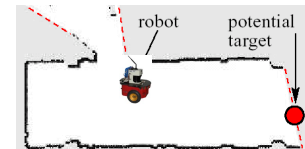CSE-571
Robotics

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 /…)
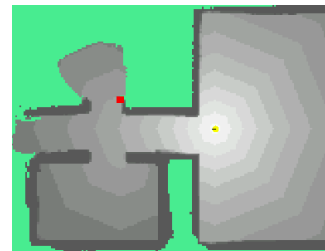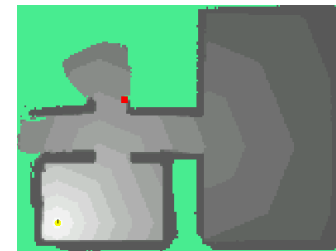

Frontier-Based Exploration

Multi-Robot Exploration

Robot 1:   **Robot 2:**

Coordinated Exploration

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

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

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

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5

Typical Trajectories in an Office Environment

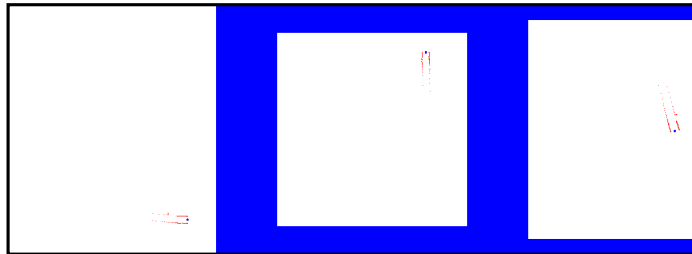Implicit / no coordination: Explicit coordination:

6

6

Exploration Time

7
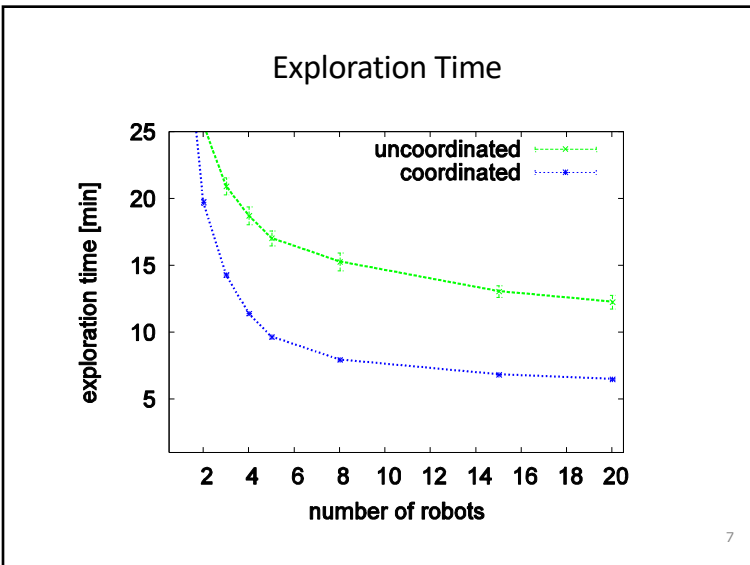
7

Multi-Robot Mapping With Known Start Locations

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8

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

9

Multi-robot Map Merging

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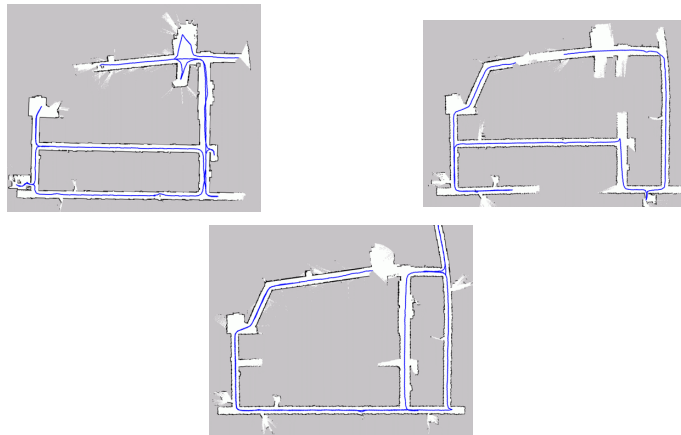 - Cannot merge maps by simply overlaying them

