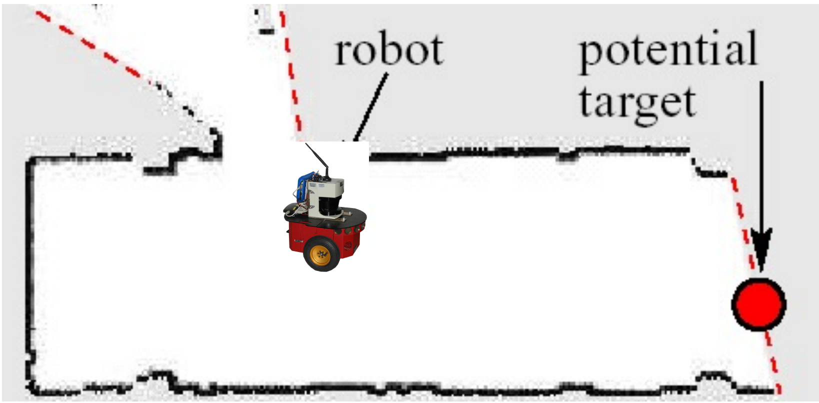
CSE-571
Robotics

Exploration

Single Robot Exploration

- Frontiers between free space and unknown areas are potential target locations
- Going to frontiers will gain information

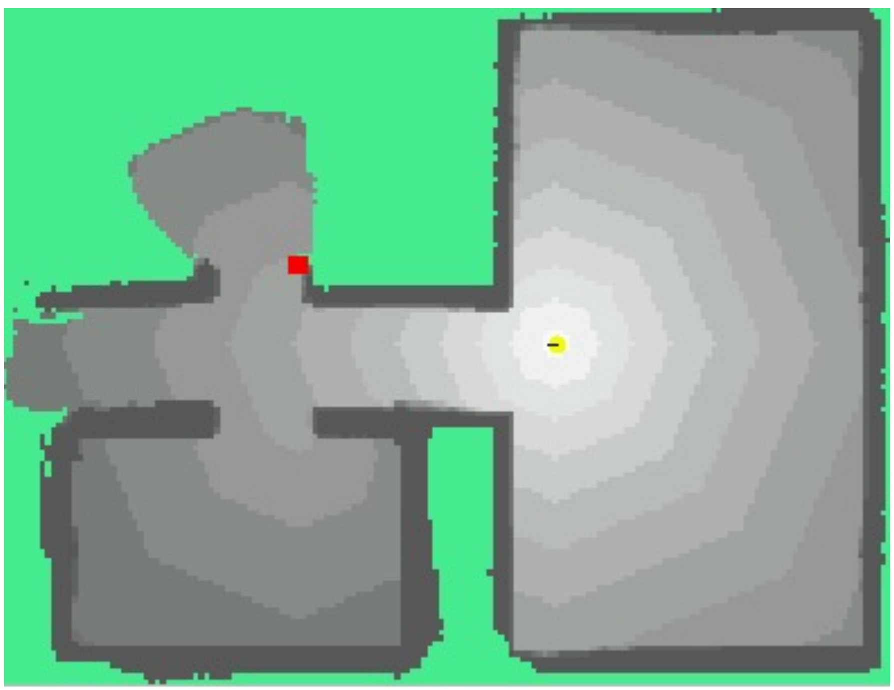


- Select the target that minimizes a cost function (e.g. travel time / distance /…)

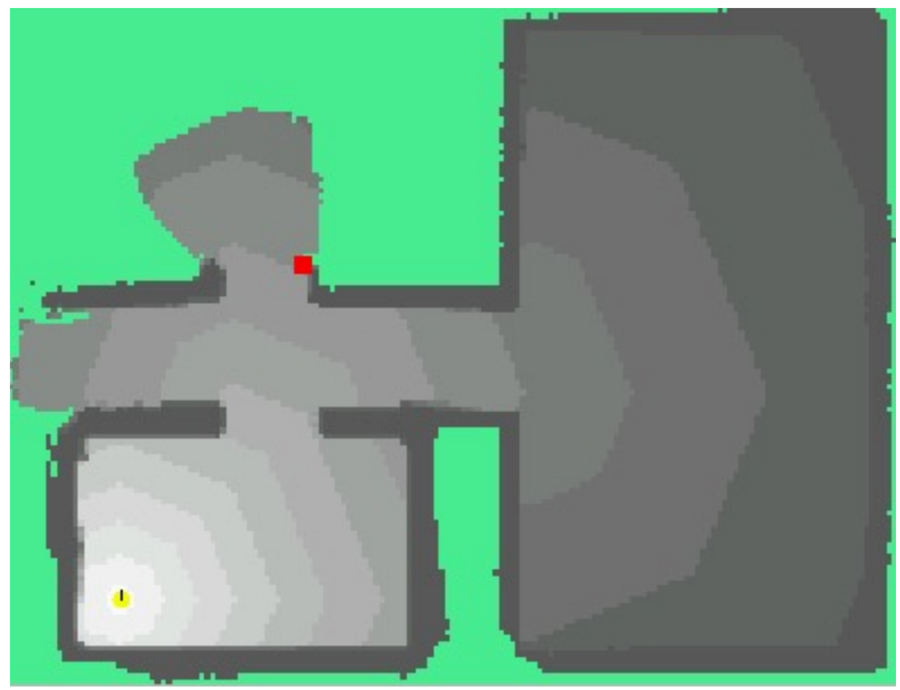
Frontier-Based Exploration

Multi-Robot Exploration

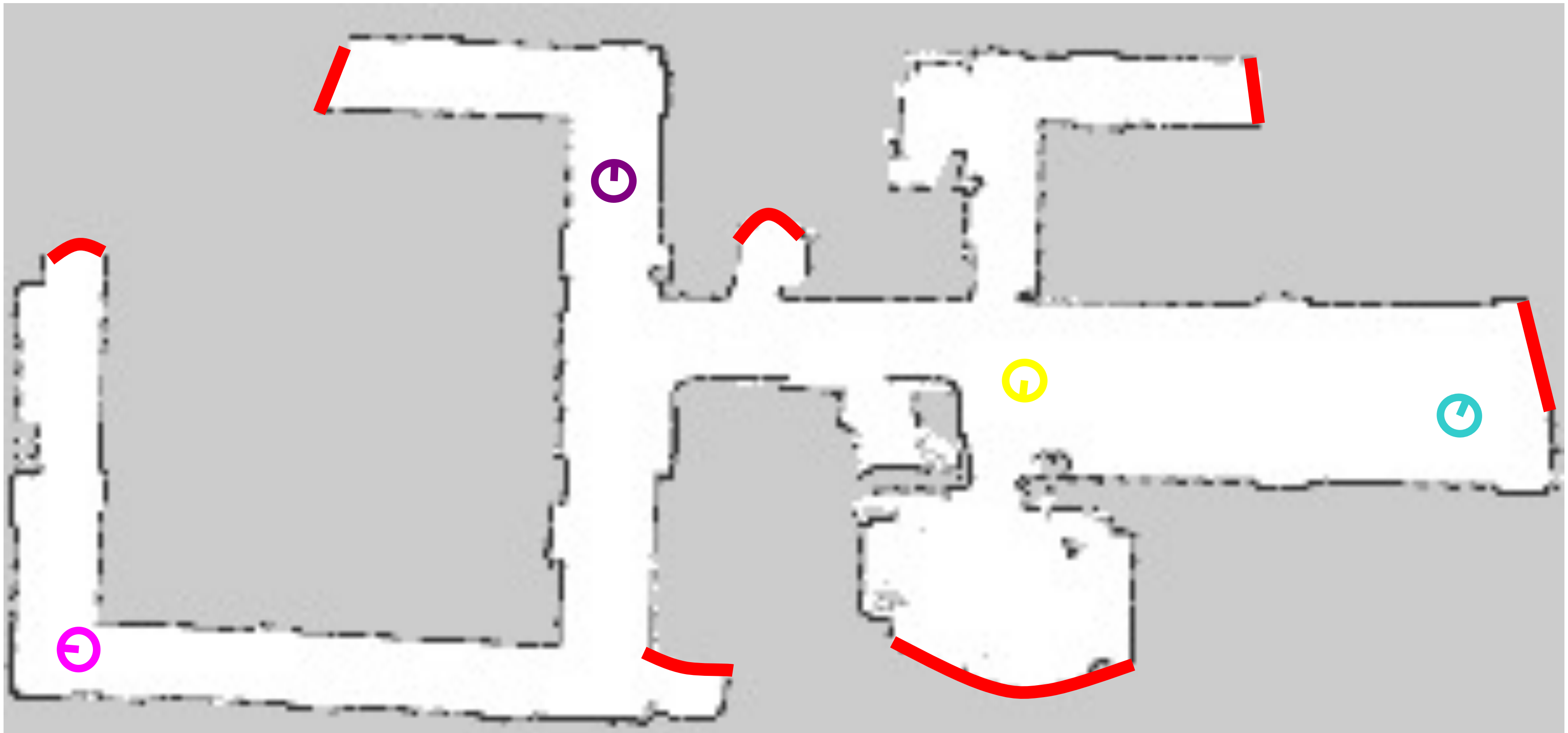
Robot 1:



