A Simplified Taxonomy of Command and Control Structures for Robot Teams

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Mission of Robotics at MITRE

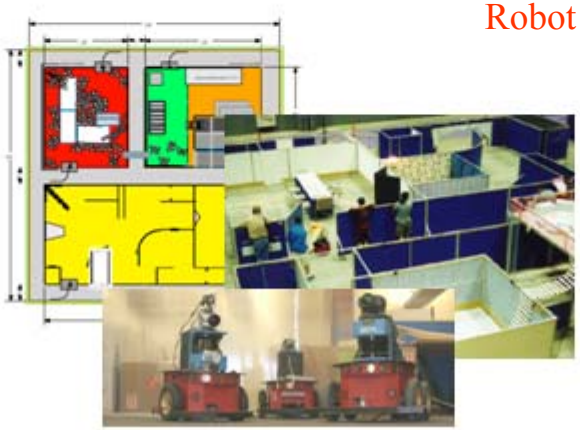
Command and Control

USGS / ITIC

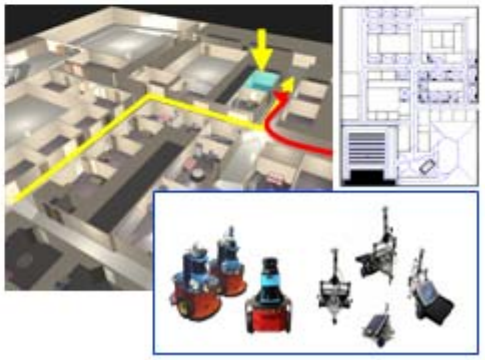
Robot Helpers

Unmanned Air Vehicles

Grand Challenge Entry



Search and Rescue



Cooperative Building Takedown

The MITRE Corporation – 3 Federally Funded Research and Development Centers (FFRDC)

- ETO – Emerging Technologies Office
- Identification of emerging technologies for unmanned systems

MITRE

Congress Mandate

"It shall be a goal of the Armed Forces to achieve the fielding of unmanned, remotely controlled technology such that --

(1) by 2010, one-third of the operational deep strike aircraft of the Armed Forces are unmanned; and

(2) by 2015, one-third of the operational ground combat vehicles of the Armed Forces are unmanned."

-- Senate Armed Services Committee Bill S.2549, National Defense Authorization Act for FY 2001

Future of combat requires integration of unmanned vehicles

- Reduces danger to humans
- Reduces staffing requirements
- Increases vigilance

Current Unmanned Systems

- Teleop
  - Packbot
  - Spinner
  - Predator
- Autonomous
  - FCS
  - Global Hawk

