

The GNATs

Pervasive Embedded Networks to Support Multi-Robot Systems

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The BORG Lab

Georgia Institute of Technology

AAAI Workshop on Sensor Networks

July 26 2004

Motivation – A Robotician's Perspective

- The application of low-cost, pervasively distributed networks to support cooperative multi-robot systems.
- Embedded networks will be pervasive in the future's infrastructure
 - e.g. Buildings, roads, forests, oceans
- And when they aren't, robots should deploy and use them as tools
 - e.g. Planetary exploration, initial network deployment

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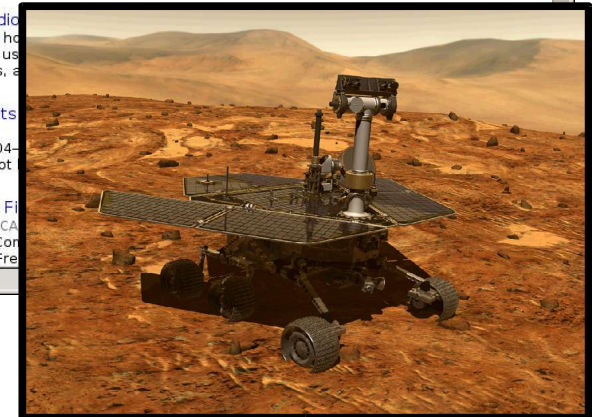
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... the Mobile Connection(TM) Core Development Kits for its Radio Frequency



Motivation – A Sensor Network-er's perspective

- The application of cooperative multi-robot systems to support low-cost, pervasively distributed networks.
- Embedded networks will be pervasive in the future's infrastructure
 - e.g. Buildings, roads, forests, oceans
- Embedded networks will be in unstructured dynamic environments
 - Autonomous robots for deployment, maintenance, etc.

Google Search: RFID - Mozilla Firefox

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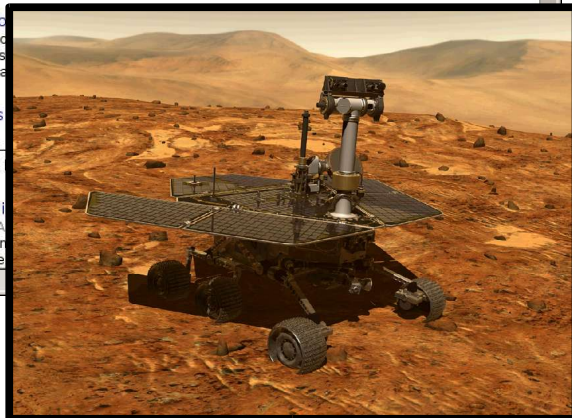
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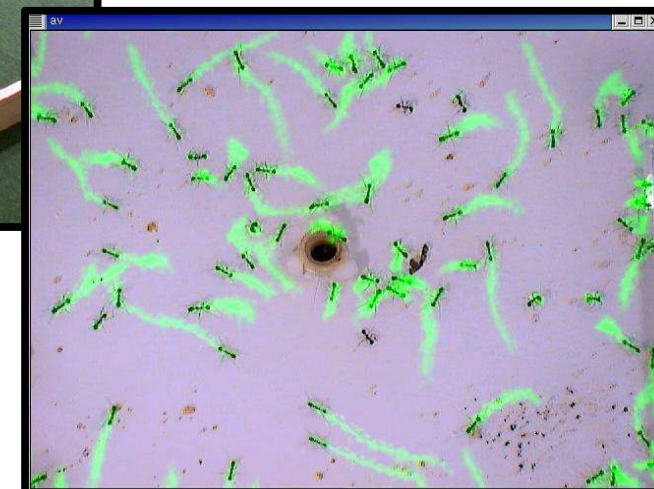
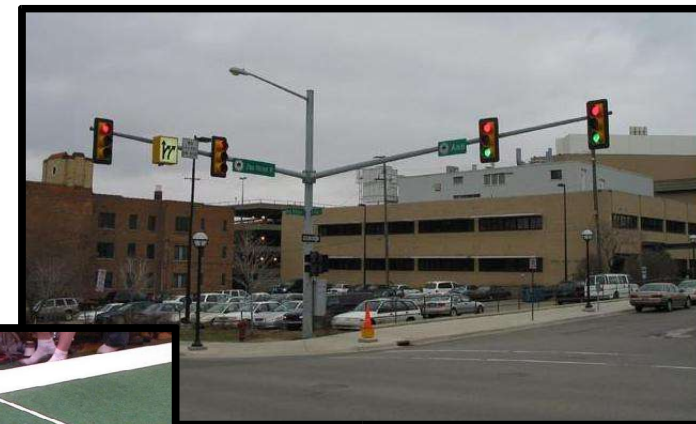
Socket Releases Industry's First RFID Development Kits for its Radio Frequency
Business Wire (press release), CA - 23 hours ago
... the Mobile Connection(TM) Core Development Kits for its Radio Frequency

Done



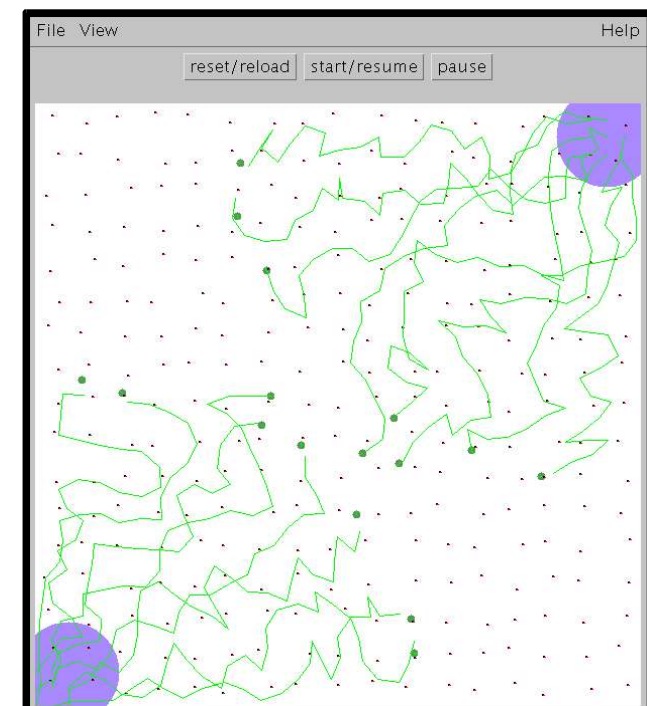
Some *Anti-Motivation*

- Dr. Mobile Robotics remarks, "Aren't you just *engineering the environment* ... that's cheating!"
 - Two Answers:
 - **Absolutely!**
 - or
 - **Nodes are just immobile robotic teammates.**
 - Solving problems by making the system bigger isn't always the best approach



Potential Applications

- Networks supporting robots:
 - Distributed Sensing
 - Navigation
 - Coverage
 - Task Allocation
 - Traffic Management
 - Coverage
- Robots supporting networks:
 - Deployment
 - Maintenance
 - Mobile extended sensors
 - Mobile extended actuators

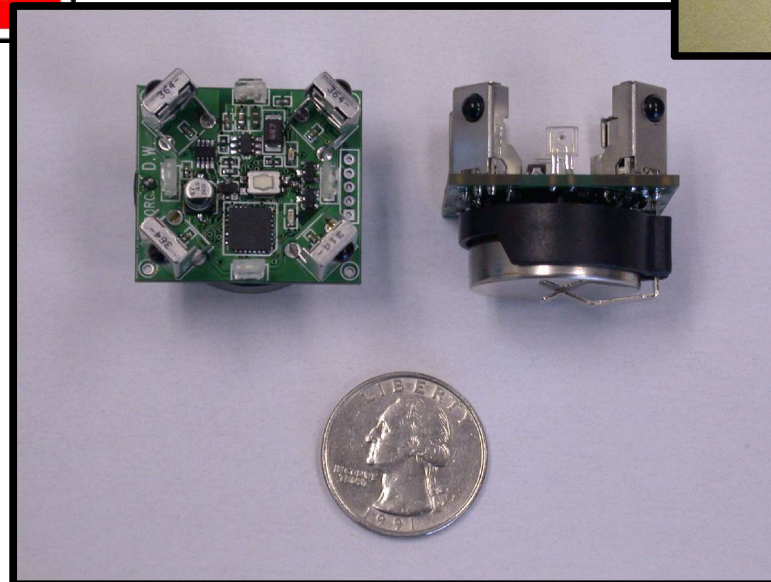
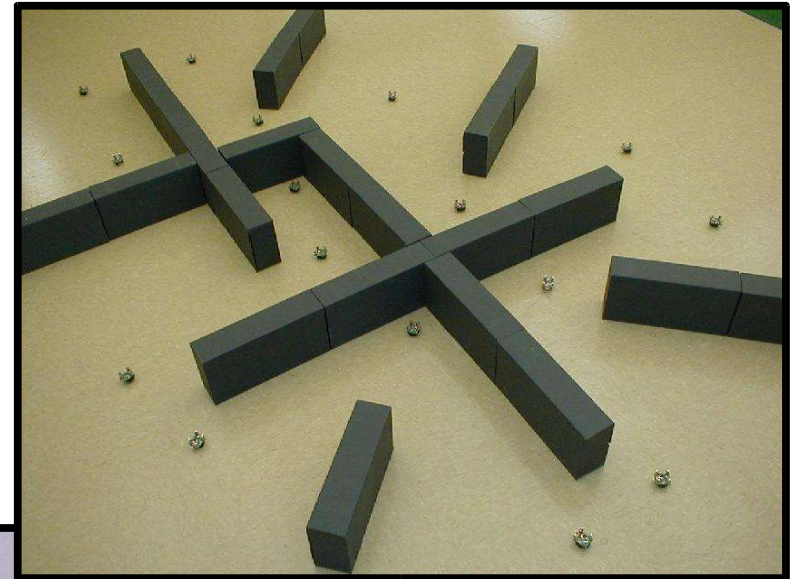
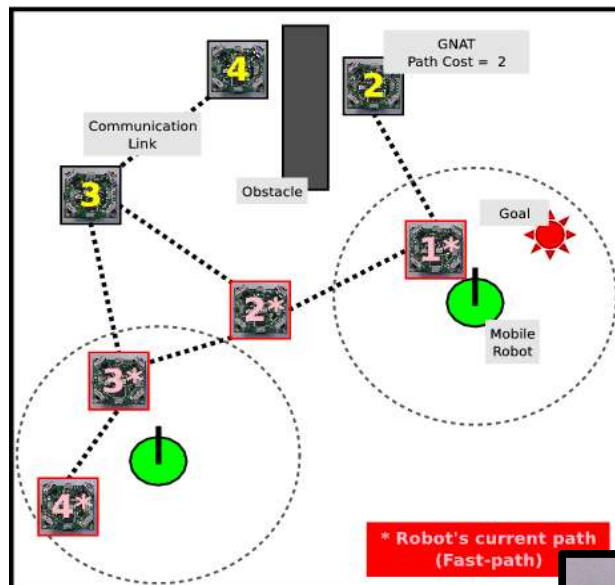