Robot 2:



Coordinated Exploration



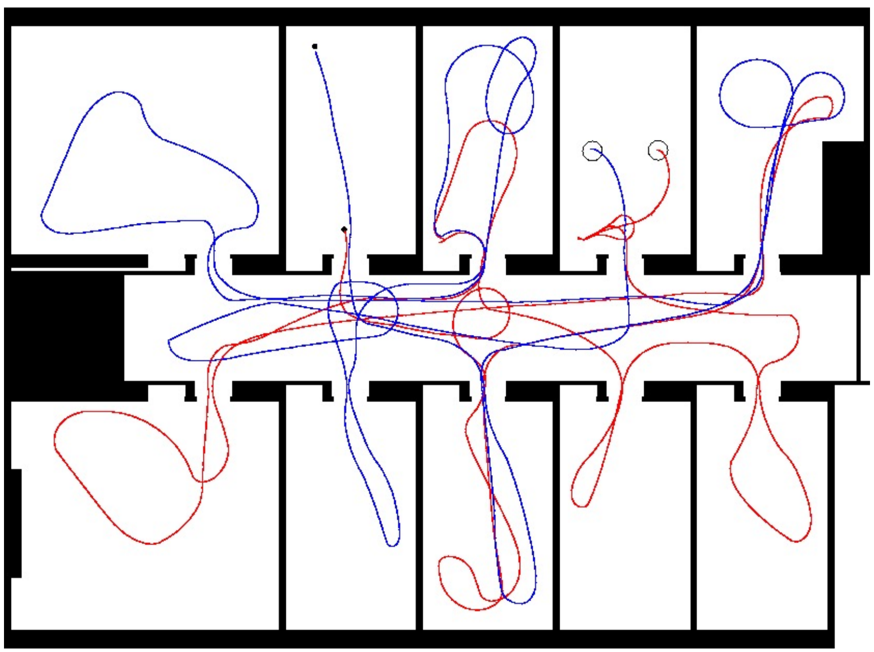
$$C(\theta) = \sum_{(i,j)\in\theta} \text{dist}(i,j) \qquad U(\theta) = \sum_{(i,j)\in\theta} \text{explore}(i,j)$$

$$\theta^* = \arg\max_{\theta}\big(U(\theta) - C(\theta)\big)$$

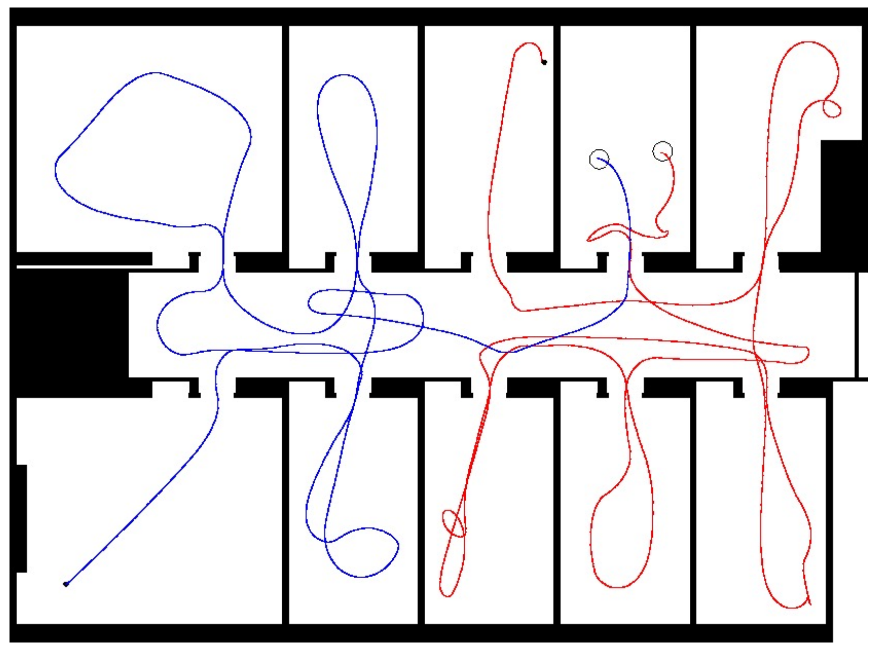
[Burgard et al. 00],
[Simmons et al. 00]

Typical Trajectories in an Office Environment

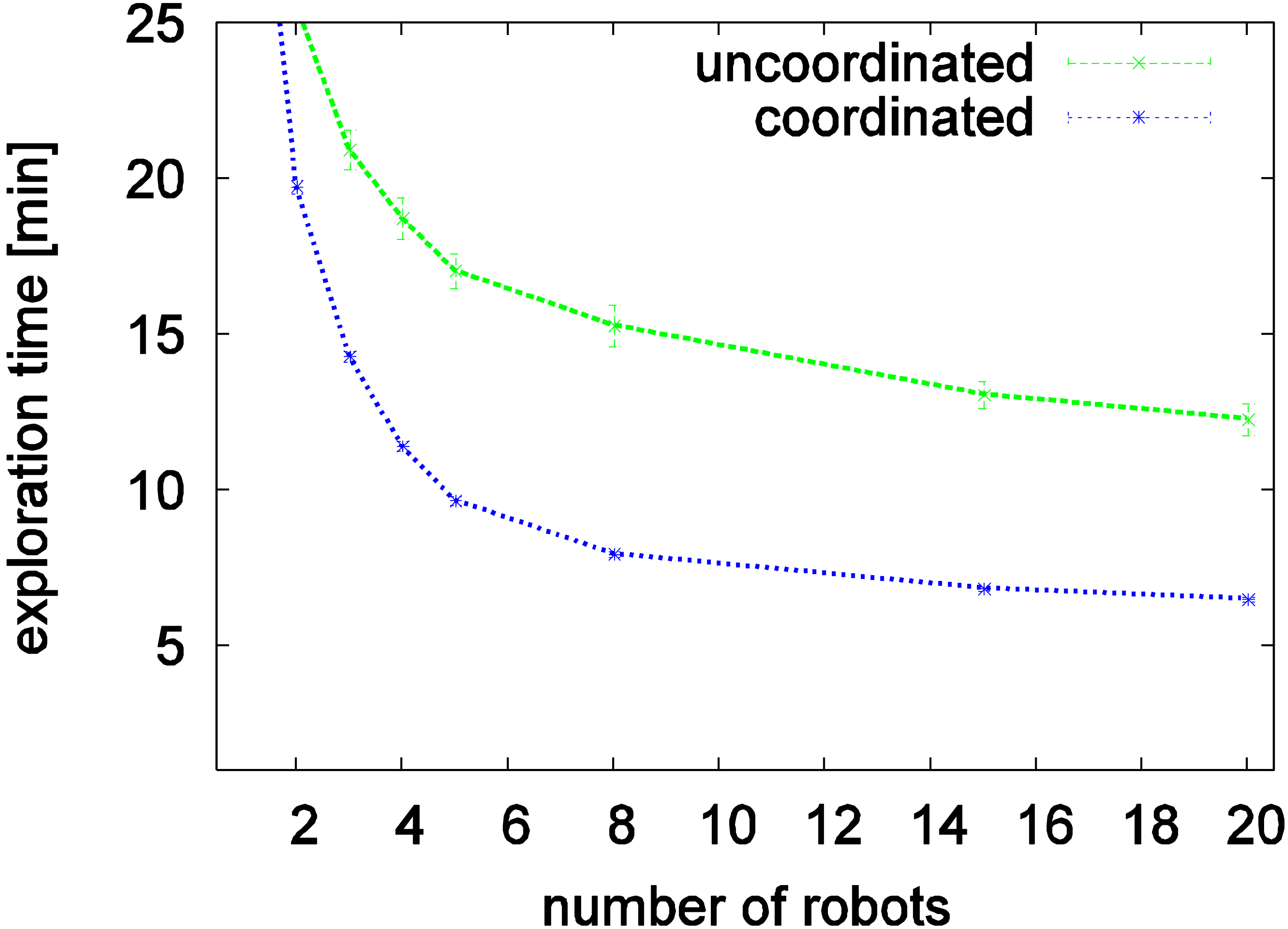
Implicit / no coordination:



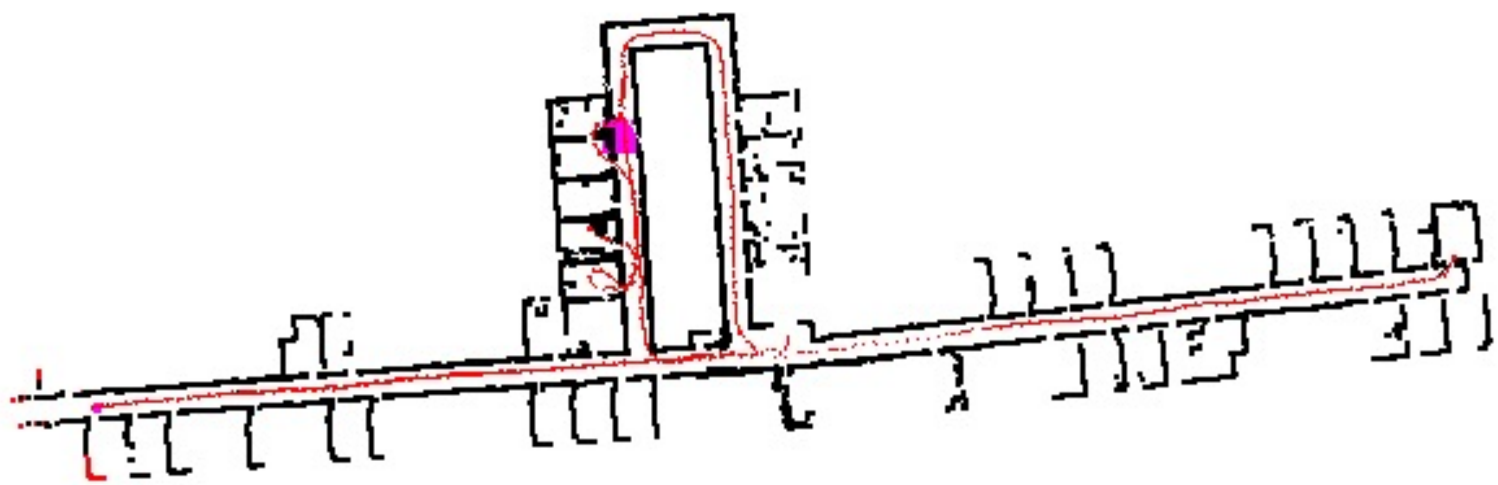
Explicit coordination:



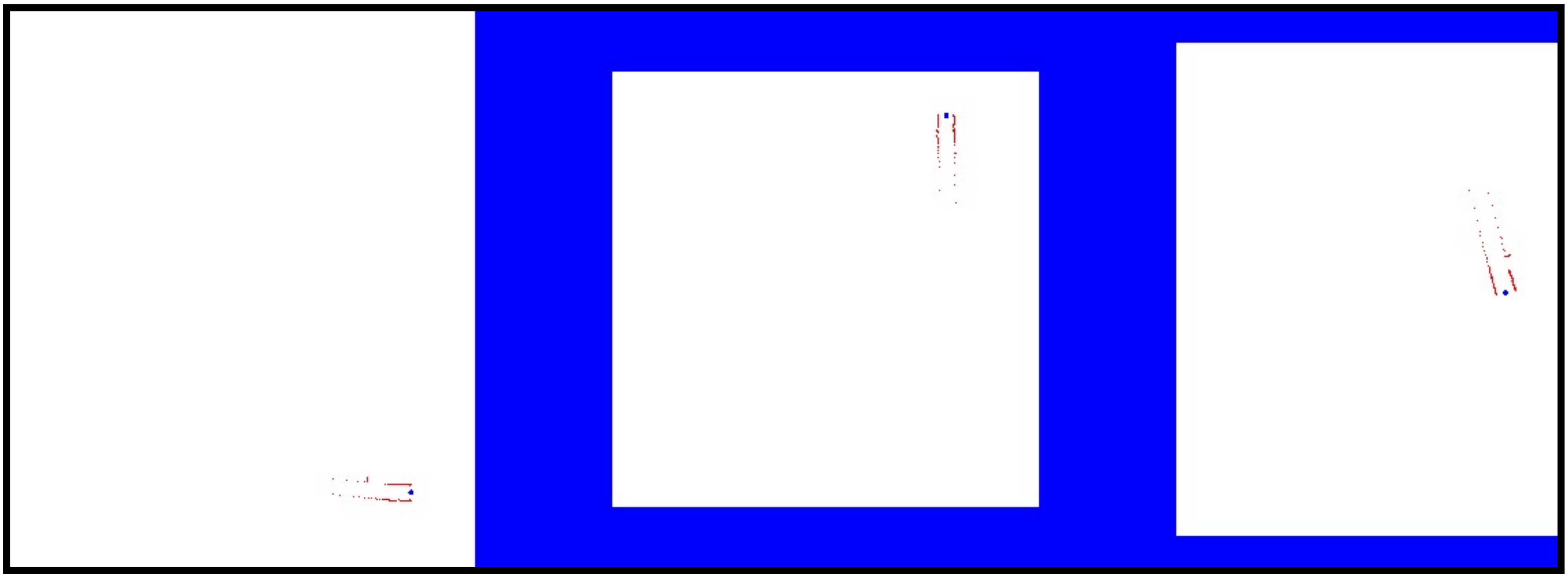
Exploration Time



Multi-Robot Mapping With Known Start Locations



Why are Unknown Start Locations Hard?



Robot A Robot B Robot C

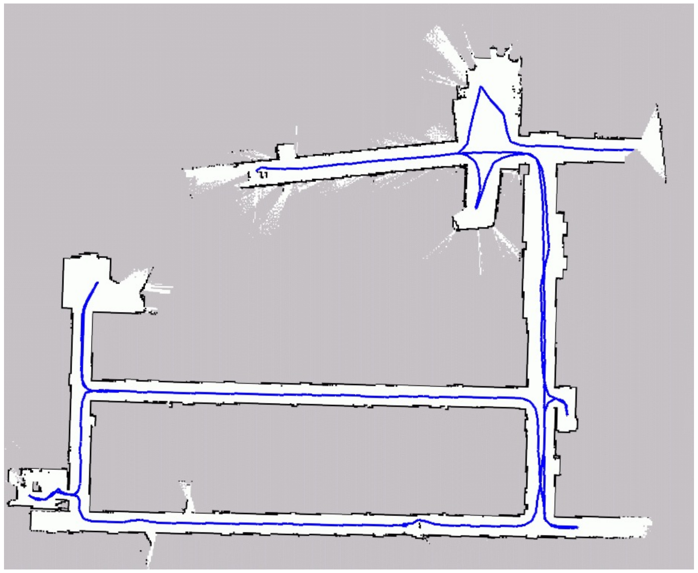
- Need to know whether or not maps overlap
- Need to know how maps overlap