Predator

Cypher

Spinner

Packbot

FCS

GlobalHawk

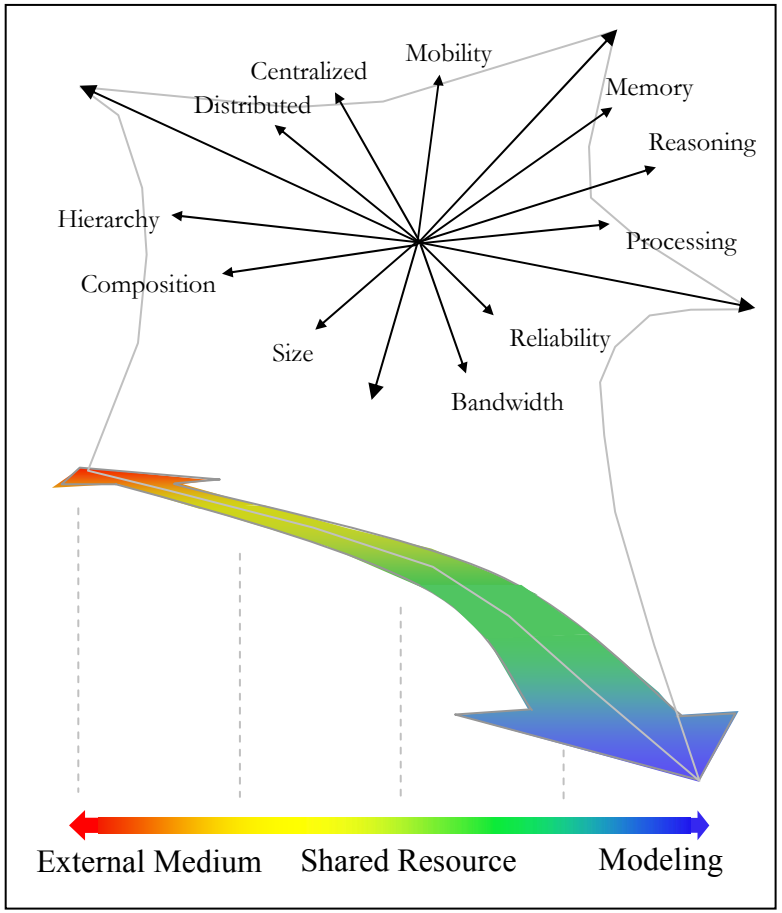
Robotics still in its adolescence

- Majority of systems teleoperated by one or more operators
- Focus currently limited to control of the individual robot

Multiple Robots

- Future of robotics is in command and control of multiple robots
  - Parallel execution
  - Greater coverage
  - Robustness to failure
  - Can exploit proximity of teammates
  - Resource distribution
  - Potentially reduced unit cost
- Our approach to evaluating multi robot teams
  - Examine mechanisms employed by existing robot teams
  - Develop a taxonomy based on mechanisms for coordination

Multi Robot Spectrum



- ***Composition***
  - Homogeneous, Heterogeneous
- ***Size of the collective***
  - Alone, Pair, Limited, Infinite
- ***Awareness***
  - Aware, Not-aware
- ***Control***
  - Centralized, Distributed
- ***Cooperation***
  - Direct (peer to peer), Indirect (central entity)
- ***Communication***
  - Infinite, Motion, Low, Zero, None
- ***Goals***
  - Single, Multiple
- ***Operator Involvement***
  - Leader, Supervisor, Consumer

- A true taxonomy is a multi-dimensional axes
- Let's tolerate a simple single axis for discussion

Multi Robot Spectrum

External Medium — Shared Resource — Modeling

Single robot

Murphy : Robots at WTC

Inspection

- Most robots in the world end up being teleoperated at some time in their mission life
- Obviously a single robot cannot cooperate with itself
- Brings up question of relationship between human and robot

Multi Robot Spectrum

External Medium — Shared Resource — Modeling

Multiple robots
Separate physical space
No awareness of others
No shared information

Reconnaissance

Univ of Minnesota : Scouts

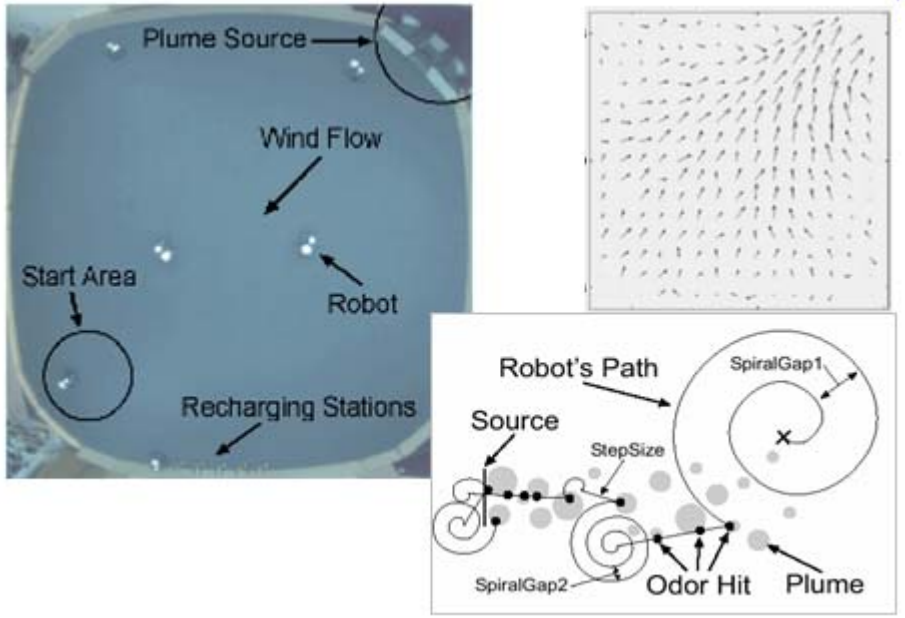
- Multiple robots to perform the task but each unaware of the others
- Benefit comes from parallel execution
- Most effective when spread out but can degrade when too close
- Pass information to a central authority (map, user) but does not exploit information