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

10

Multi-robot Map Merging

11

Multi-robot Map Merging
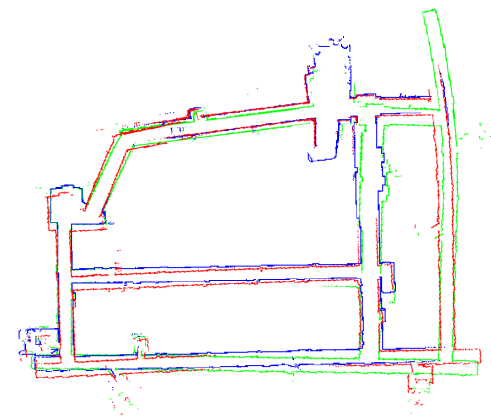
12

3

Multi-robot Map Merging
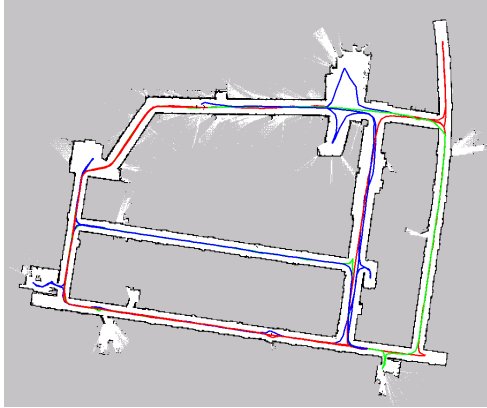
13

Experimental setup

14

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

15

Sponsored by DARPA-SDR, NSF, Intel

▶ Map an unknown area
▶ Search for an "object of value"
▶ Set up a surveillance network
▶ Track any intruders

16

CentiBots: Experimental Evaluation

- Rigorously evaluated by outside evaluation team

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

17

Control Center and Test Team

18

19

Comparison to "Ground Truth Map"

20

Three Mapping Runs

21

Three Overlayed Maps

22

Courtesy of Vijay Kumar

3D Exploration

[Shen-Michael-Kumar: IIJRR-2012]

4x

23

[Krainin-Henry-Ren-F: IJRR-11]
Active Object Modeling:
Joint Tracking and Modeling