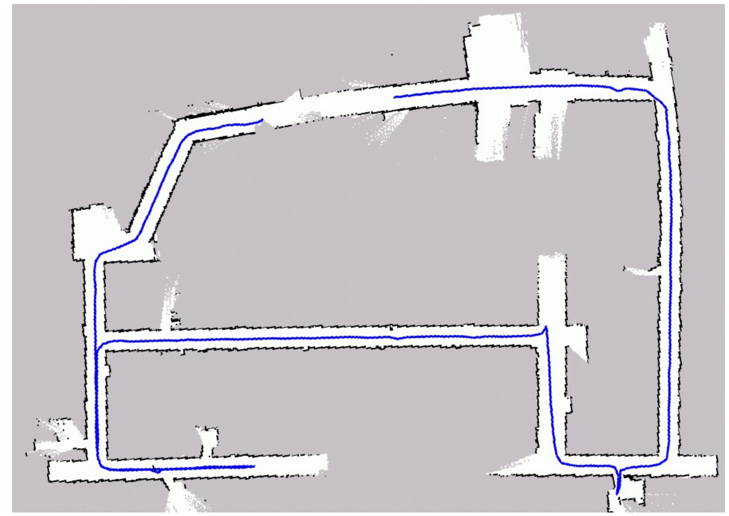
Multi-robot Map Merging

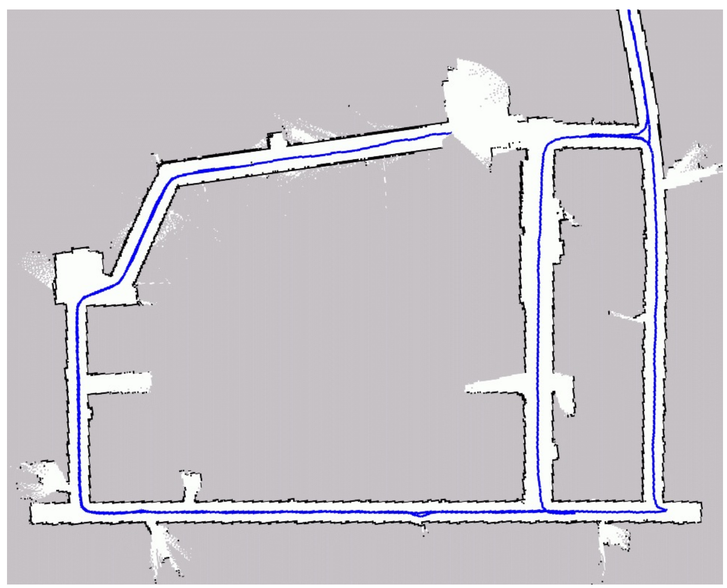
- Problems
  - Number of possible merges is exponential in number of robots
  - Cannot merge maps by simply overlaying them

- Wanted
  - Scalability, robustness
  - Merge maps as soon as possible

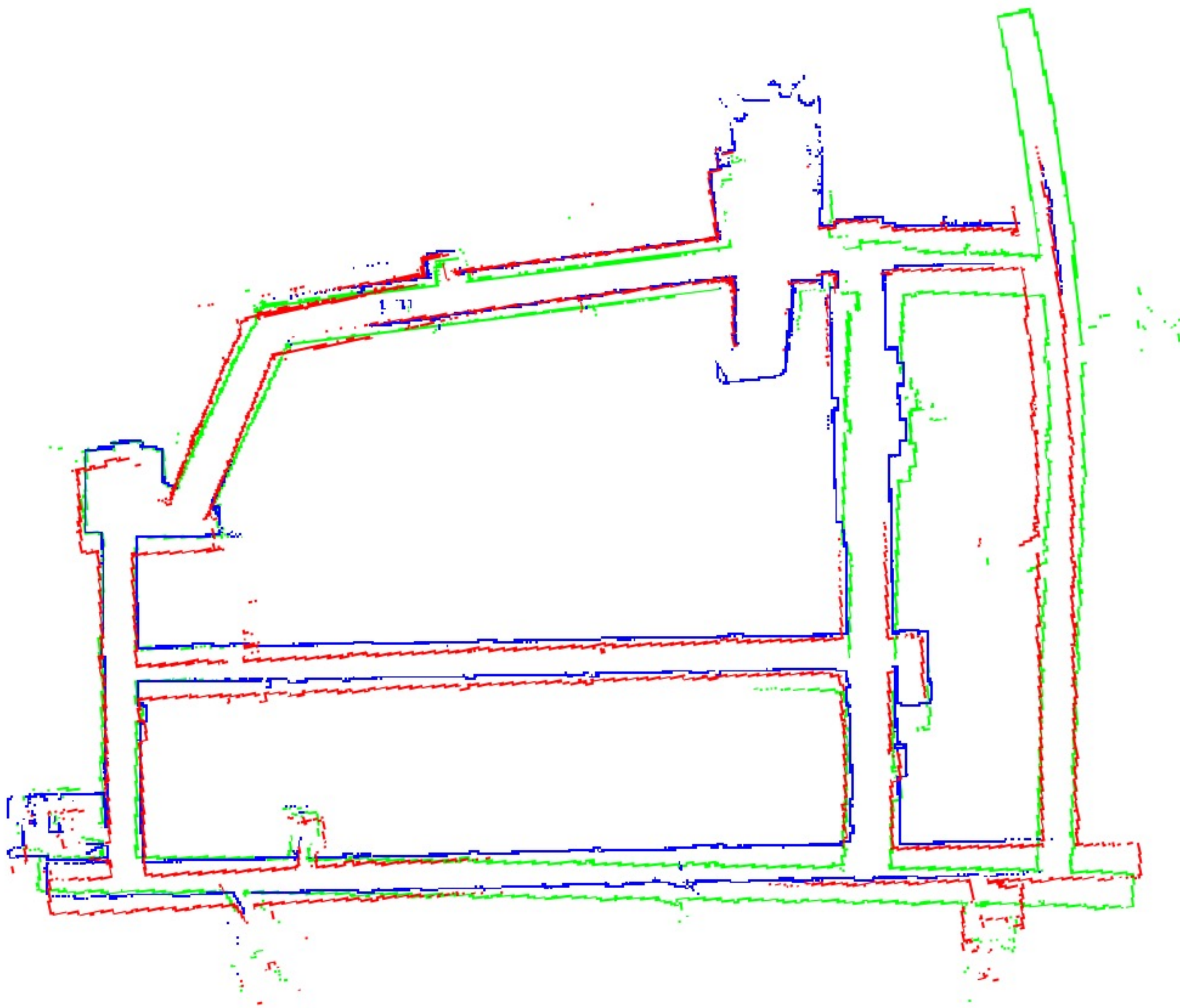
Multi-robot Map Merging



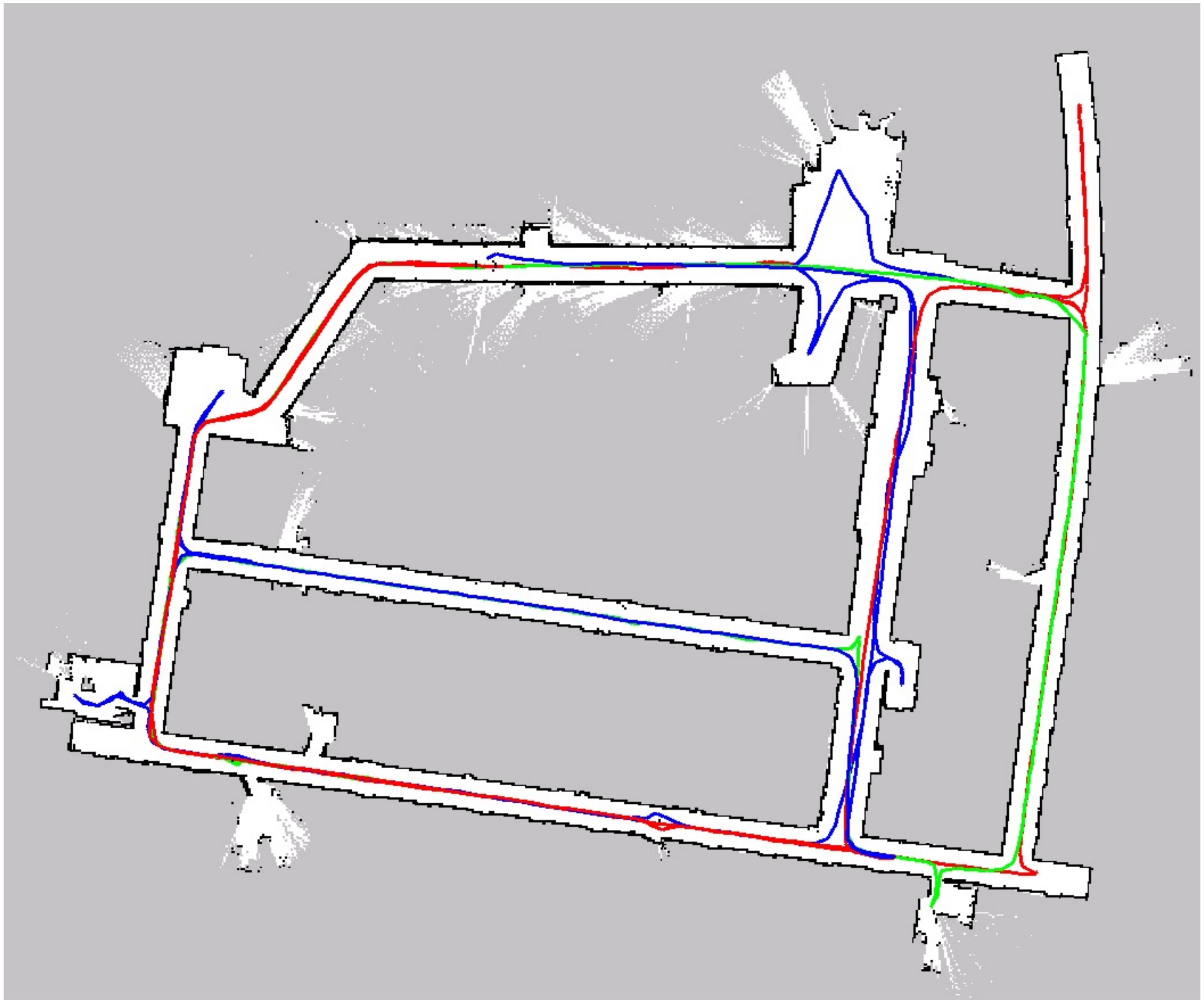




Multi-robot Map Merging



Multi-robot Map Merging



Experimental setup

Coordinated exploration with three robots
from unknown start locations

The robots are fully autonomous.
All computation is performed on–board.