Multi Robot Spectrum

External Medium — Shared Resource — Modeling

Multiple robots
Same physical space
No awareness of others
No shared information

Plume Tracing



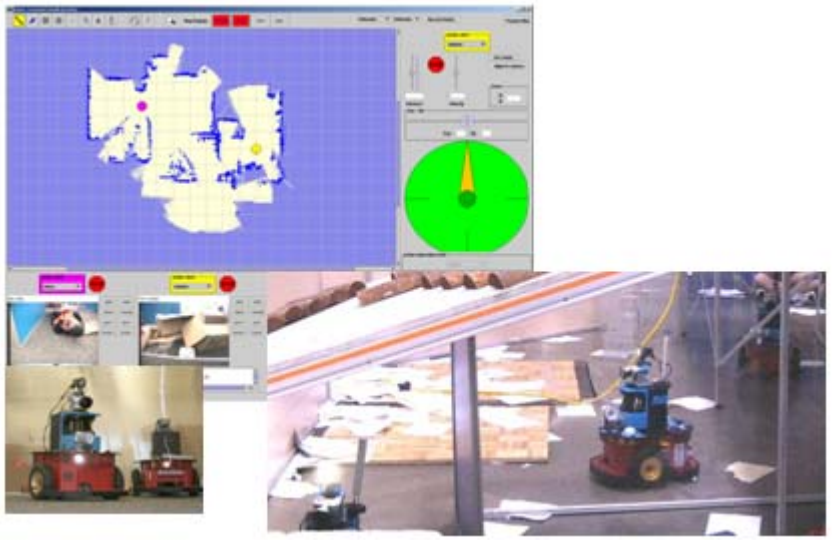
Hayes : Plume tracing robots

- Robots use environment to guide actions and arbitrate conflict
- Coordination embedded in environment

Multi Robot Spectrum

External Medium — Shared Resource — Modeling

Multiple robots
Same physical space
Shared information
Independent resource allocation



MITRE : Search and Rescue

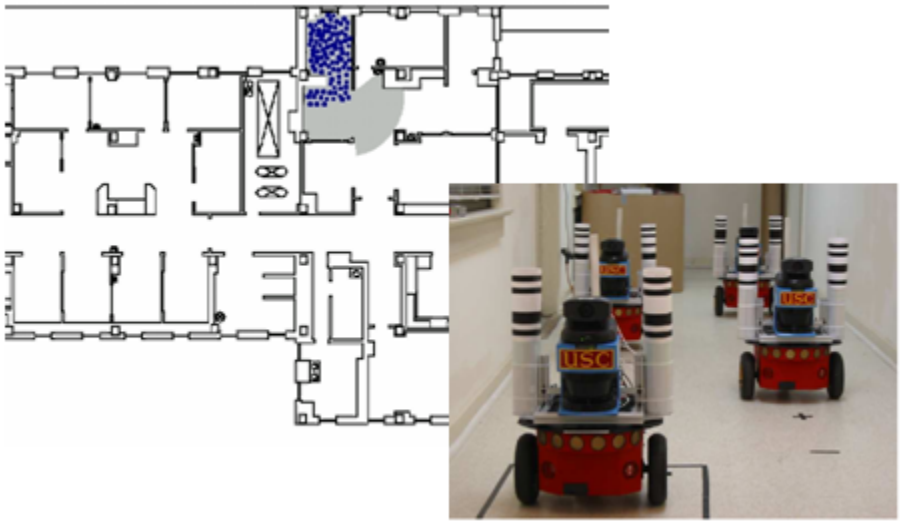
Search and Rescue

- Robots start to share information - most common method is via shared map
- Robots have global information but still decide as an individual
- Can lead to conflicts when two robots choose the same task or area