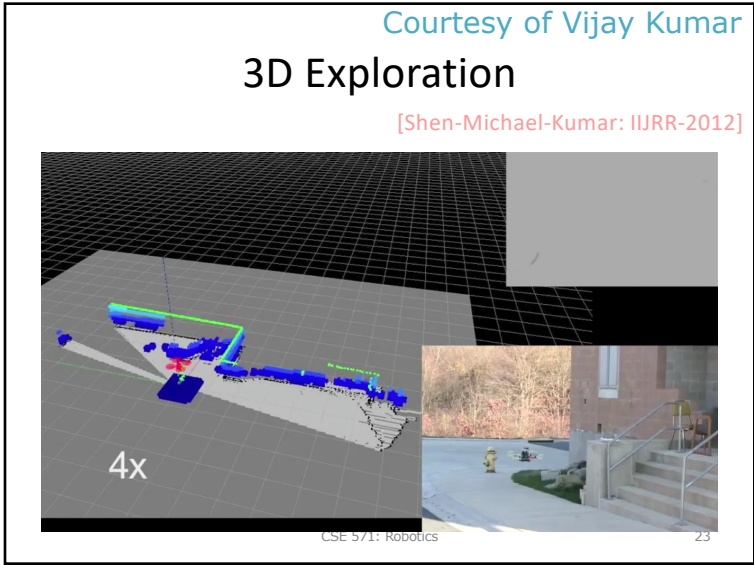- EKF with articulated ICP over manipulator joint angles, camera pose and pose of (partial) object
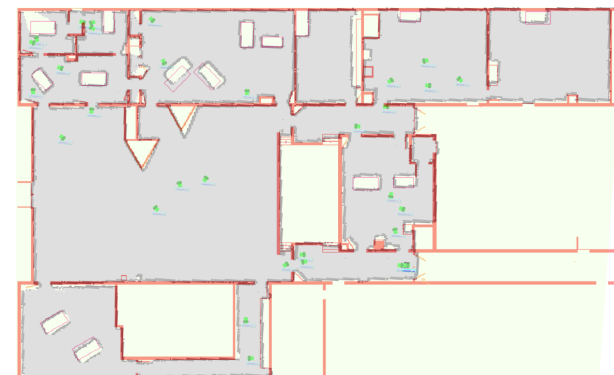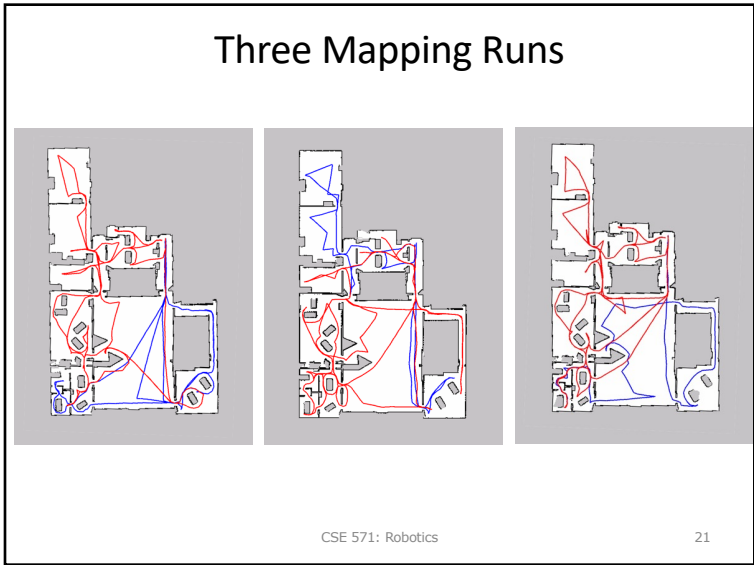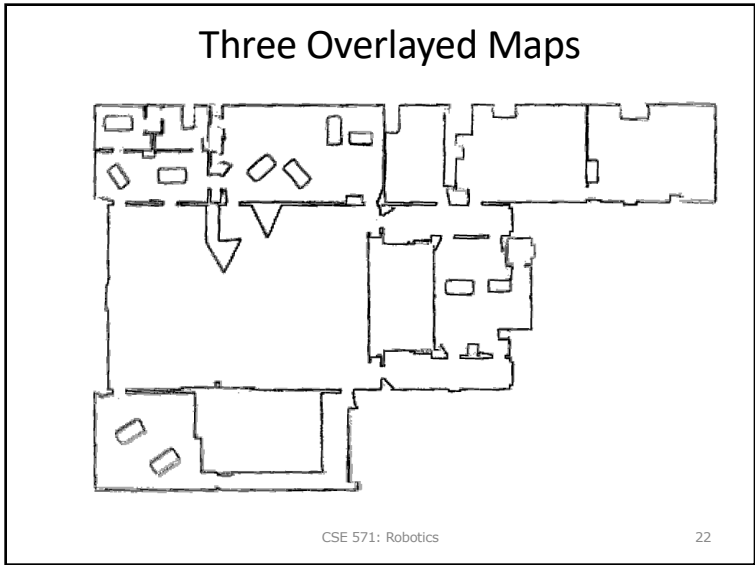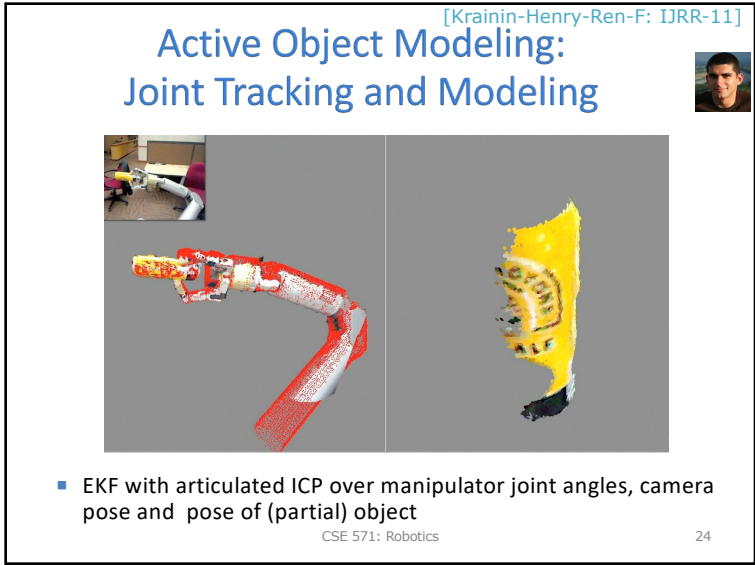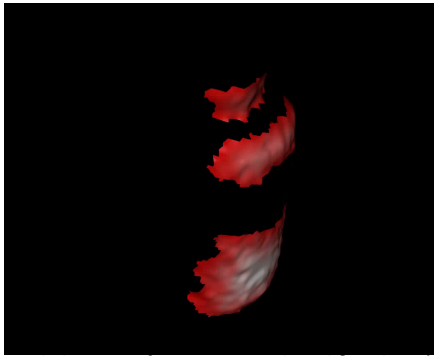
24