Related Work – Sensor Nets supporting Robots

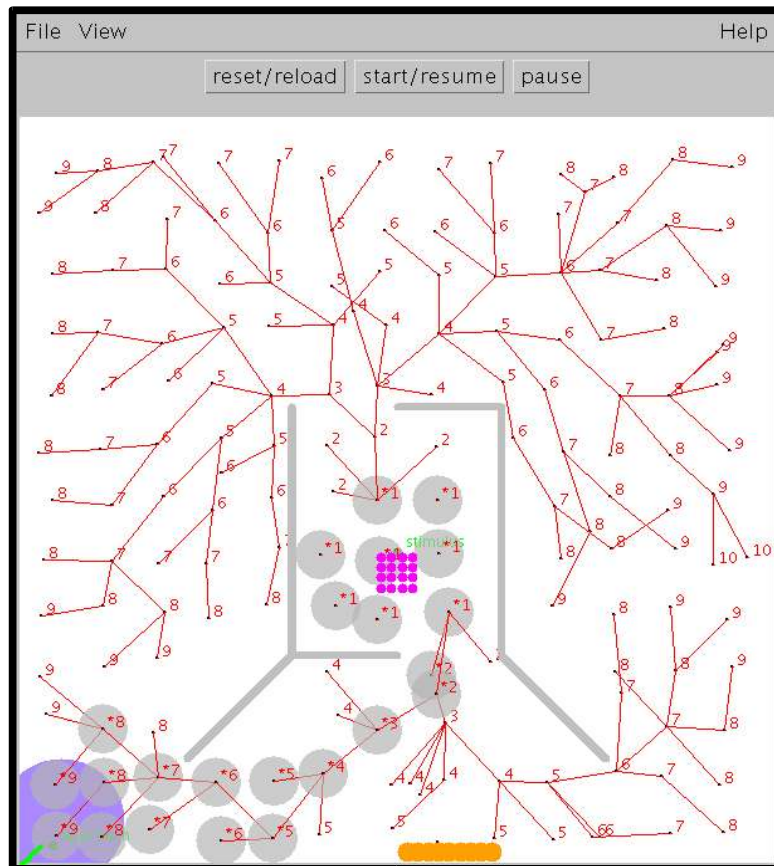
- Payton et al
 - Virtual pheromones, “World Embedded Computation” using swarm of robots
- Batalin and Sukhatme
 - Navigation, coverage, and task allocation using motes
- Li and Rus
 - Navigation using motes
- Parunak et al
 - UAV navigation using “pheromones”
- And many more ...

The GNATs - Introduction

The Georgia Tech Network to Support Autonomous Tasks

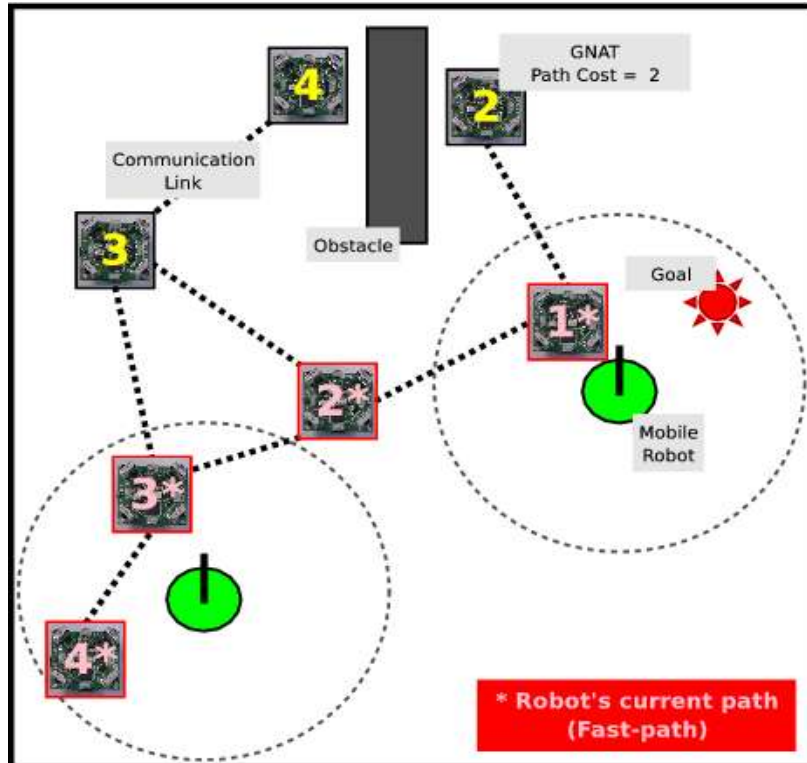


The GNATs Simulations



- Current simulations use TeamBots multi-robot simulation environment
 - Modified to allow for large simulations (up to 300 robots)
 - Soon will make use of the GNATs simulator
- Robot capabilities
 - No localization
 - Bearing estimation to embedded nodes
- Communication model
 - 4 meter range
 - Line-of-sight
- Robot control systems
 - Encoded in Clay behavioral architecture
 - Use motor schemas for local reactive navigation

The GNATs for Physical Path Planning (1)



Assumptions for Embedded Nodes

- Embedded nodes have limited computation and memory
- Short range communication
- Communication paths are similar to navigation paths
- Already deployed
- Lots of them