Shown is the perspective of one robot

Sponsored by DARPA-SDR, NSF, Intel

CENTIBOTS

- Map an unknown area
- Search for an “object of value”
- Set up a surveillance network
- Track any intruders

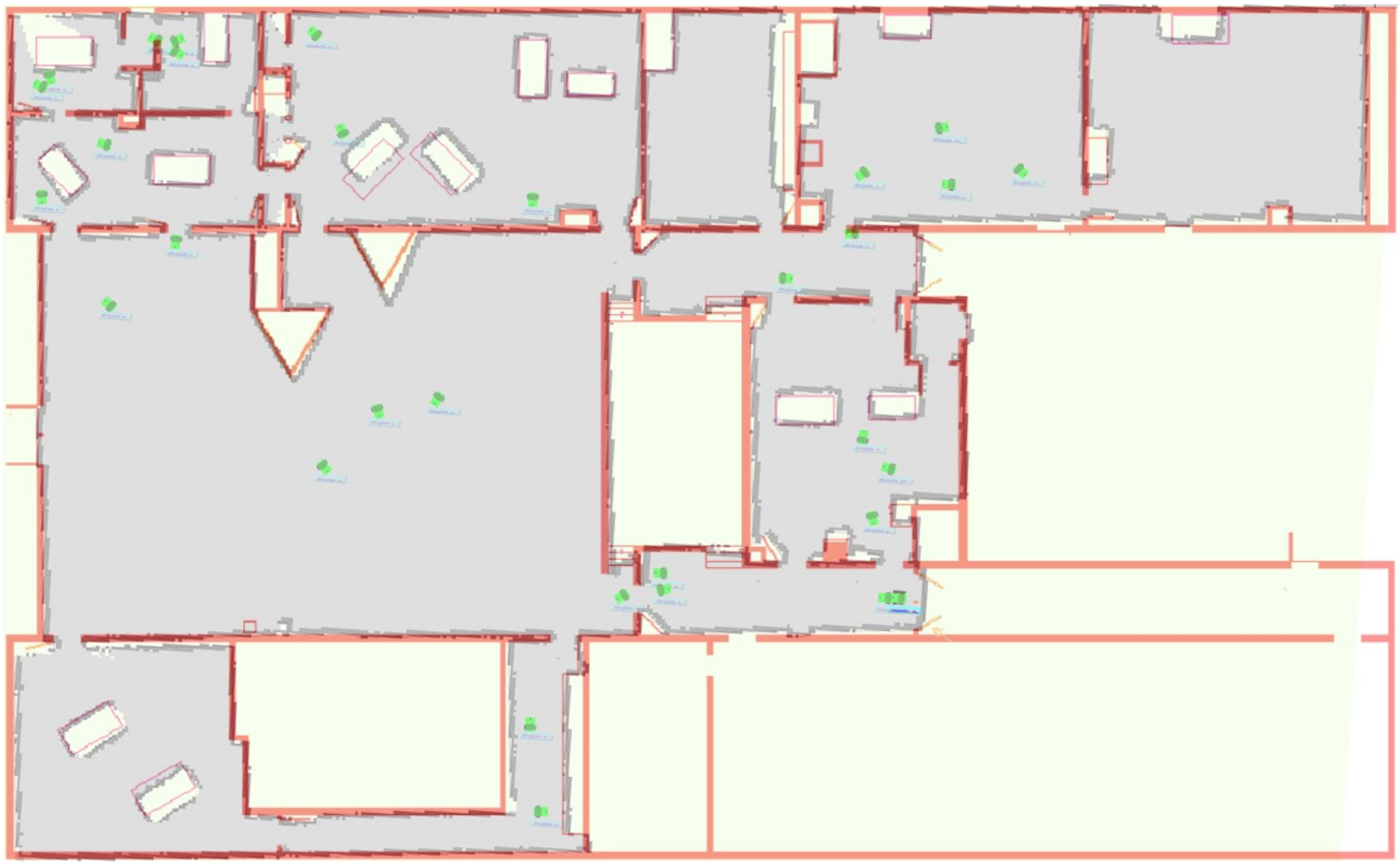
CentiBots: Experimental Evaluation

- Rigorously tested by outside evaluation team

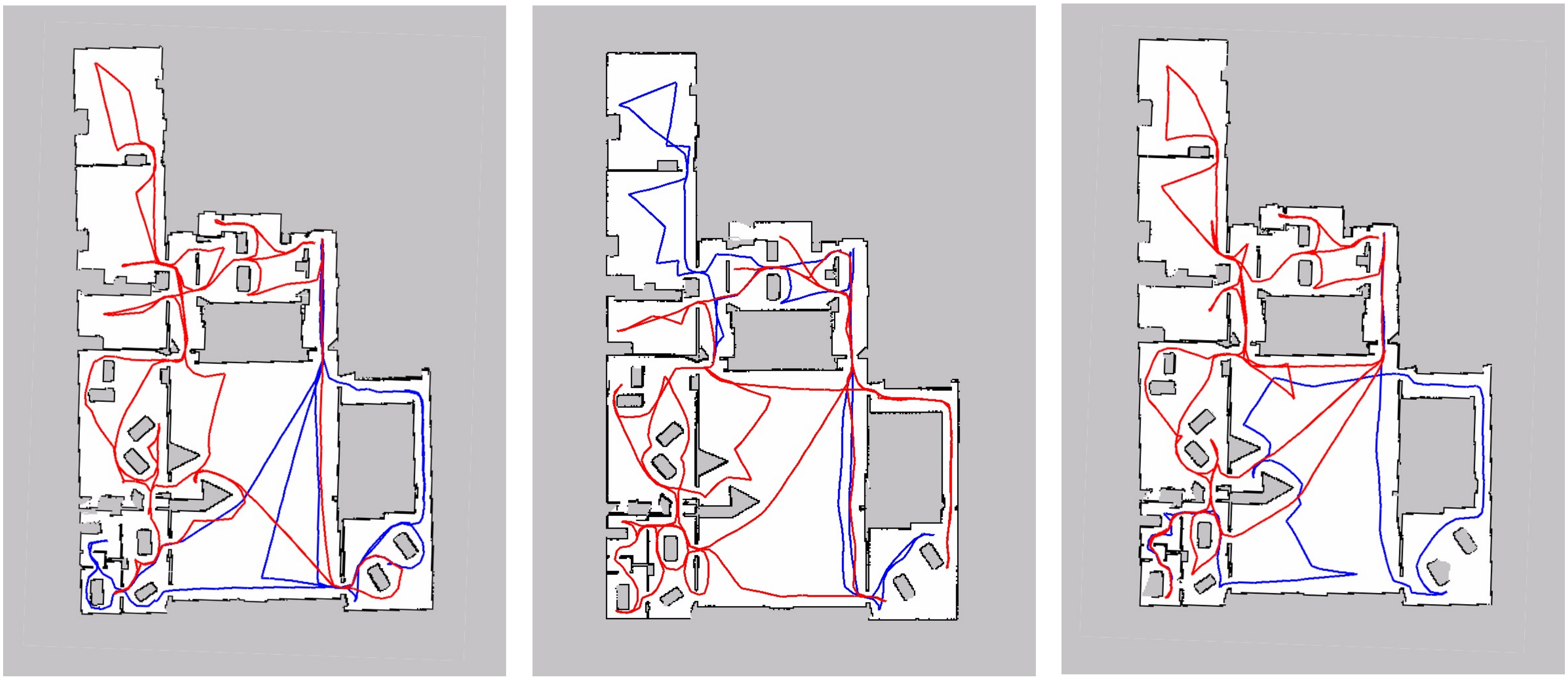
- No testing allowed in 1/2 of environment
- Limited communication
- No intervention / observation during experiment
- Comparison to “ground truth” map