Multi Robot Spectrum

External Medium — Shared Resource — Modeling

Multiple robots
Same physical space
Shared Information
Simple resource allocation



Howard : coverage

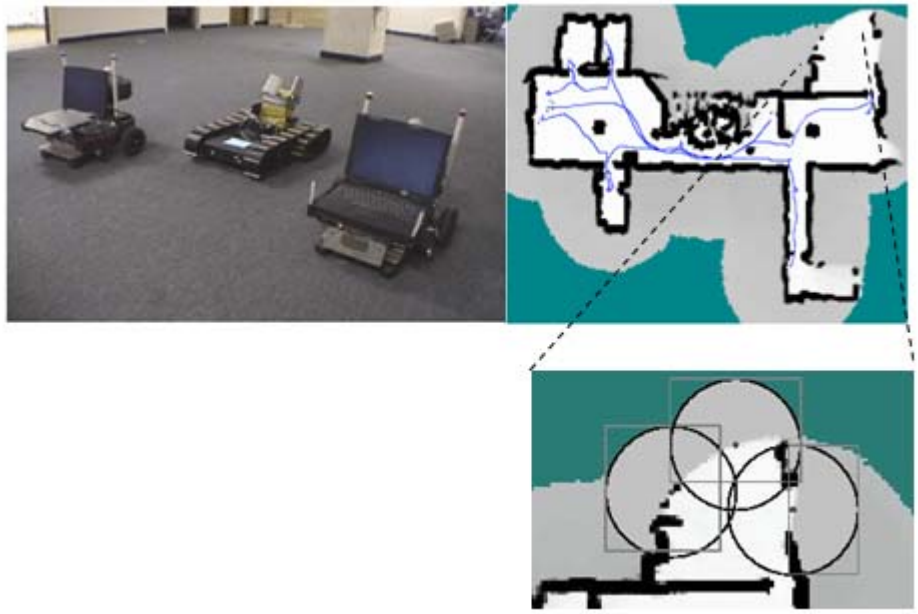
Security

- Robots share information in form of a map
- Some implicit methods for dividing the space or task (local policies)

Multi Robot Spectrum

External Medium — Shared Resource — Modeling

Multiple robots
Same physical space
Shared information
Resource allocation



Exploration

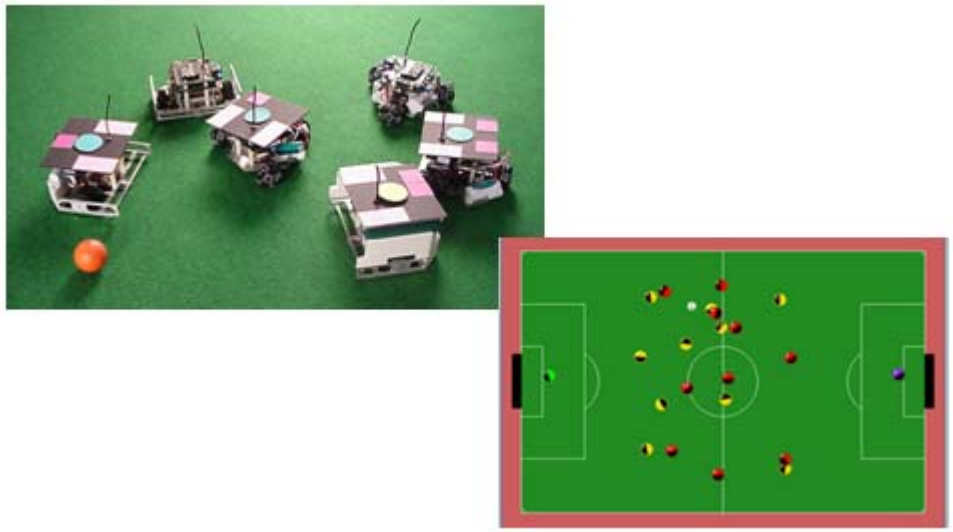
- More advanced methods for dividing task
- Multiple metrics – distance, coverage, time, degree of coverage
- Robots coordinate primarily by acting on shared information