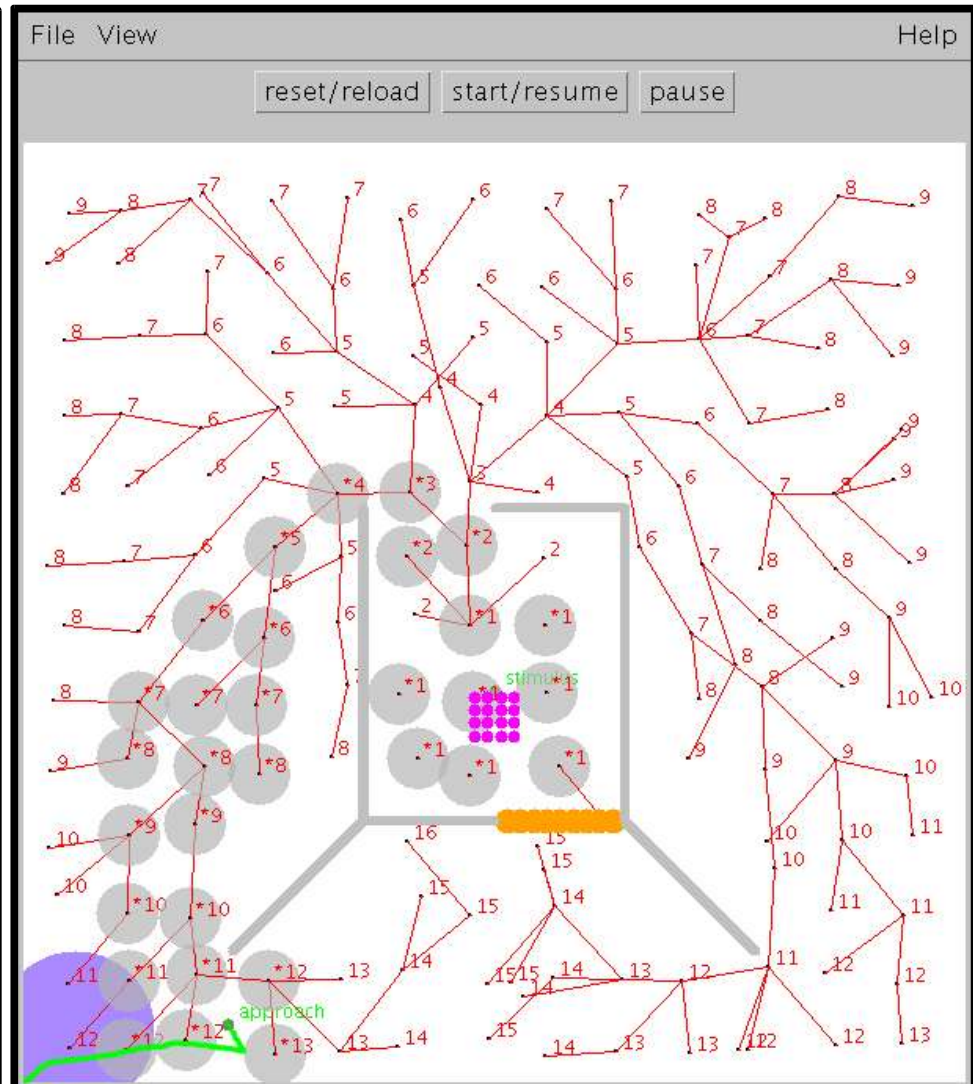
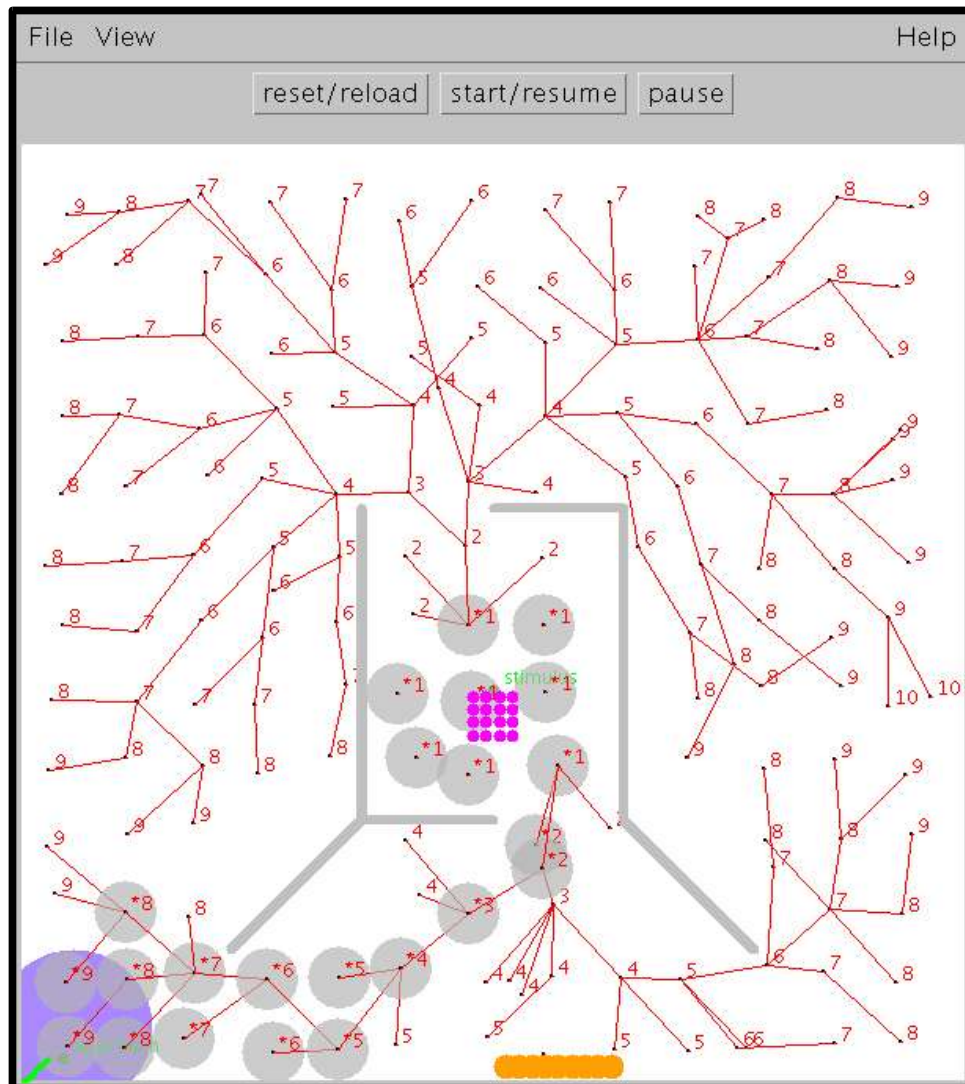
Assumptions for Mobile Robots

- Robots can communicate with embedded nodes
- Relative bearing estimation to nearby embedded nodes
- Local obstacle and attractor sensing

Distributed Path Planning

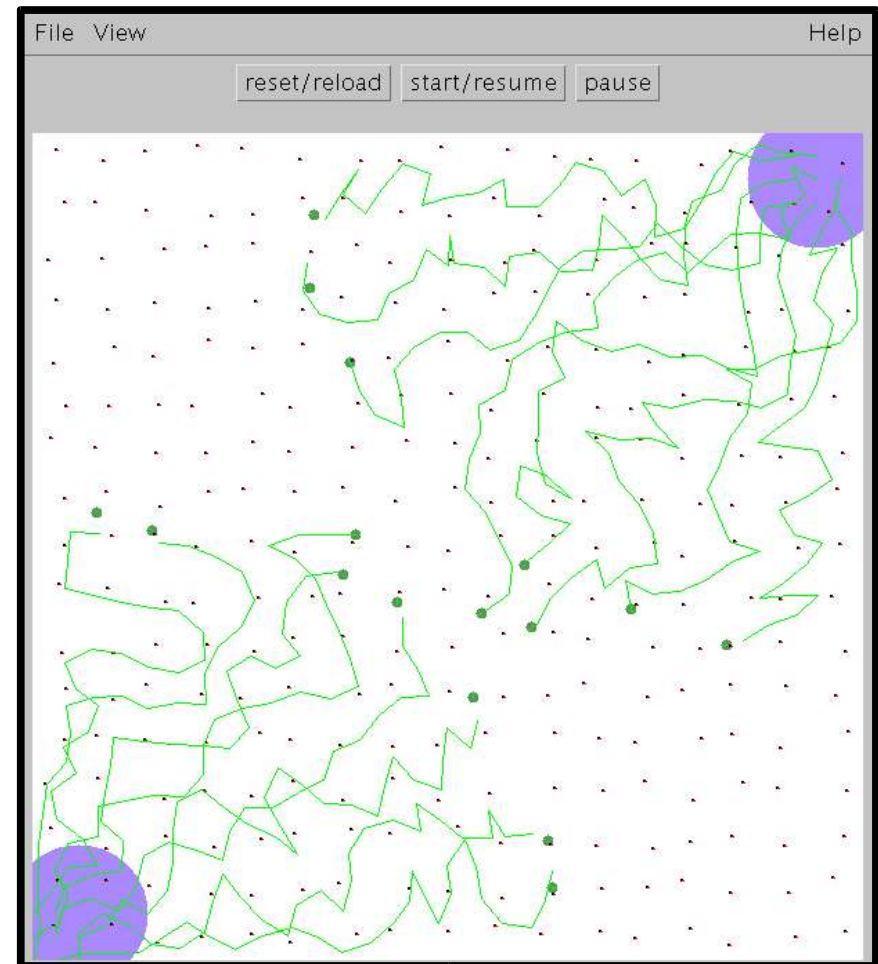
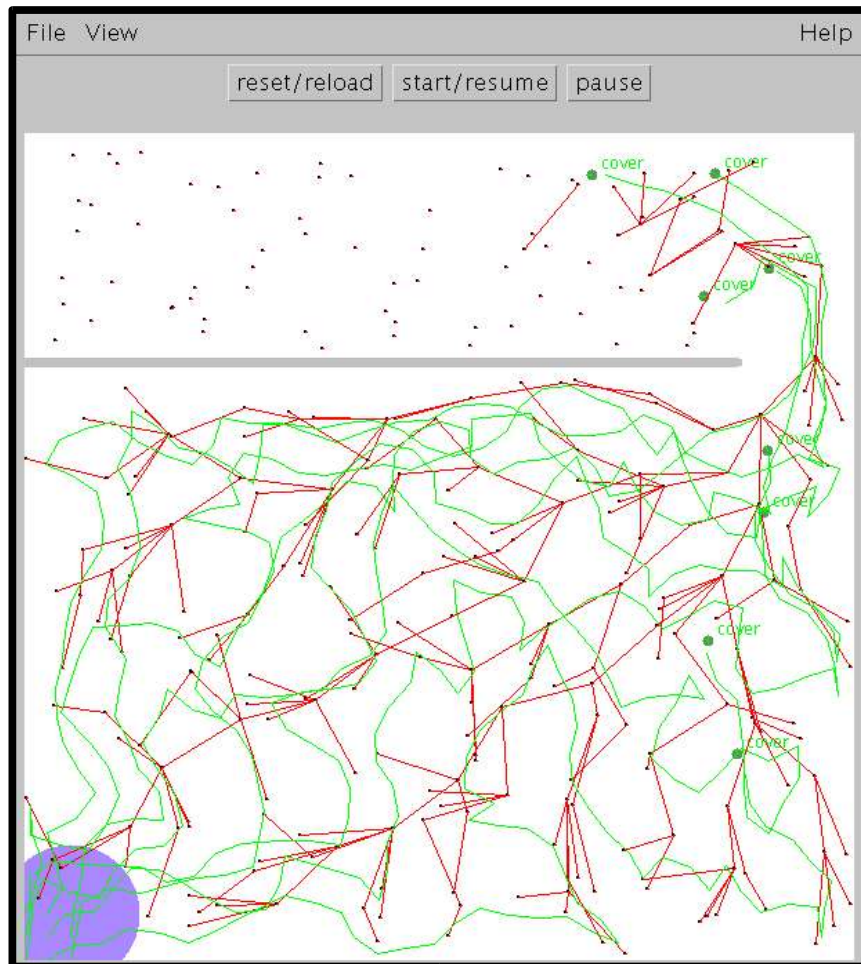
- Distributed Bellman-Ford Algorithm
- Embedded nodes share path-costs
- Embedded nodes monitor neighbors
- The robots' current path(s) are monitored more often to detect changes in environment

