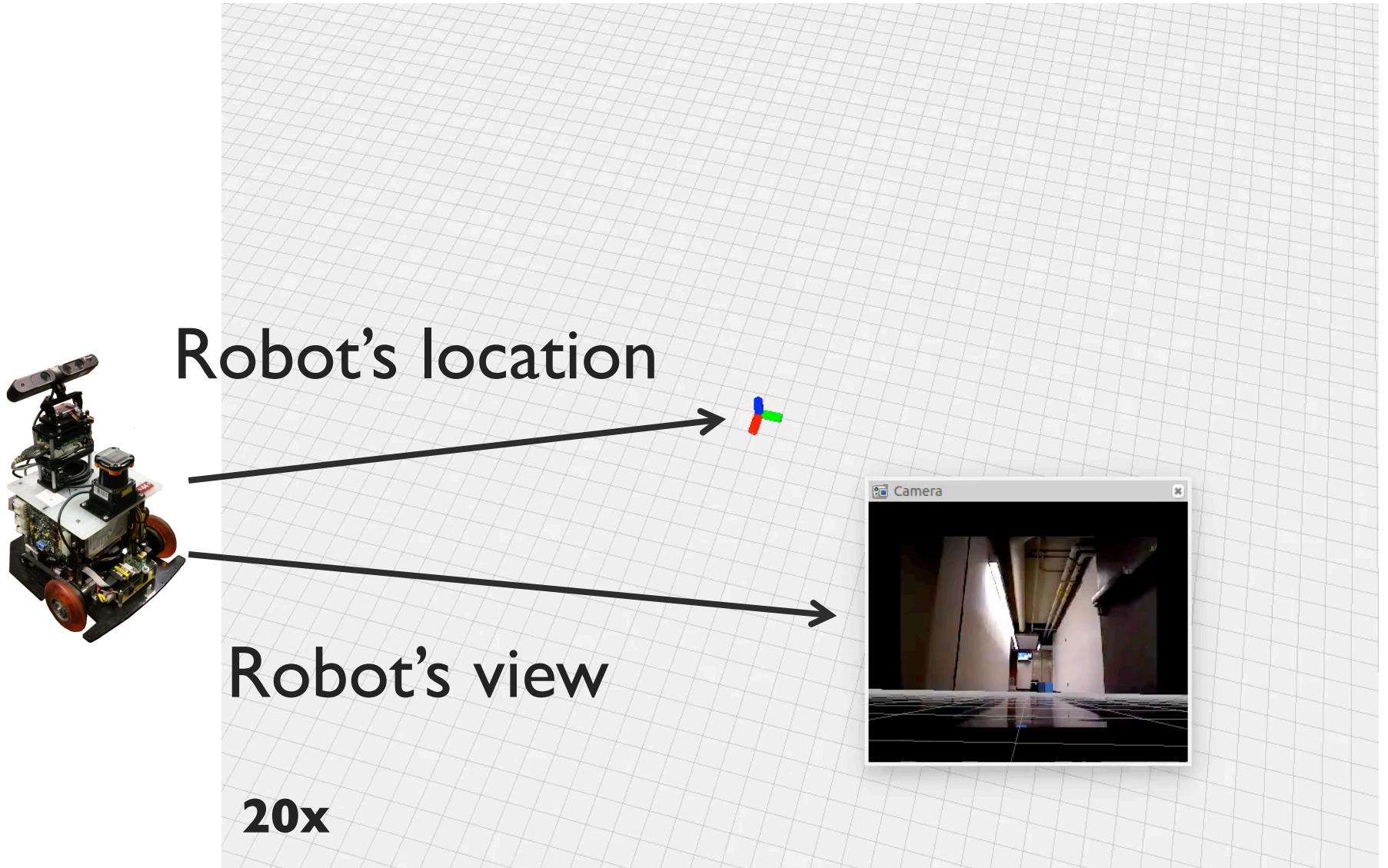


Control Policy

Reduce uncertainty of map by maximizing information gain



Active Mapping



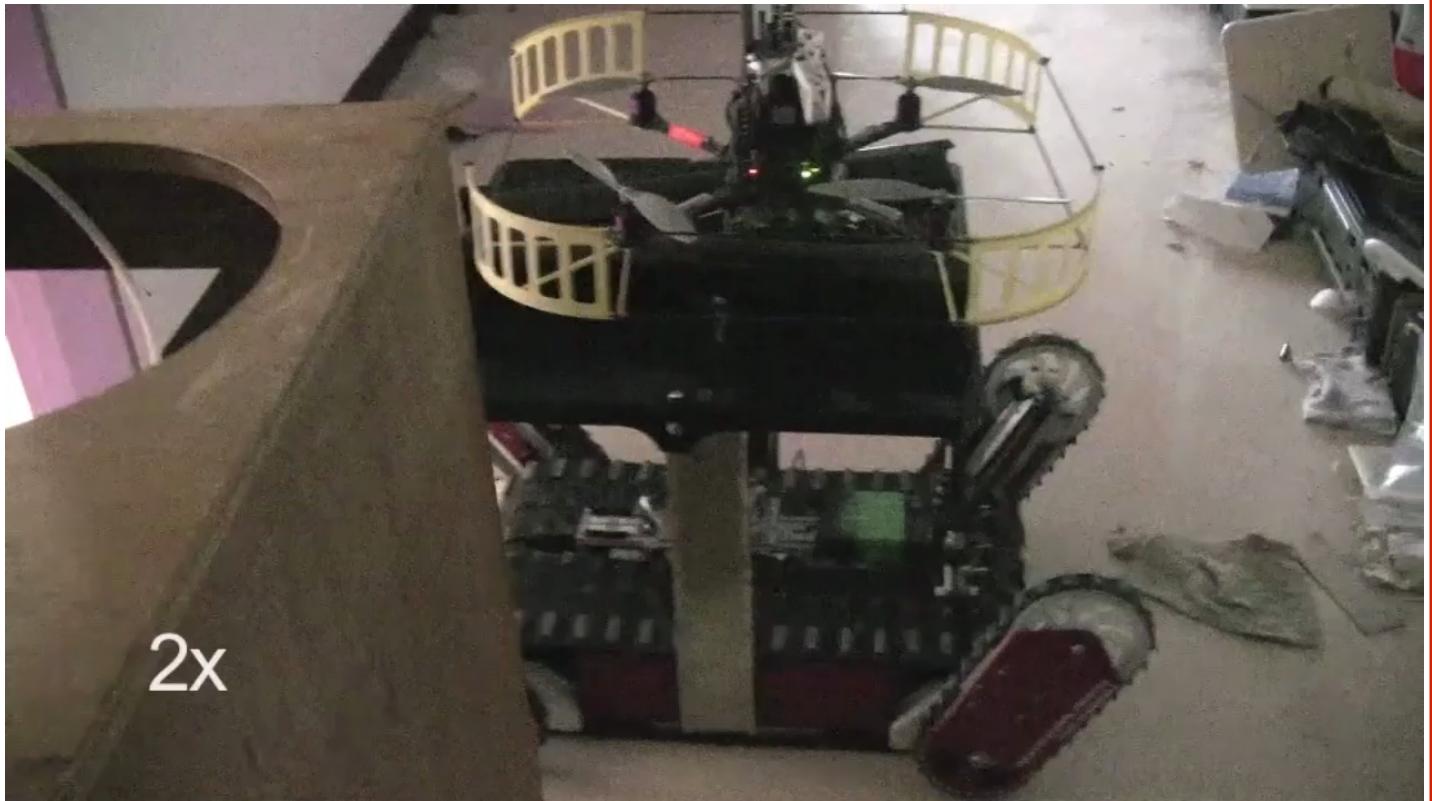