Simmons : multi robot exploration

Multi Robot Spectrum

External Medium — Shared Resource — Modeling

Multiple robots
Same physical space
Shared information
Resource allocation
Modeling of task



Veloso : soccer

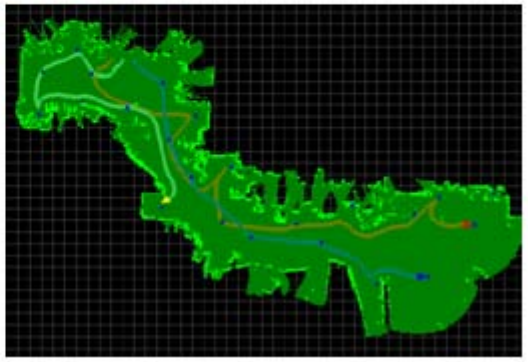
Competition

- Robots start to model their role in the task to aid in partitioning task
- In soccer, each robot knows where it needs to be
- Task implicitly divided based on assigned roles (goalie does not compete with striker)

Multi Robot Spectrum

External Medium — Shared Resource — Modeling

Multiple Robots
Same Physical Space
Shared Information
Resource Allocation
Modeling of agents



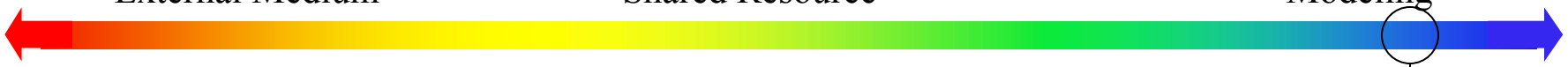
Diaz : Multi robot exploration

Negotiation

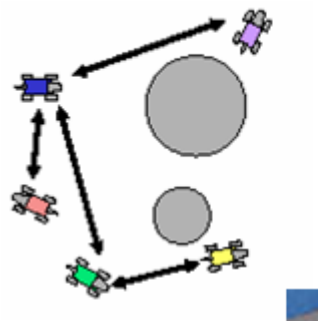
- Robots are able to model task
- Robots begin to compete for subtasks
- Begin to model societal interaction - Free market architecture

Multi Robot Spectrum

External Medium — Shared Resource — Modeling



Multiple robots
Same physical space
Shared information
Resource allocation
Modeling of agents
Peer-to-Peer negotiations



Coordination

Stroupe : Multirobot exploration

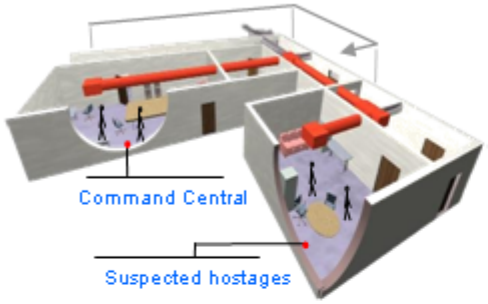
- Robots begin to model actions of other robots
- Make predictions about how own move will couple with teammate's move

Summary

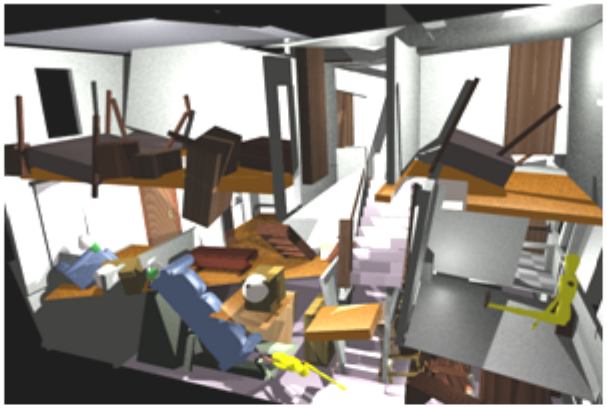
- Many robots can be faster, cover more area
  - Parallel execution
  - Distribution of resources
  - Greater physical presence
- Dimensions for categorizing:
  - Composition, control, communications, size, awareness, goals
- Multiple mechanisms for coordination
  - Environment as medium
  - Shared map with allocation metrics
  - Modeling of role in task
  - Competition for tasks
  - Modeling of interaction with other robots
- Simplified taxonomy allows us to compare robot teams