The GNATs for Physical Path Planning (2)

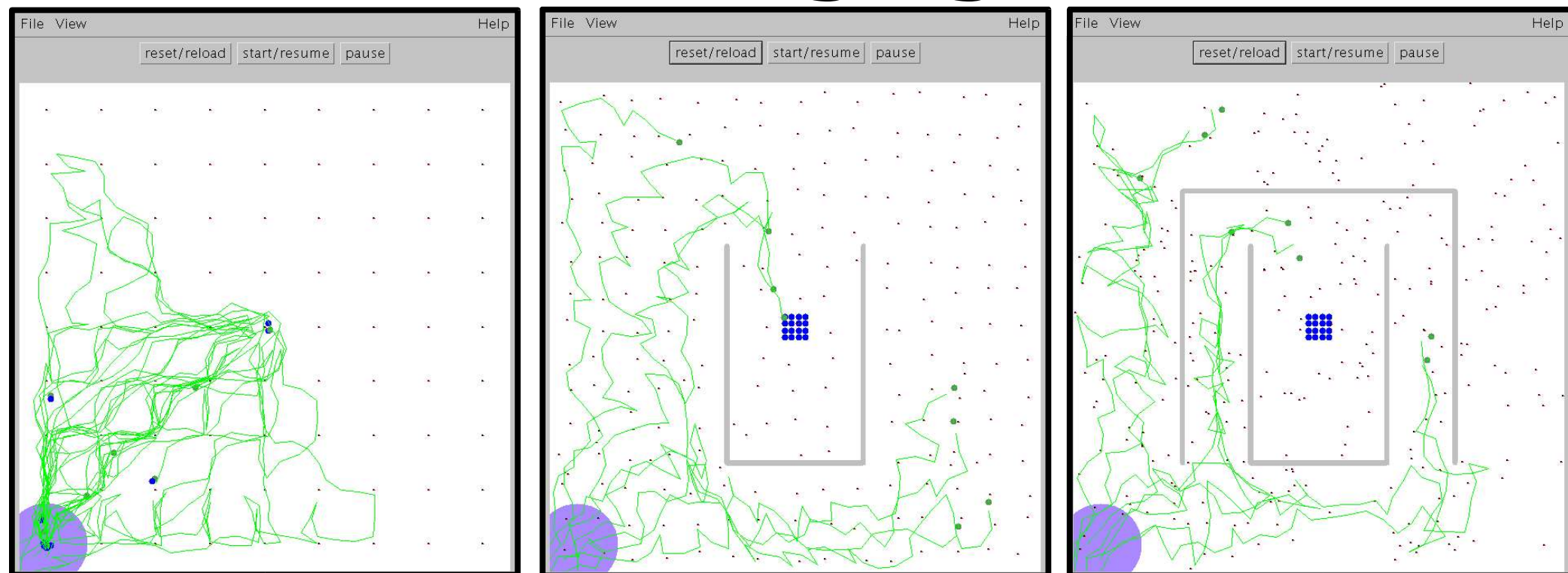


The GNATs for Coverage

- Every unvisited node is a goal
- Visited nodes propagate information about unvisited nodes



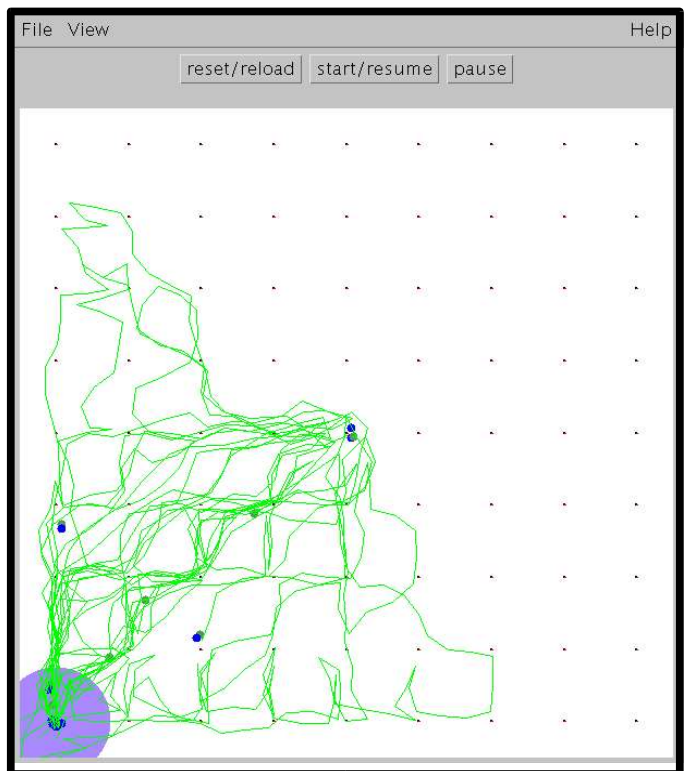
The GNATs for Multi-Robot Foraging



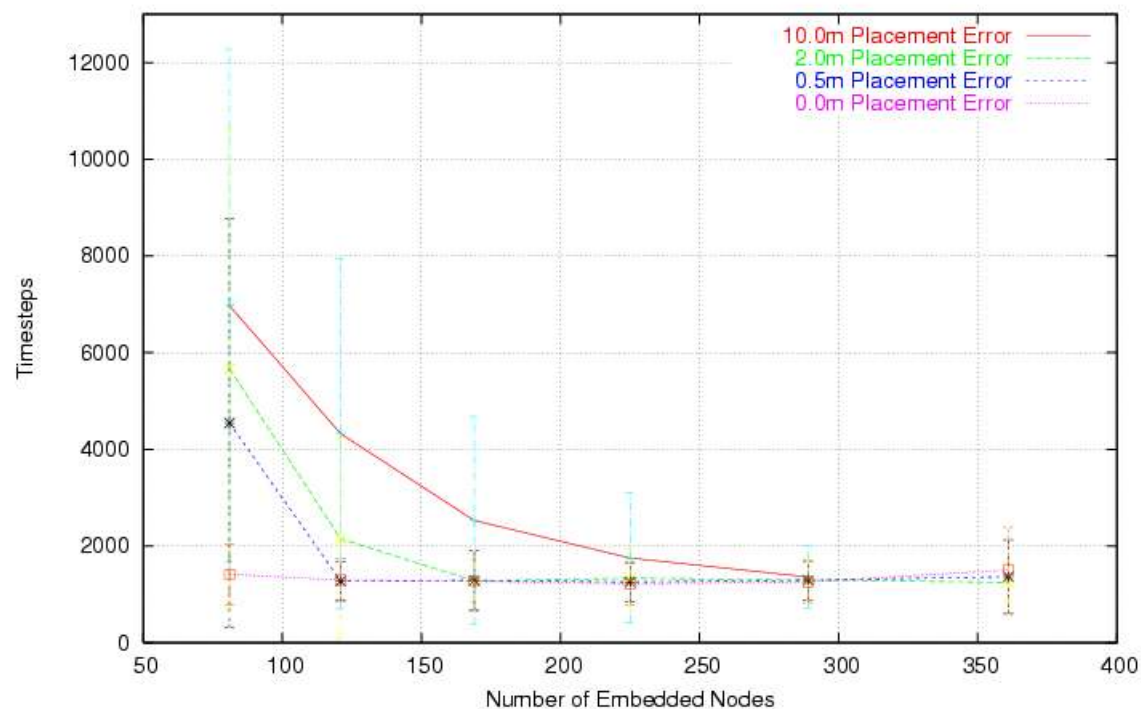
- Environmental complexity
- Number of nodes
- Uniformity of node placement

