Multi-Robot Coordination

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http://www.andrew.cmu.edu/course/15-491

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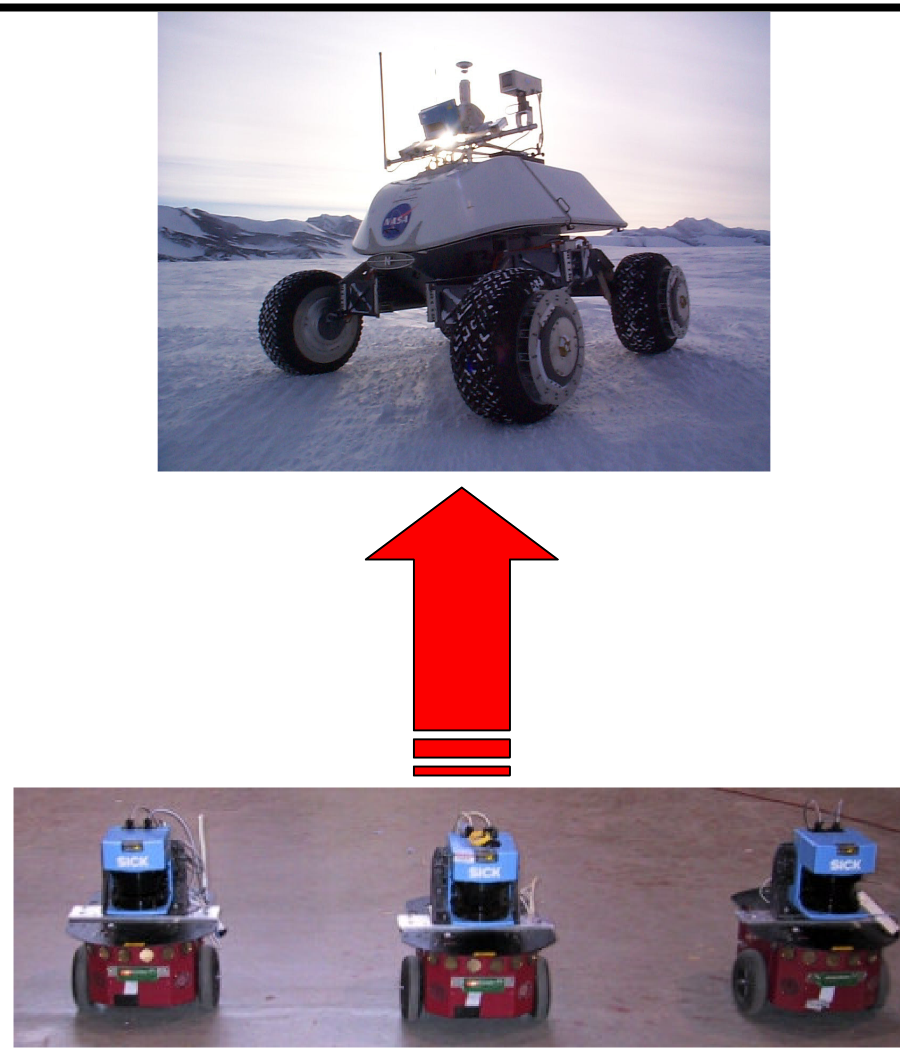
Carnegie Mellon

Why Multiple Robots?

- Faster execution
- More robust
- Simplify design of robots
- Task requires it

Why Not Multiple Robots?

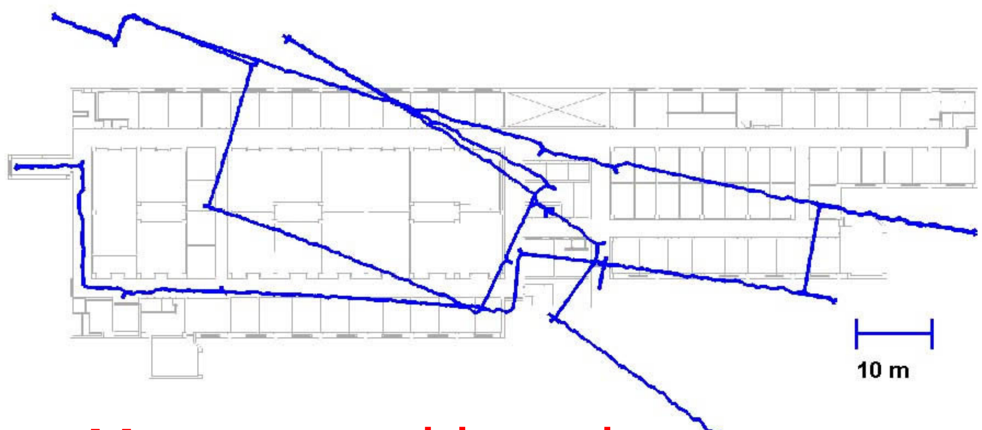
- More communication
- More complexity
- Harder to test
- N x the trouble
- Expensive



Tasks for Multi-Robot Teams - I

- Mapping and exploration
- Hazardous clean-up
- Reconnaissance
- Tracking

Loosely-coordinated



▲ Map created by robot team.