Control Center and Test Team

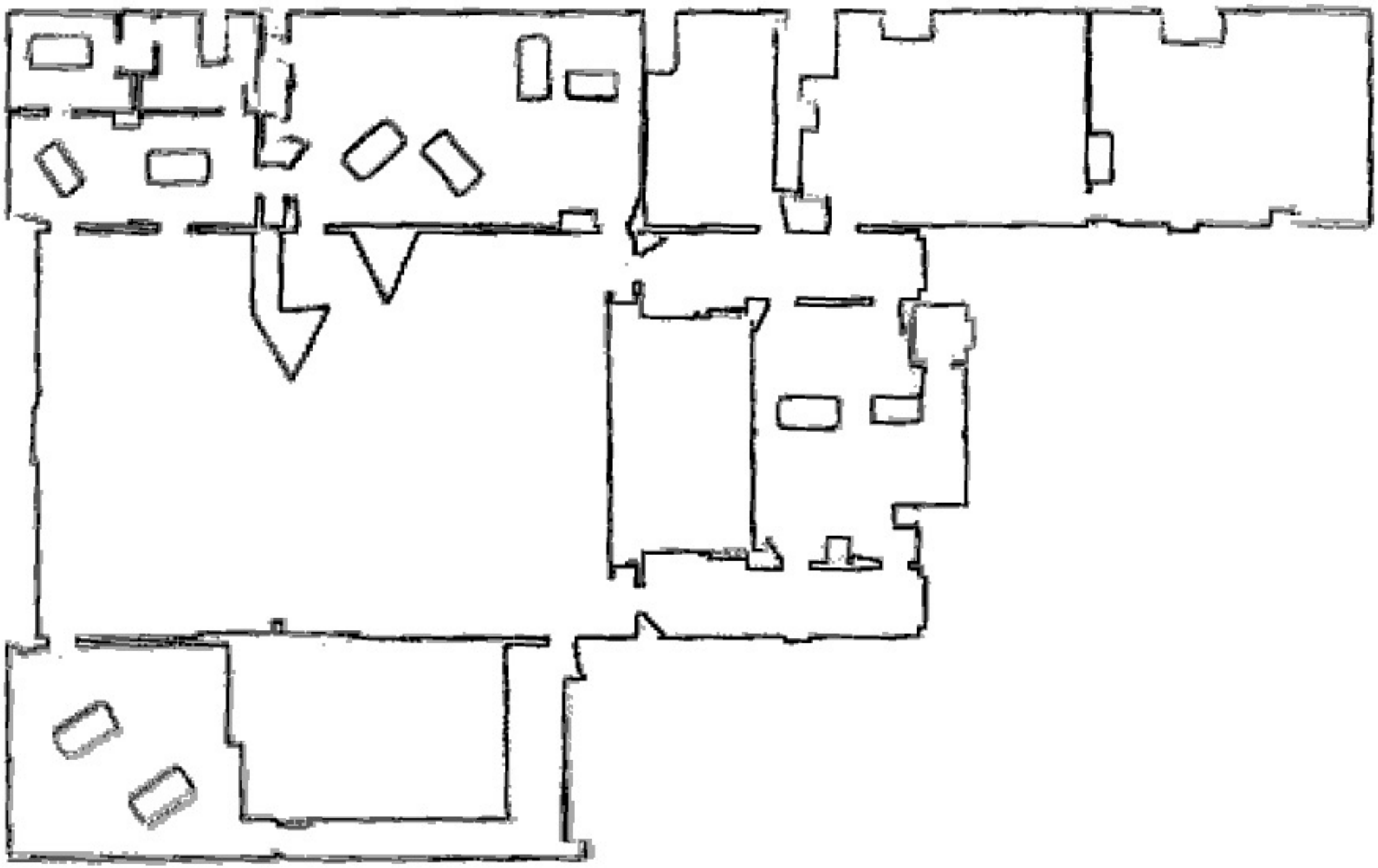
Comparison to "Ground Truth Map"