Foraging Performance

Map 1

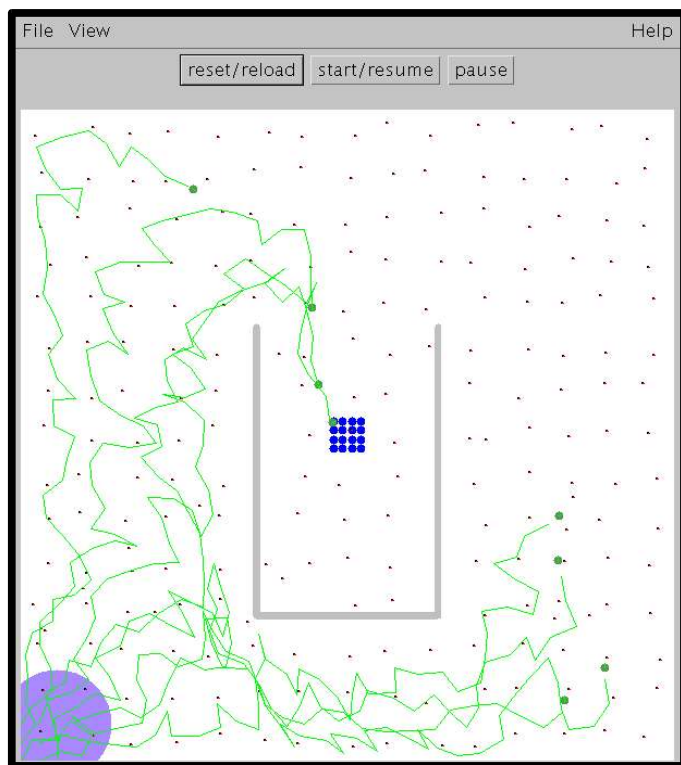


Average Time to retrieve a food source of 16 items using 8 mobile robots
Averaged over 10 runs
Obstacle-Free 36mx36m Environment

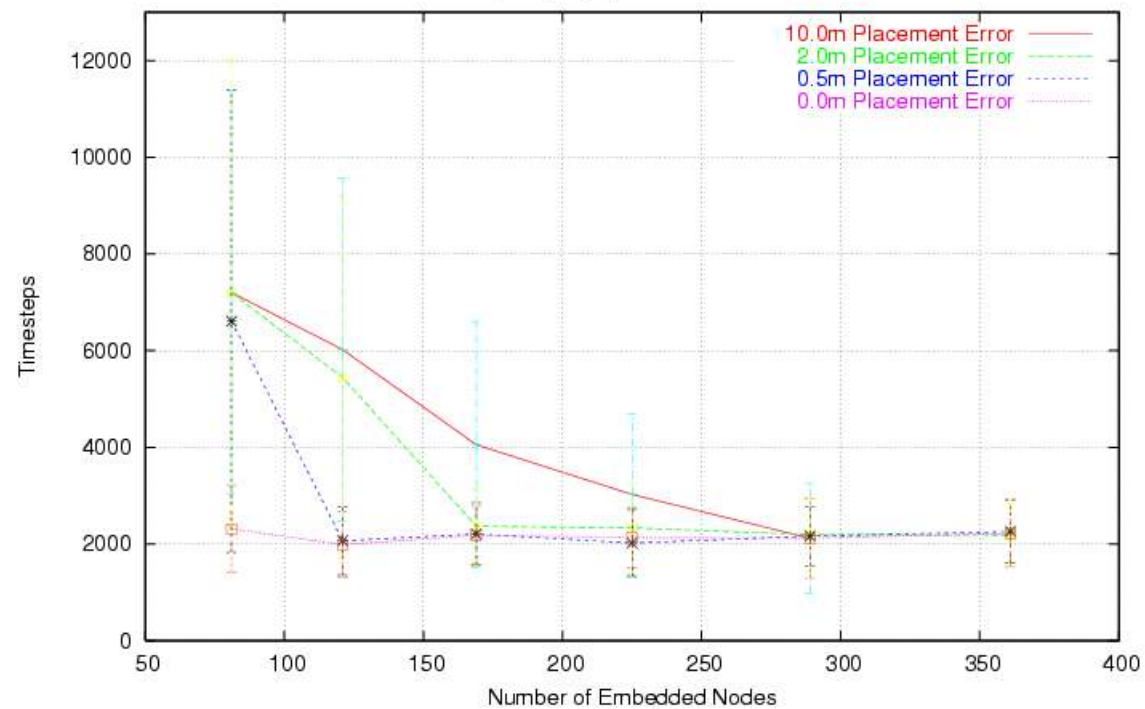


Foraging Performance

Map 2

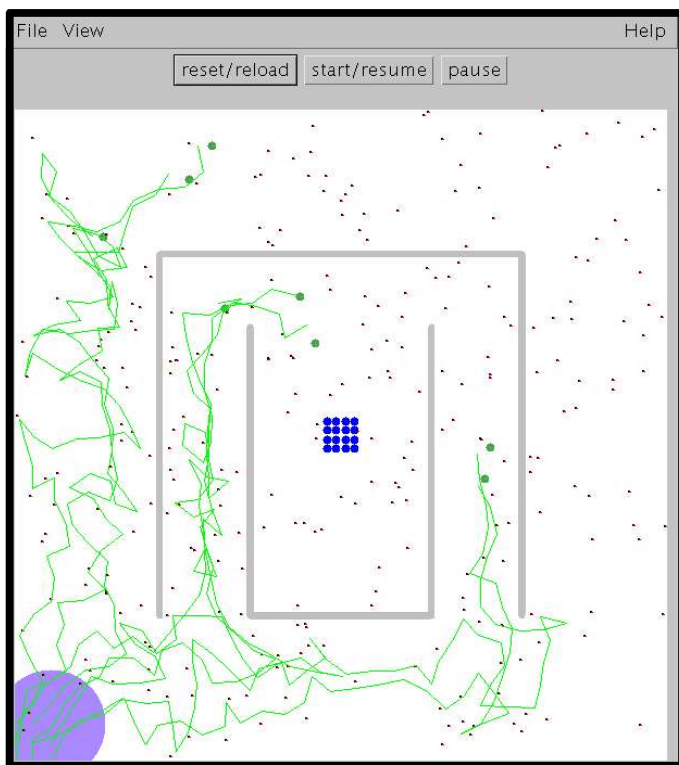


Average Time to retrieve a food source of 16 items using 8 mobile robots
 Averaged over 10 runs
 Box-Canyon (Map 1) 36mx36m Environment

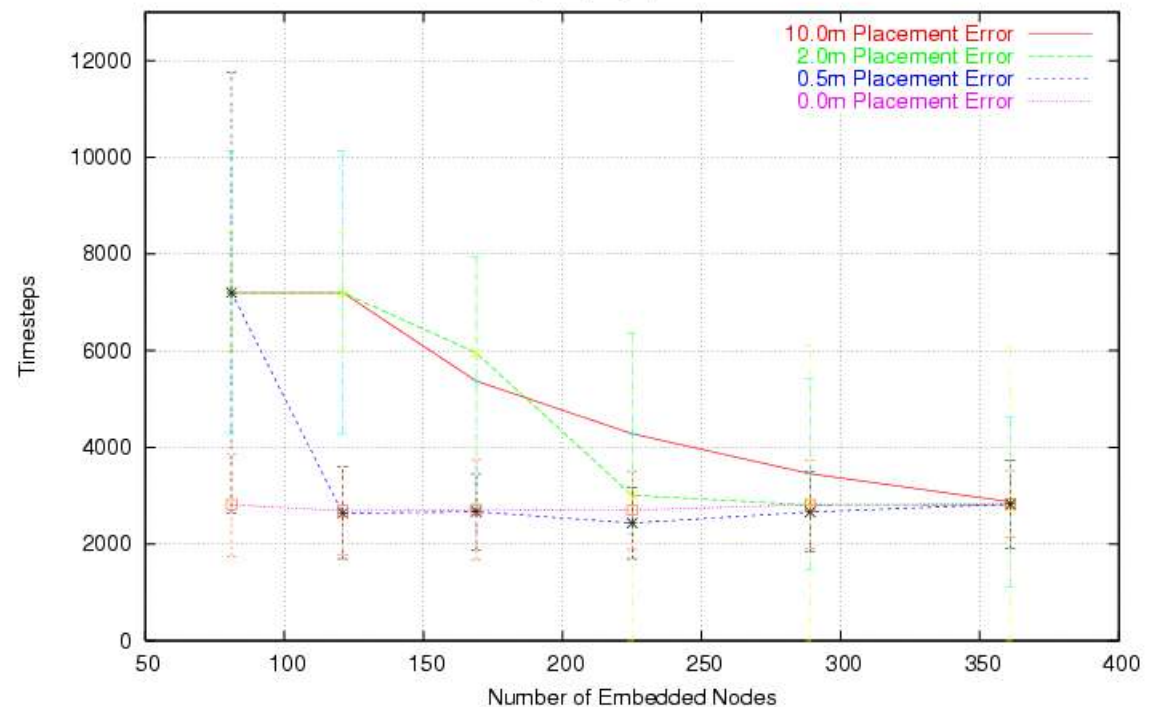


Foraging Performance

Map 3

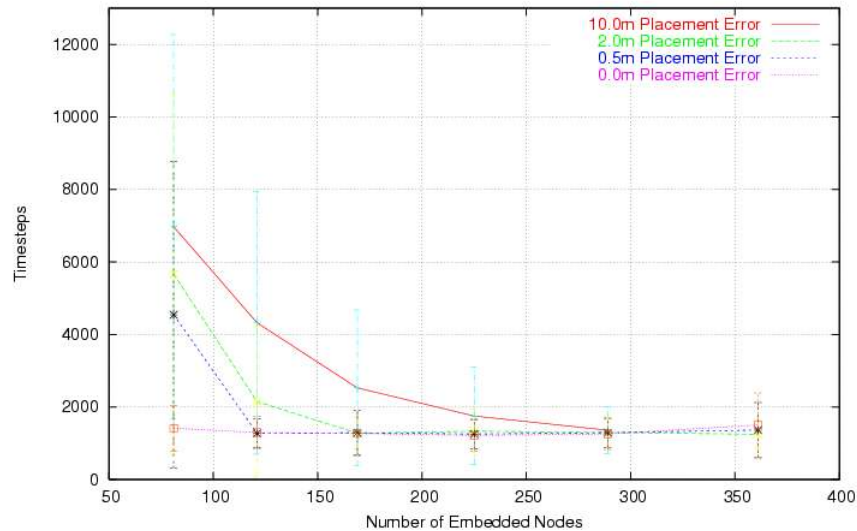


Average Time to retrieve a food source of 16 items using 8 mobile robots
Averaged over 10 runs
Double-Box Canyon (Map 2) 36mx36m Environment