Tasks for Multi-Robot Teams - II

- Carrying objects
- Robot soccer
- Large-scale construction
- Constrained exploration
- Coordinated Reconn.

Tightly Coordinated

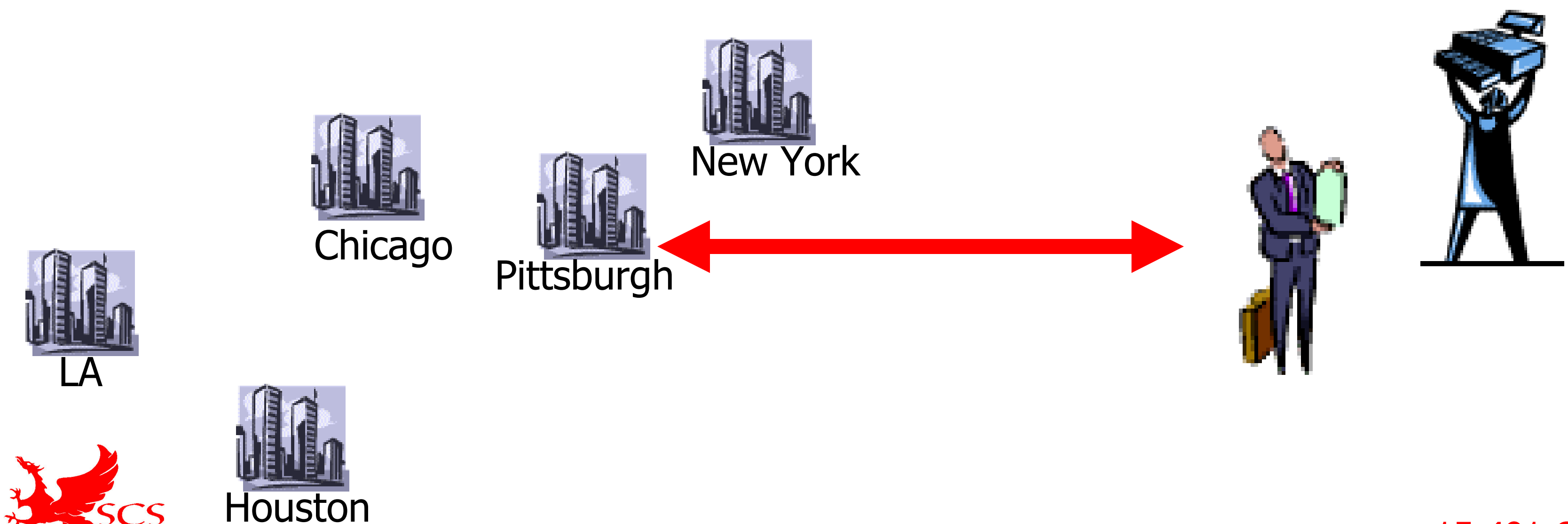
Robotic Construction.

Box Carrying

SCS Carnegie Mellon

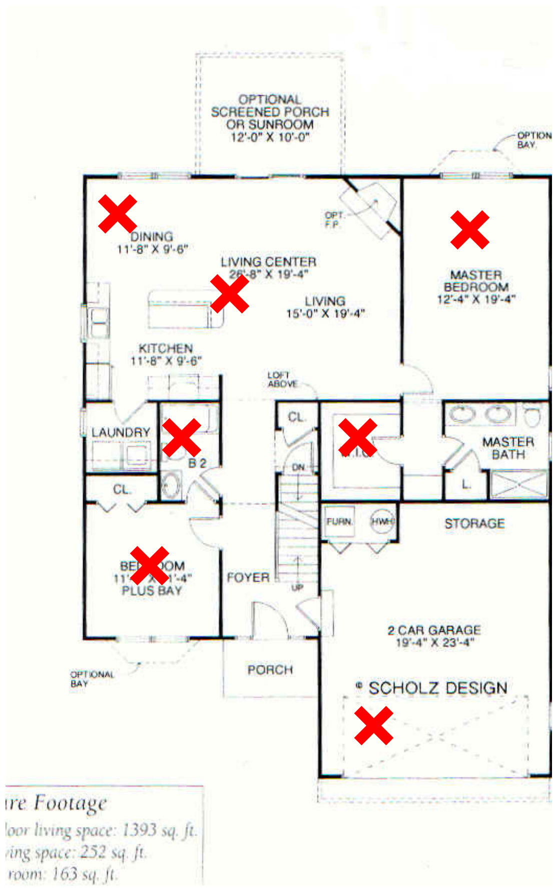
Multi-Depot TSP

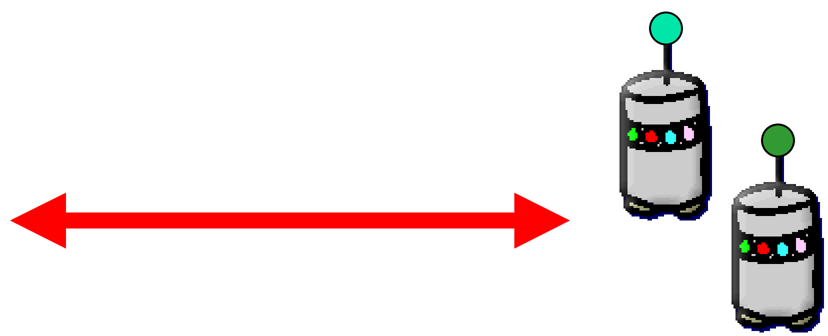
- Lots of cities, lots of salesmen
- Distribute cities to salesmen so total distance is minimized.
- What domains have MD-TSP?