Three Mapping Runs



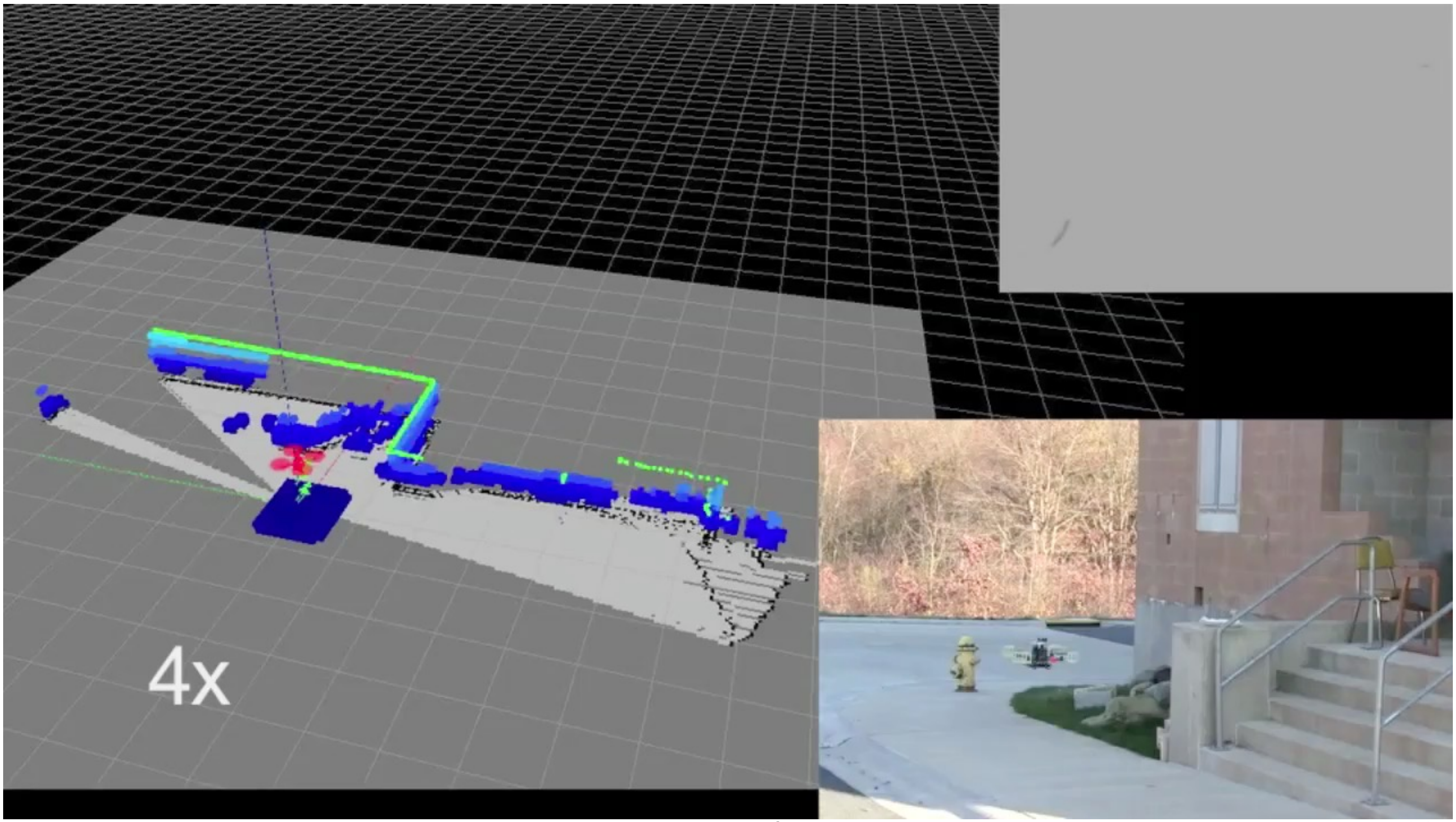
Three Overlayed Maps



Courtesy of Vijay Kumar

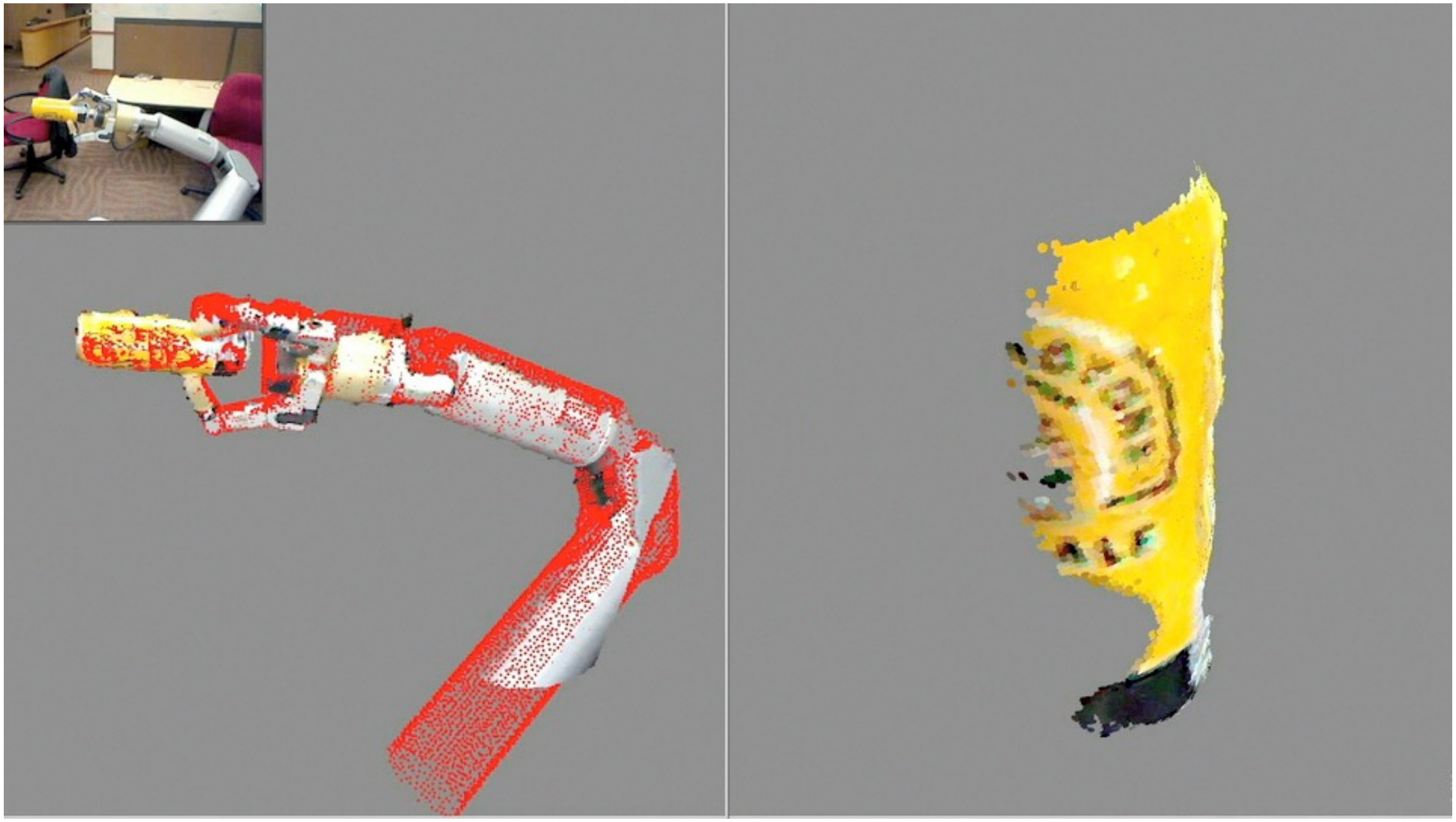
3D Exploration

[Shen-Michael-Kumar: IIJRR-2012]



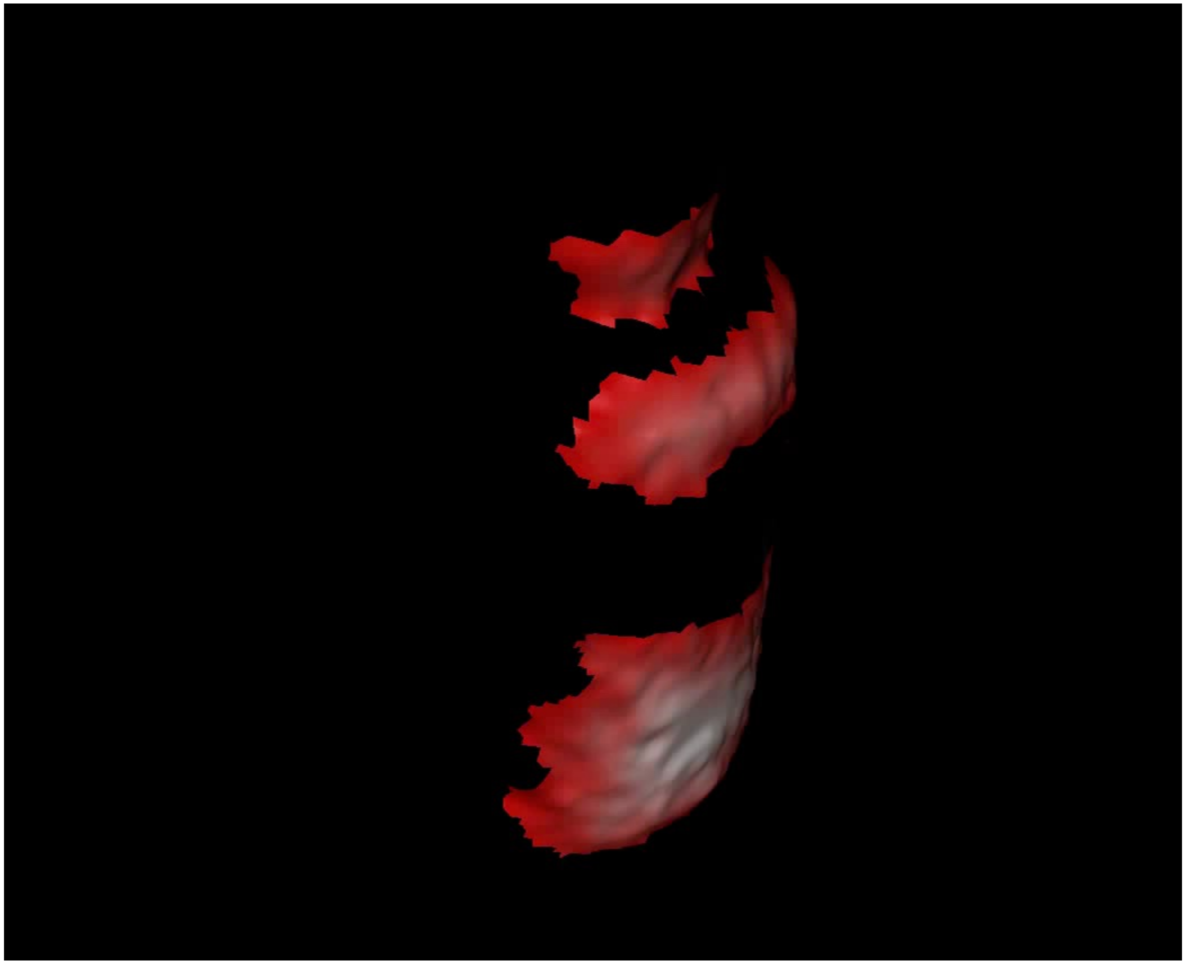
[Krainin-Henry-Ren-F: IJRR-11]

Active Object Modeling: Joint Tracking and Modeling



- EKF with articulated ICP over manipulator joint angles, camera pose and pose of (partial) object

Uncertainty in Object Surface

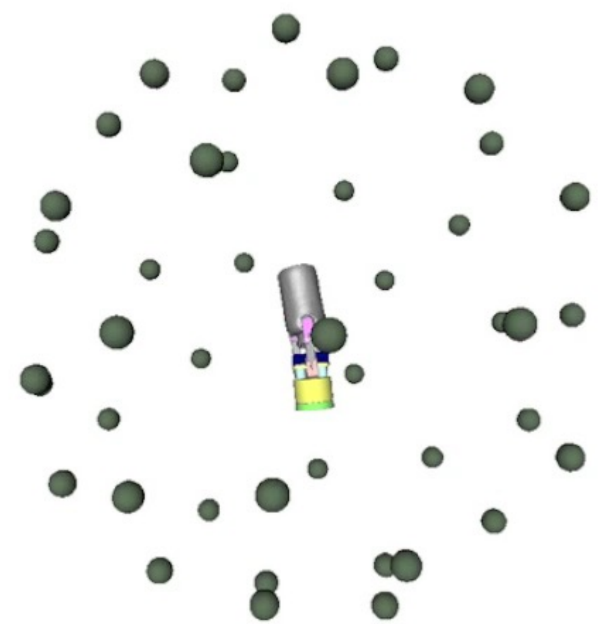


- Signed-distance function voxel grid [Curless '96]
- Surface uncertainty from beam-based noise model