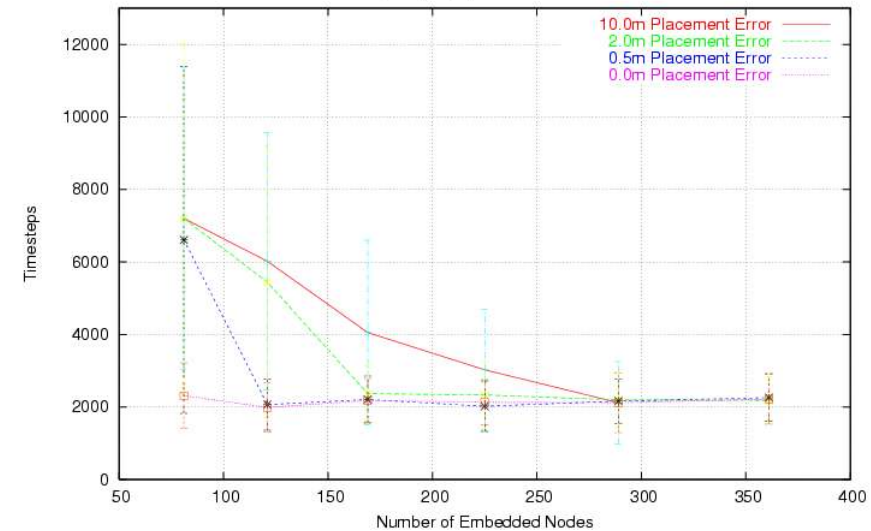


Performance Summary

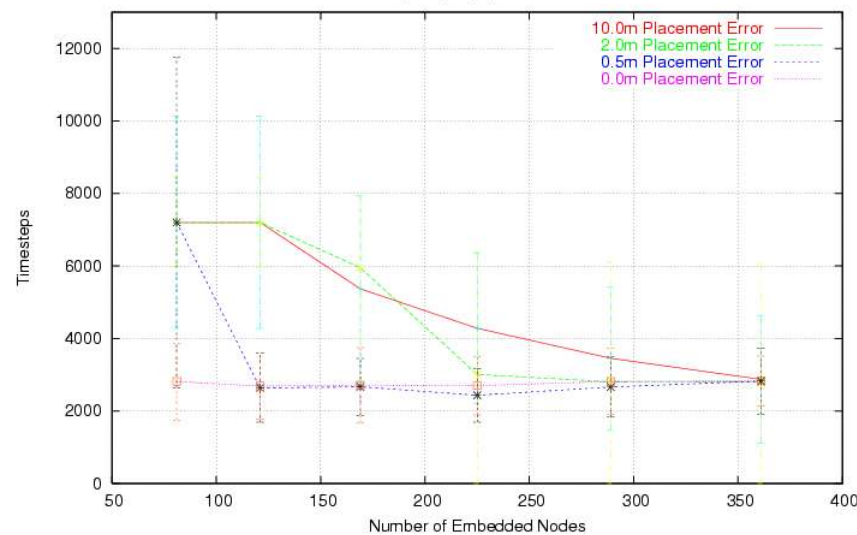
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Averaged over 10 runs
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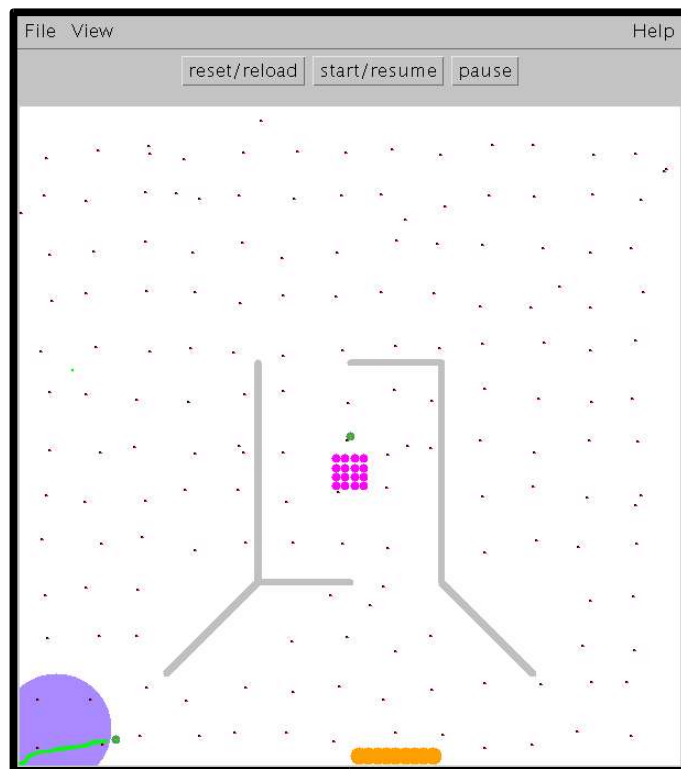
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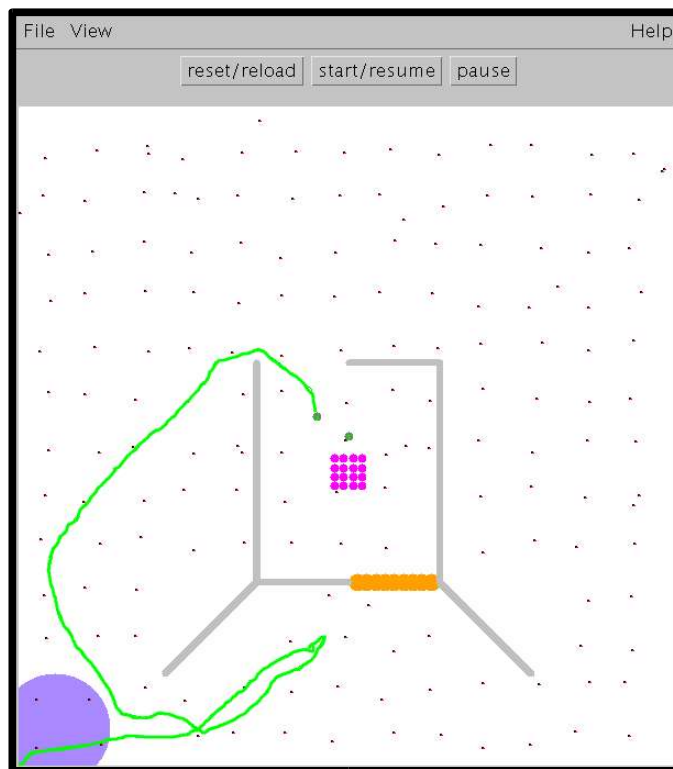
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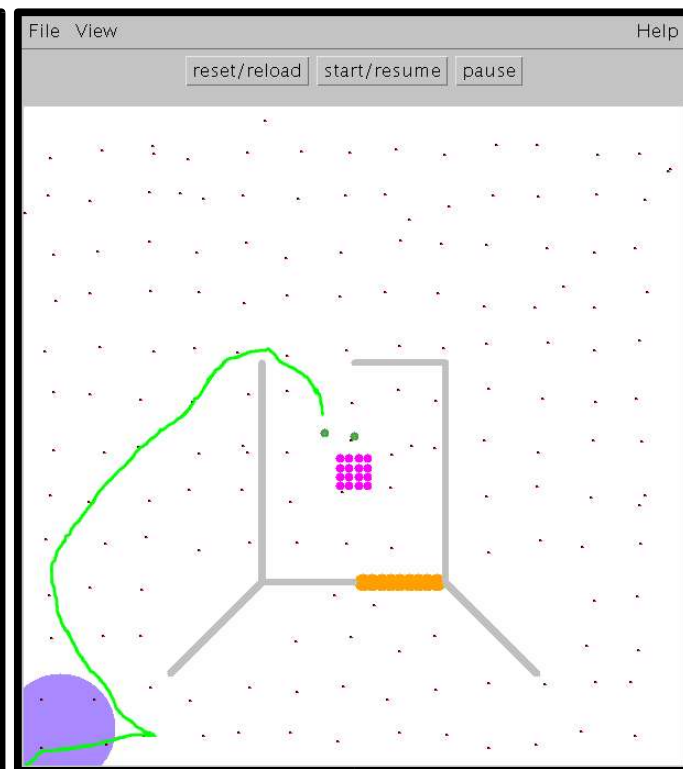
Path Planning in Dynamic Environments