Backup Slides

Potential Multirobot Applications



SWAT Support



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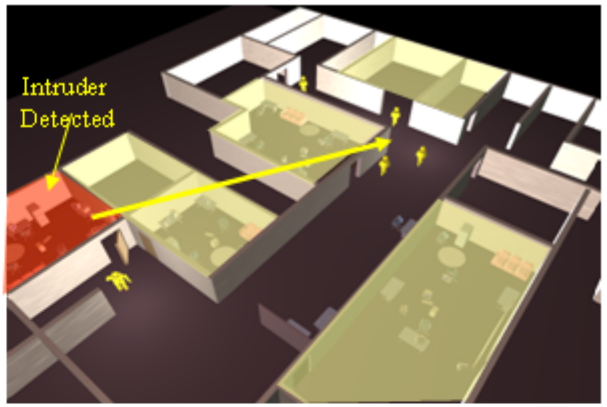
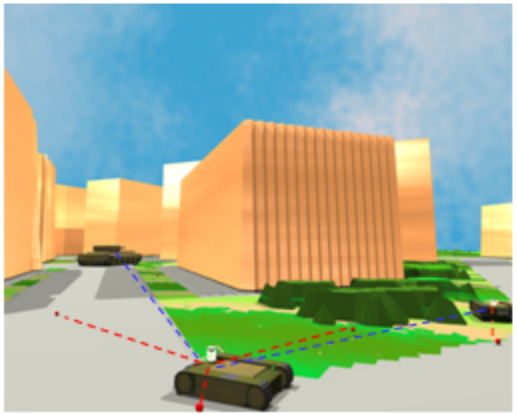
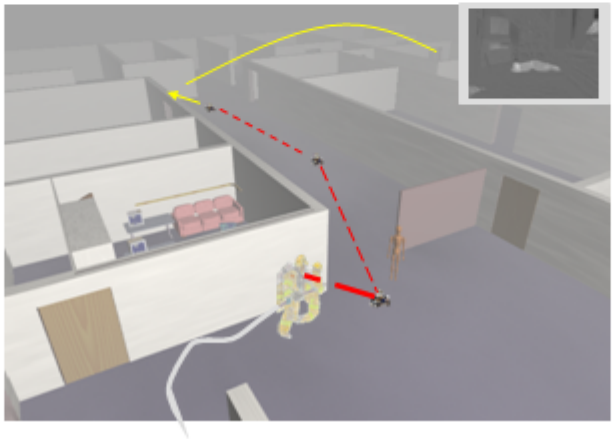


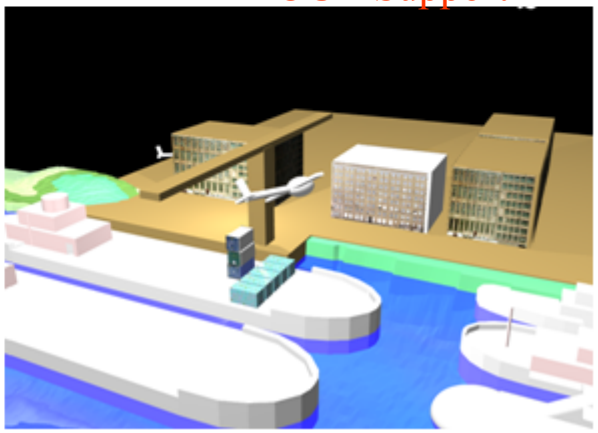
MOUT Support



Combat Support



Reconnaissance



Homeland Security

- Targeted primarily toward military applications of robotics
- Potential cross fertilization to support of civilian authorities and homeland security

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