Active Mapping

Quadrotor Experiment

Search and Rescue

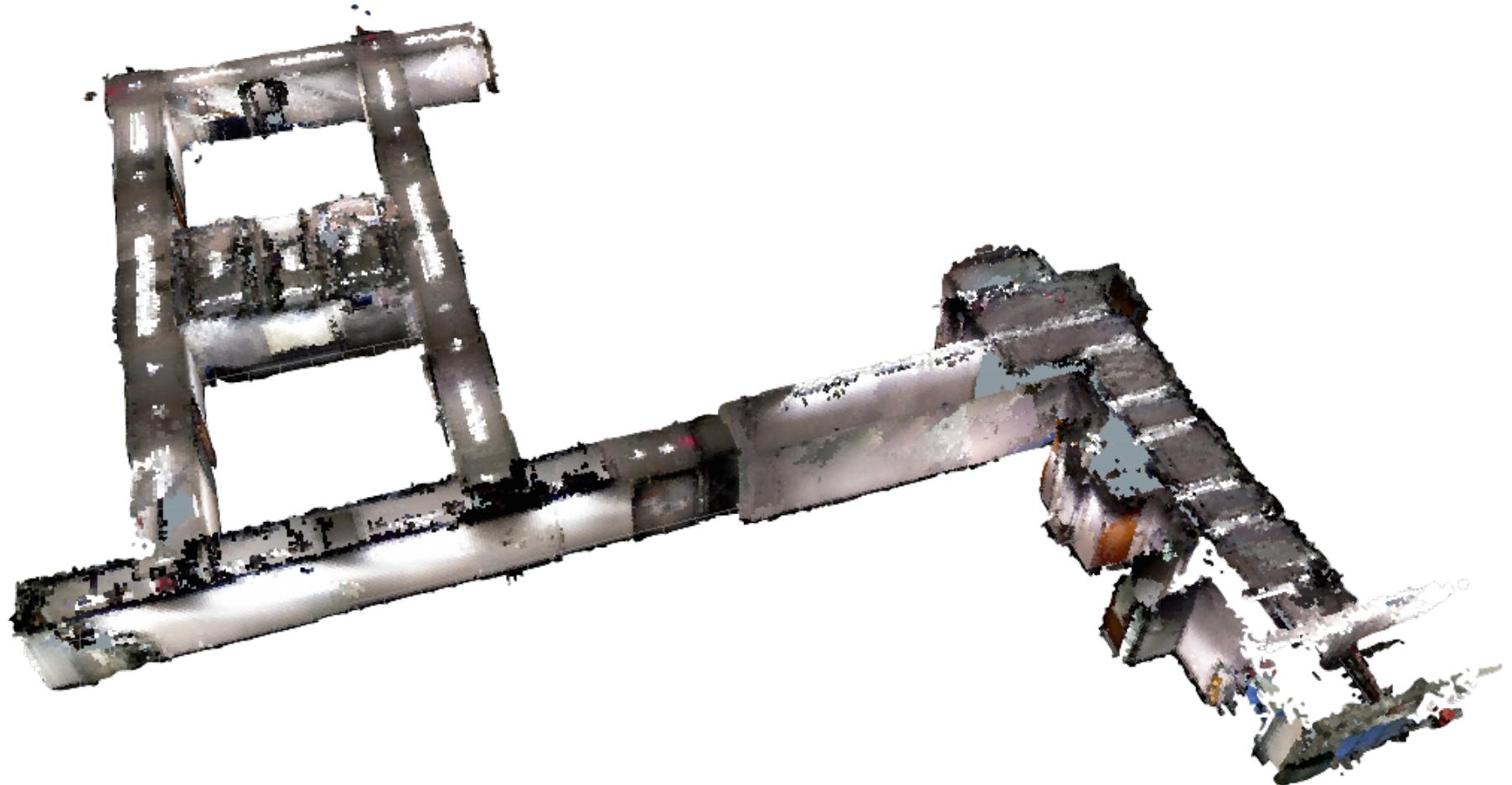


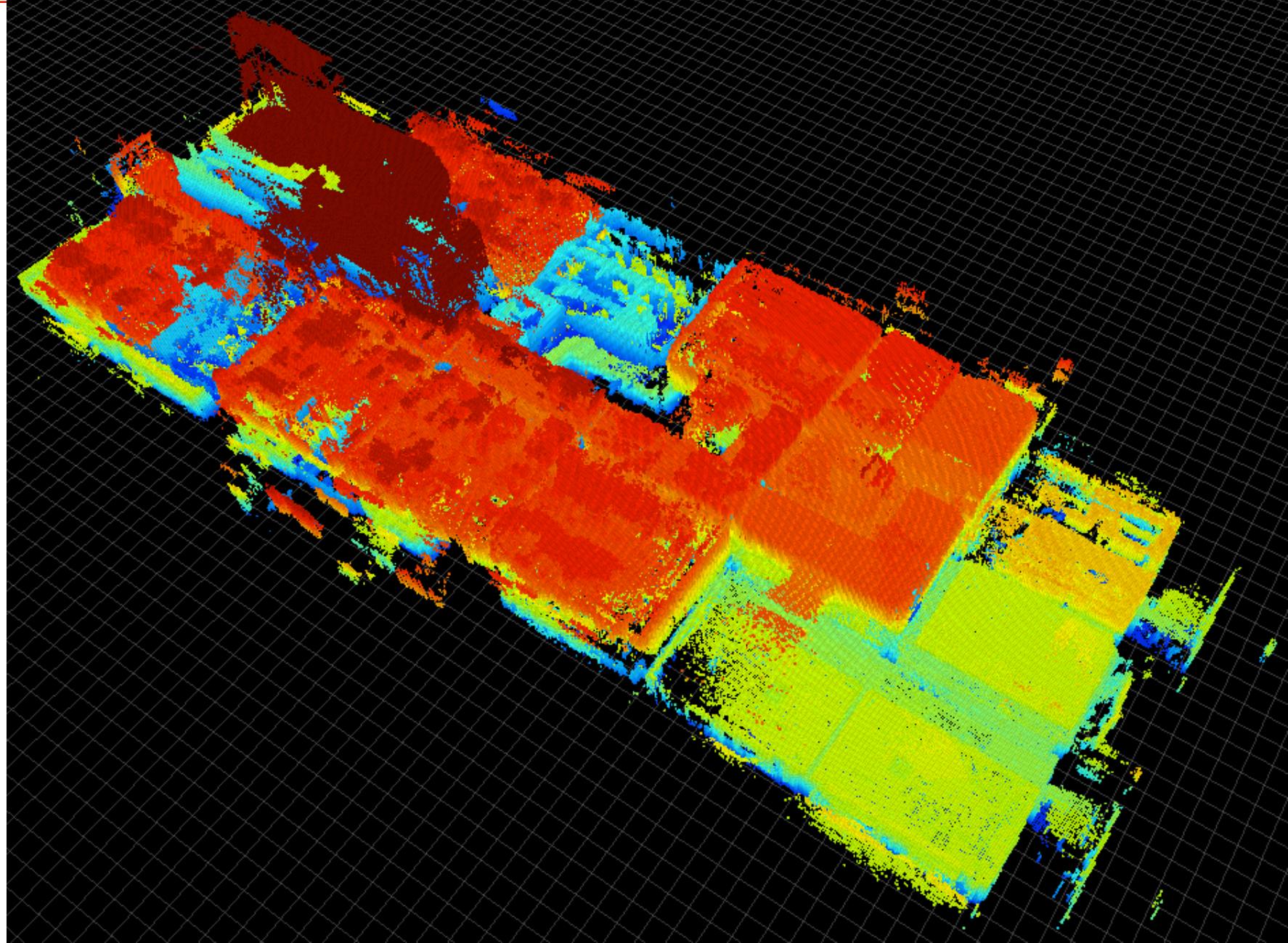
N. Michael, S. Shen, K. Mohta, Y. Mulgaonkar, V. Kumar, K. Nagatani, Y. Okada, S. Kiribayashi, K. Otake, K. Yoshida, K. Ohno, E. Takeuchi, and S. Tadokoro, "Collaborative mapping of an earthquake-damaged building via ground and aerial robots," *J. Field Robotics*, vol. 29, no. 5, pp. 832–841, 2012.



[Michael et al, 2012]

Final Map





3 floors of a 9 story building



Swarms!