Original Environment



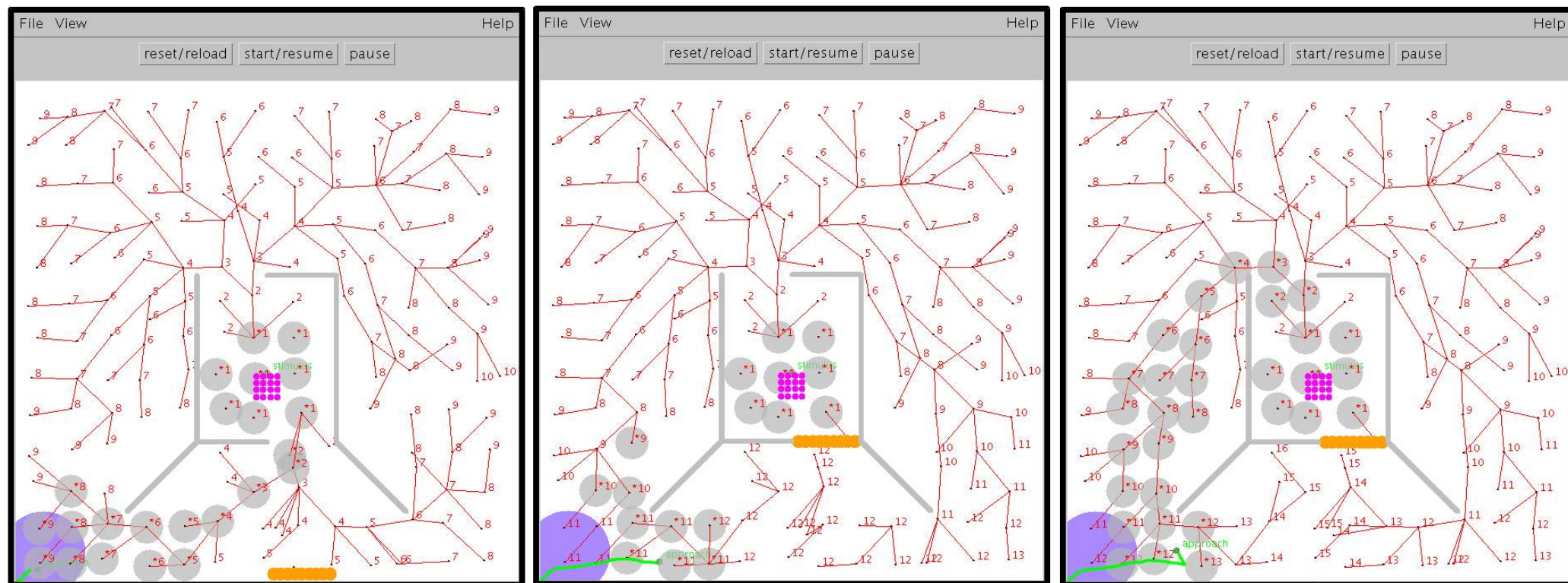
Slow Neighbor Monitoring



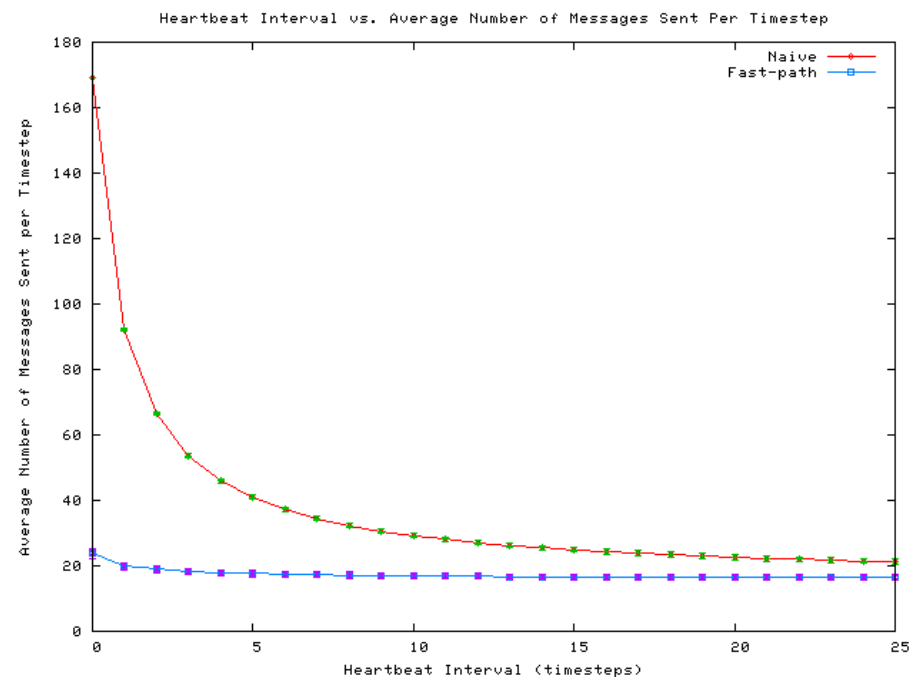
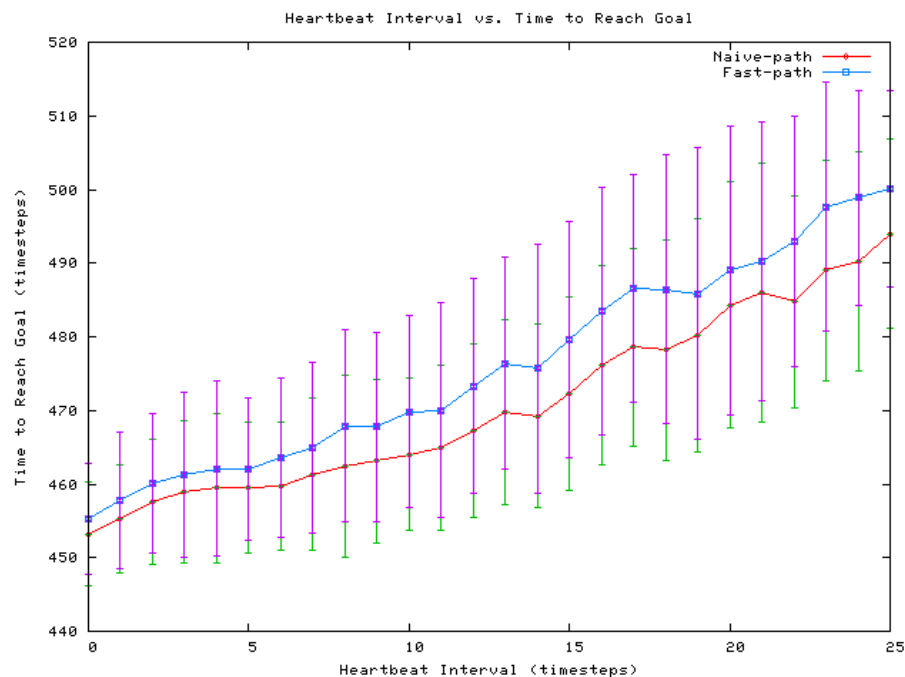
Fast Neighbor Monitoring

Efficient Replanning

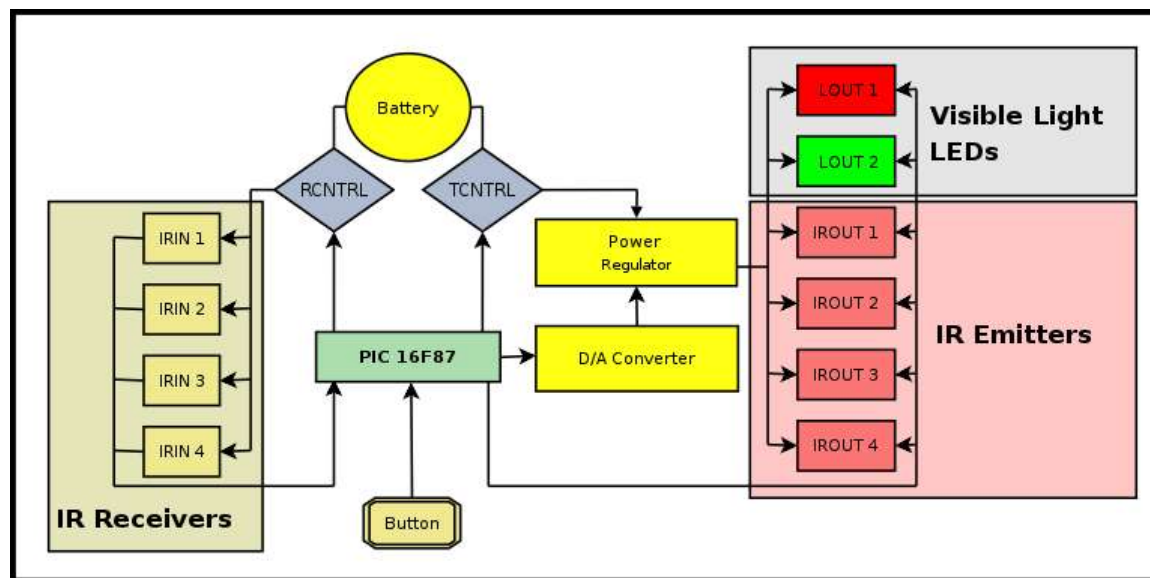
- Nodes on the robots' current paths send heartbeats often