View Selection Algorithm

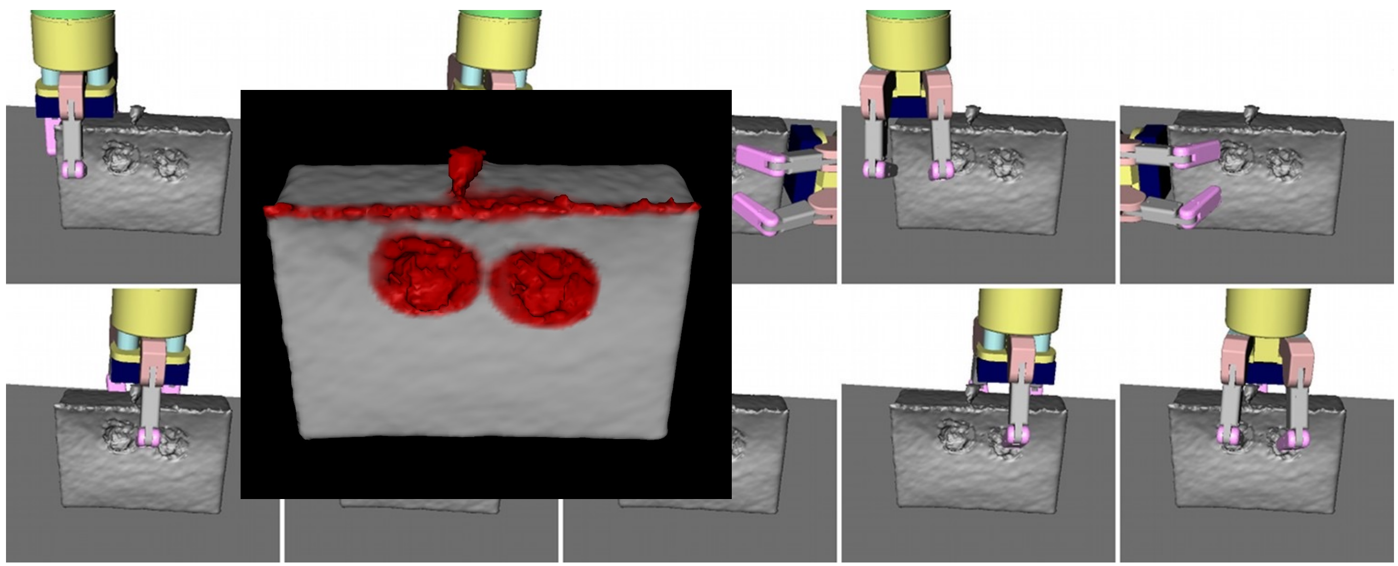
- Conceptually similar to Planetarium Algorithm [Connolly '85]

- Procedure:
  - Generate kinematically achievable viewpoints
  - Compute information gain (quality) for each viewpoint
  - Select view as tradeoff between quality and cost



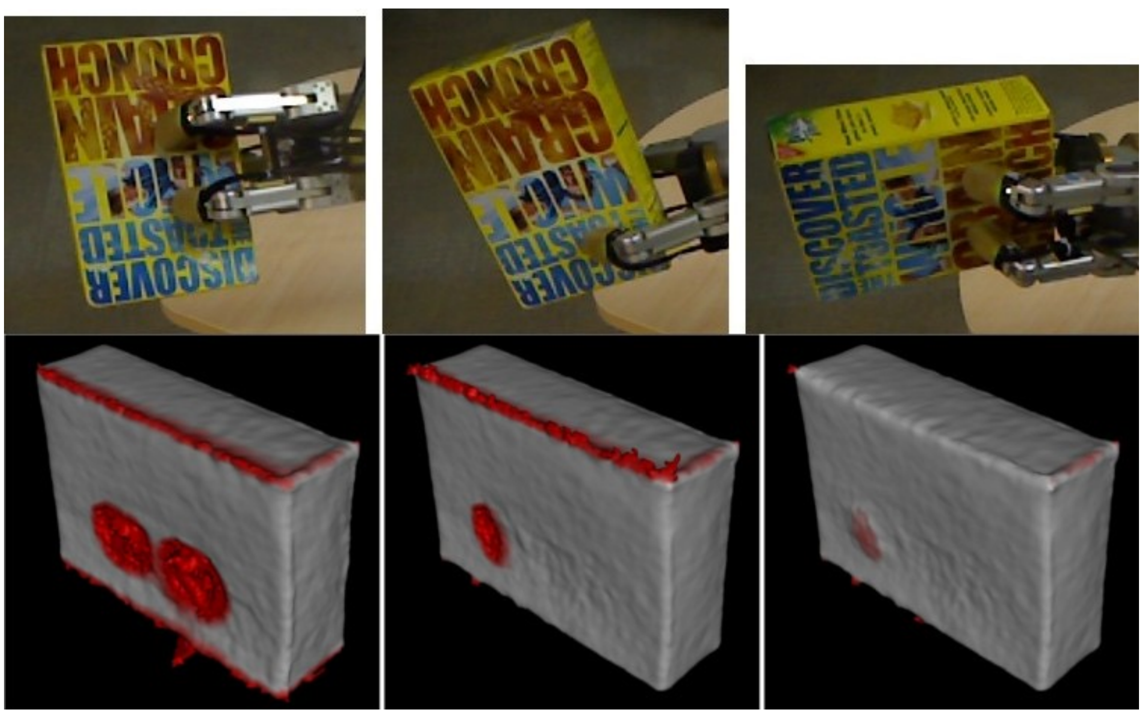
Re-Grasp Selection

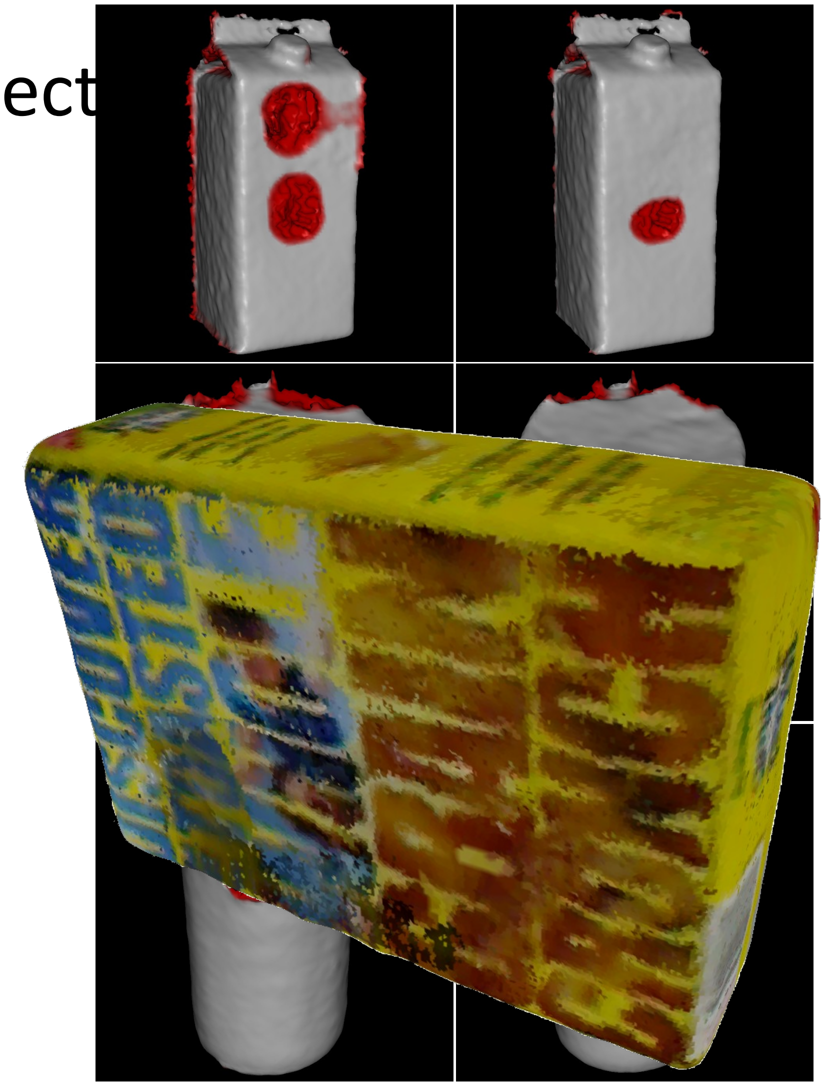
- Generate candidate grasps [Diankov '10]
- Select grasp by maximum information gain, accounting for occlusion caused by grasp



Multiple Grasp Results

- Evaluated regrasping on four object
- Includes box with three grasps





Active Object Modeling