Uncertainty in Object Surface

- Signed-distance function voxel grid [Curless '96]
- Surface uncertainty from beam-based noise model
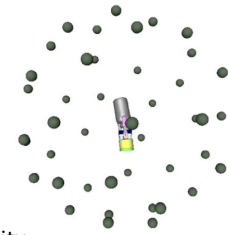
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25

View Selection Algorithm

- Conceptually similar to Planetarium Algorithm [Connolly '85]

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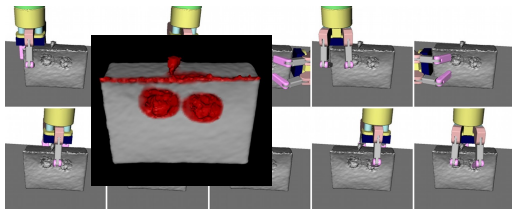 - Select view as tradeoff between quality and cost

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26

Re-Grasp Selection

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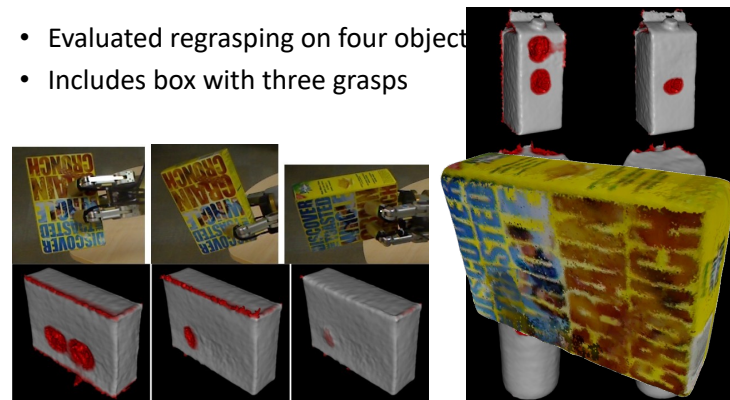

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27

Multiple Grasp Results

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

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28

7

Active Object Modeling

**Next Best View Planning
for 3D In-Hand Modeling**

29

8