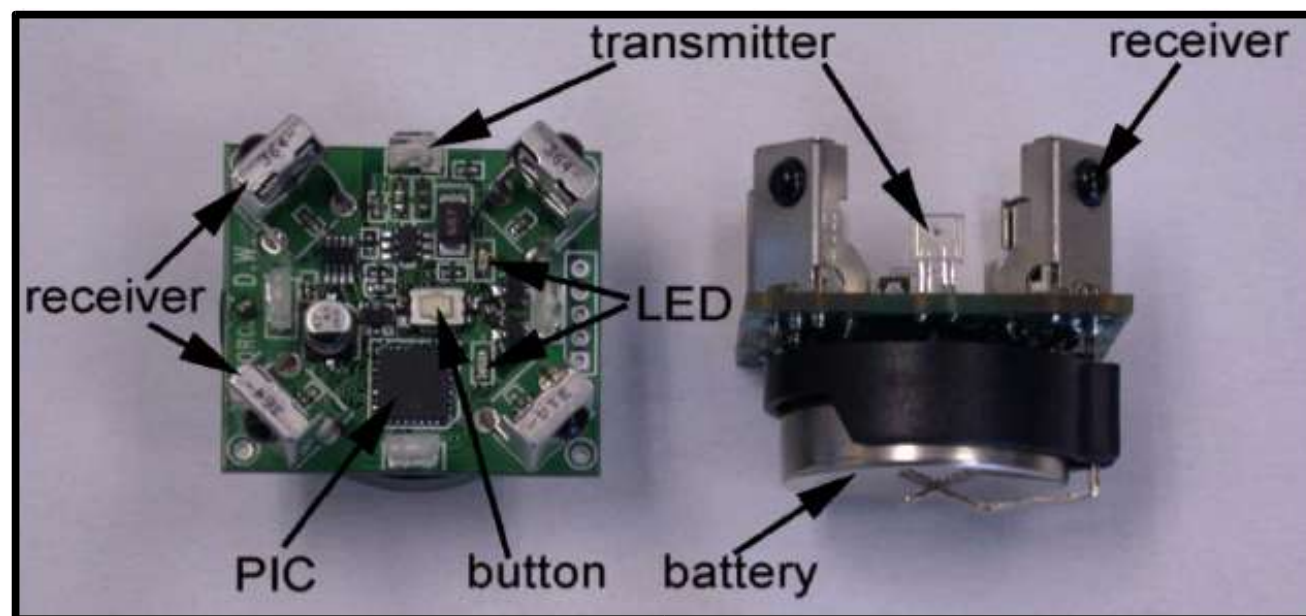
Efficient Neighbor Monitoring Analysis



The GNATs Hardware Platform (1)

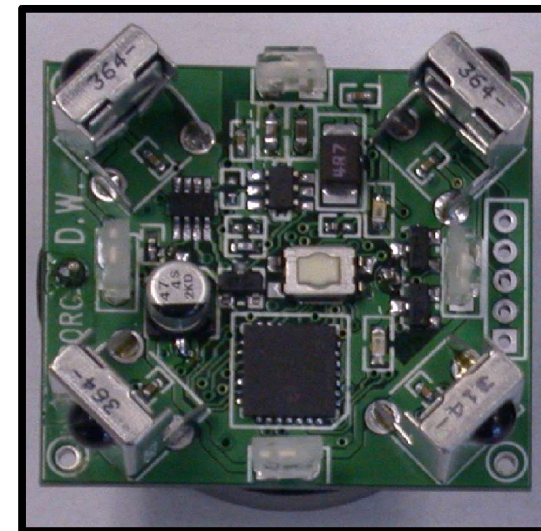
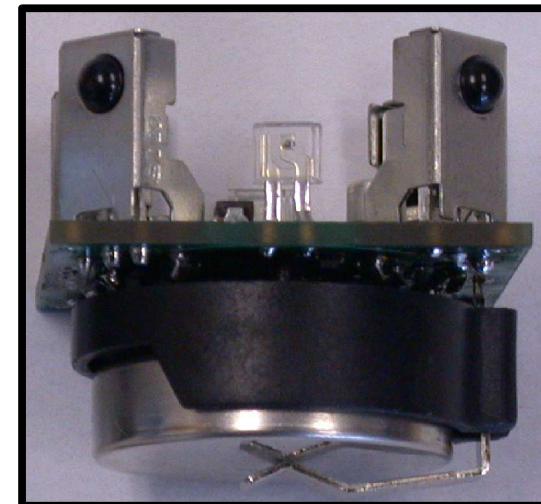


- Internal Oscillator: 125-8 MHz
- 4k programmable flash memory
- 368 bytes RAM
- ~\$30 to build

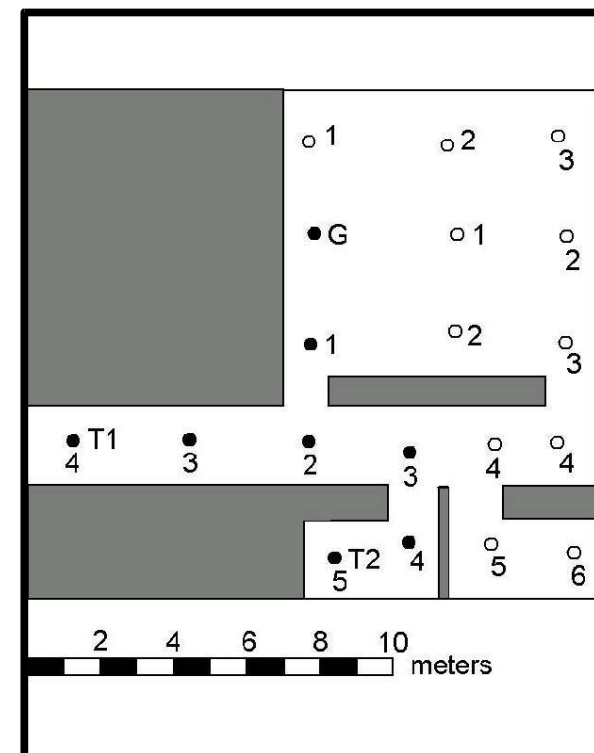
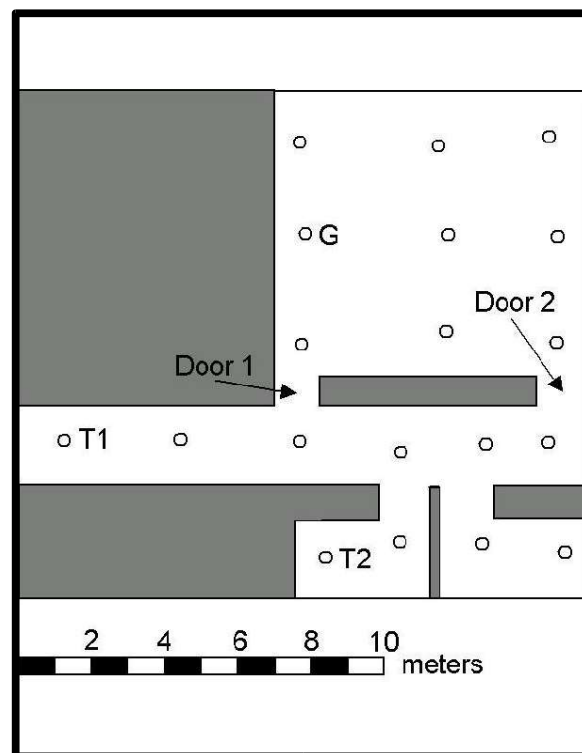
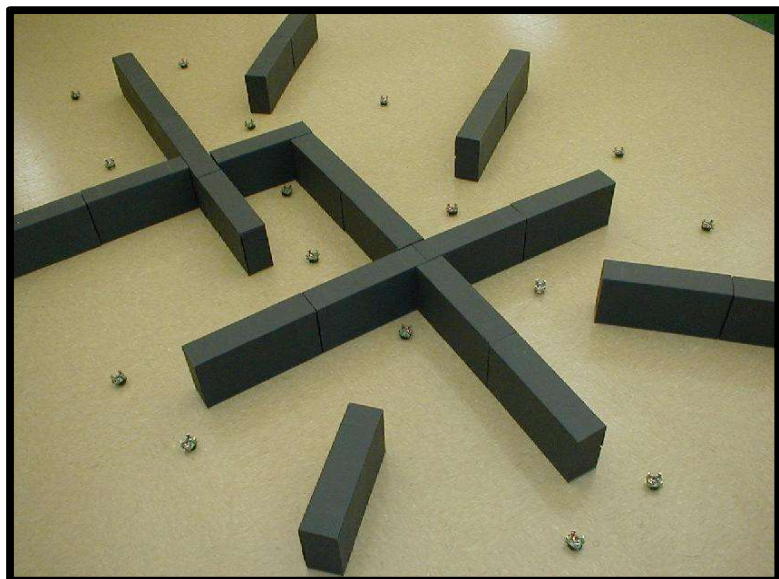


The GNATs Hardware Platform (2)

- Line of sight communication
 - Broad range of output power settings
 - Reliable up to 3 meters
- Demonstrated 2 month battery life
 - CPU on 100%
 - Visible light LED on 50%
- Very low power sleep mode
 - Extend life to months or years
 - Wake on timer or IR input



Initial Path Planning Experiments with the GNATs



Current and Future Work

- Mobile robots interacting with the GNATs
 - Use an on-board GNAT as sensor
 - Use vision to see visible-light or IR LEDs
- Software infrastructure
- Self-programmability
- Adding external sensors to the GNATs
- Use real robot navigation experiences to reinforce paths
- Using the GNATs for supporting other multi-robot tasks

