Multi-Robot Complete Coverage

- Multiple Robots:
  - Efficiency
  - Robustness
  - Higher Complexity

- Inter-Robot Communication Abilities

- Guarantee of Complete Coverage
Multi Robot Complete Coverage
Limited Communication: Main Ideas

• Communication is limited to Line of Sight
• Coverage of a single cell
  – Robots have two roles:
    - Explorers
    - Coverers
• Team coordination for complete coverage of the environment
  – Limited communication
  – Deterministic approach
  – Team splits only once
Single Cell Coverage

- Each team of $N$ robots has:
  - 2 explorers, $N-2$ coverers
- The explorers trace the top and bottom border of the Cell maintaining the same X-coordinate until the Line of Sight is broken (i.e. a critical point is detected)
Single Cell Coverage

- Each team of $N$ robots has:
  - 2 explorers, $N-2$ coverers

- The explorers trace the top and bottom border of the Cell maintaining the same X-coordinate until the Line of Sight is broken (i.e. a critical point is detected)

- The coverers use an up-and-down motion to cover the interior of the cell
Critical Point Detection

- The explorers are able to detect all critical points:
  - Forward Concave CP (encountered only at start-up)
  - Reverse Concave CP (explorers approach each other)
  - Reverse Convex CP (Line of Sight breaks)
  - Forward Convex CP (Explorer reverses direction)

Direction of Coverage
Team Coverage

- The team splits only once into two sub-teams in order to encircle an obstacle.
- One sub-team moves clockwise around the obstacle, the other sub-team moves counter-clockwise.
- If a sub-team encounters a dead-end it backtracks.
- Guaranteed re-joining of the two sub-teams.
Team Splitting and Rejoining

Coverage direction
Coverage Example
Multi-Robot Coverage Paradigm
Multi Robot Complete Coverage
Main Ideas

- Unrestricted Communication / Good Localization
- Environment is divided into as many stripes as robots
- Cooperative Exploration
  - Each robot explores the boundaries of its stripe
  - Robots Auction parts of the non reachable parts of their stripe
- Cooperative Coverage
  - Connectivity of the environment is known
  - Each robot covers the closest cell
  - Robots Auction coverage tasks
Example

- See it on vlc...
Auctions!

- Used to improve performance
- A central coordinator or one team member call/administer the auction
- Robots bid for tasks based on some estimated reward/cost
More Multi-Robot Ideas

- Marsupial Robots

Also watch: http://www.youtube.com/watch?v=hCGgoPS91Rw

More Multi-Robot Ideas

- Marsupial Robots

From: http://distrob.cs.umn.edu/demos.php
More Multi-Robot Ideas

- Formations
More Multi-Robot Ideas

• Cooperative Localization, Mapping, and Exploration
Cooperative Localization

- Pose of the moving robot is estimated relative to the pose of the stationary robot. **Stationary Robot** observes the **Moving Robot**.

**Robot Tracker Returns:**

\[<\rho, \theta, \phi>\]

\[
x_{m_{est}}(k + 1) = \begin{pmatrix}
x_{m_{est}} \\
y_{m_{est}} \\
\theta_{m_{est}}
\end{pmatrix} = \begin{pmatrix}
x_s + \rho \cos(\theta + \theta_s) \\
y_s + \rho \sin(\theta + \theta_s) \\
\pi - (\phi - (\theta + \theta_s))
\end{pmatrix}
\]
Laser Robot Tracker

Robot Tracker Returns:
\( <\rho, \theta, \phi> \)
• If the line of visual contact is not interrupted during the motion, then the triangle \([R_s, T_1, T_2]\) is free space.

• Connect the triangles of free space in order to construct a map of the environment.
Triangulation Algorithm: Main Ideas

- **Bounded Area:** The range of the tracker sensor is larger than any diagonal of the environment
Triangulation Algorithm: Main Ideas

• **Robot Position:**
  – Stationary Robot: Positioned at the corners of the environment (vertices of the polygon).
  – Moving Robot: Follows the walls.

• **Exploration order:** The two robots explore the free space by following the Dual Graph of the Triangulation.

• **Decision points:** Reflex vertices.
Cooperative Exploration
Experimental Results
(Triangulation)

Mapping of two Laboratories
Moving out
2 Laboratories, Sonar Data
2 Laboratories, Laser Data

All Data

Scan Matched
Using S. Gutmann s/w based on Lu and Milios algorithm.
Map from Scan Match (S. Gutmann)