Task Allocation

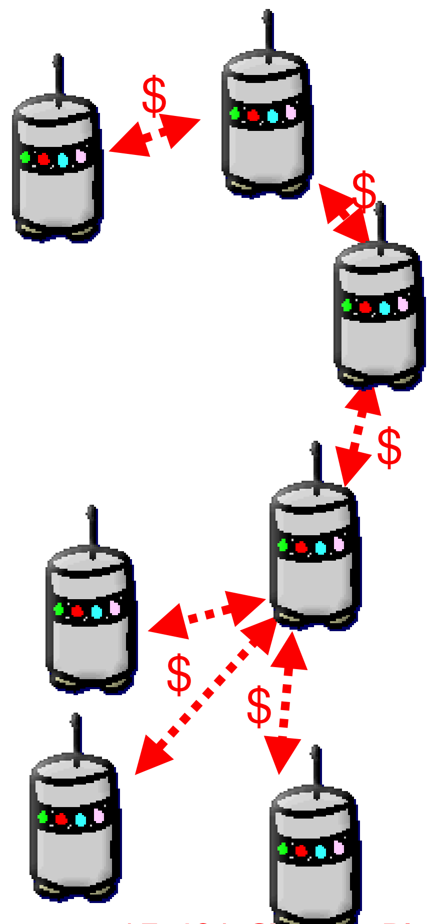
- How do we assign the cities (tasks) to the salesmen (robots)? Ideas?



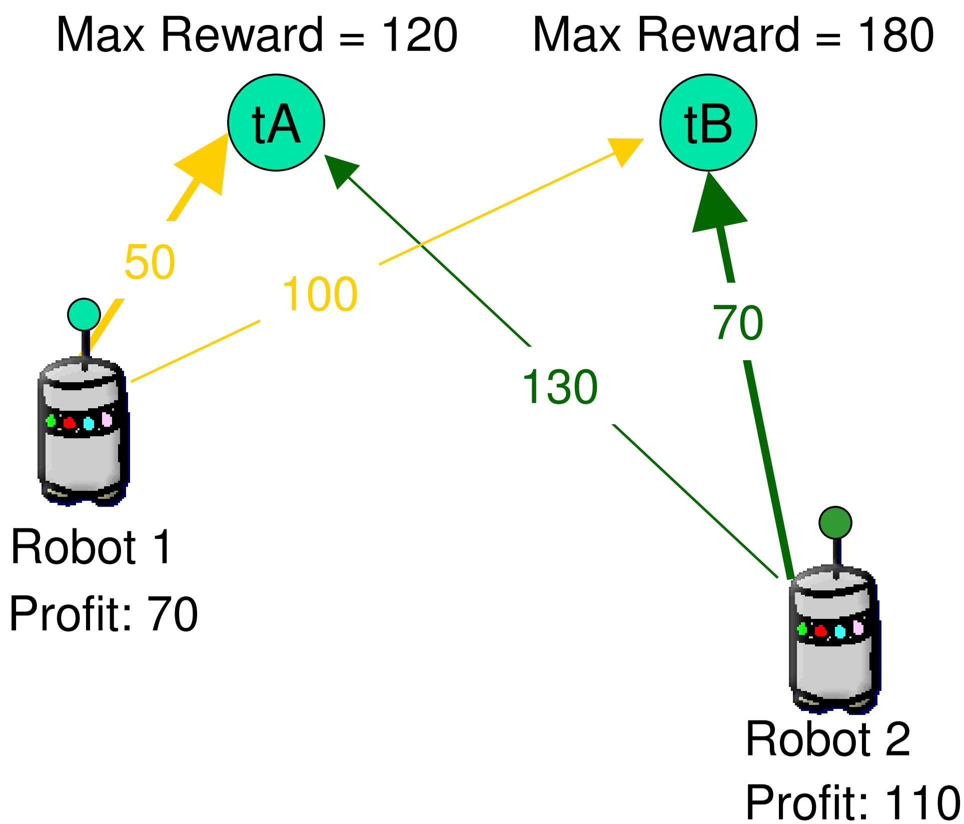


Market-Based Approaches

- Robots model an economy:
  - Accomplish task → receive revenue
  - Consume resources → incur cost
  - Robot goal: maximize own profit
  - Trade tasks and resources over the market (auctions, etc.)
- By maximizing individual profits, team finds better solution
- Time permitting, more centralized
- Limited computational resources, more distributed



A Simple Example:

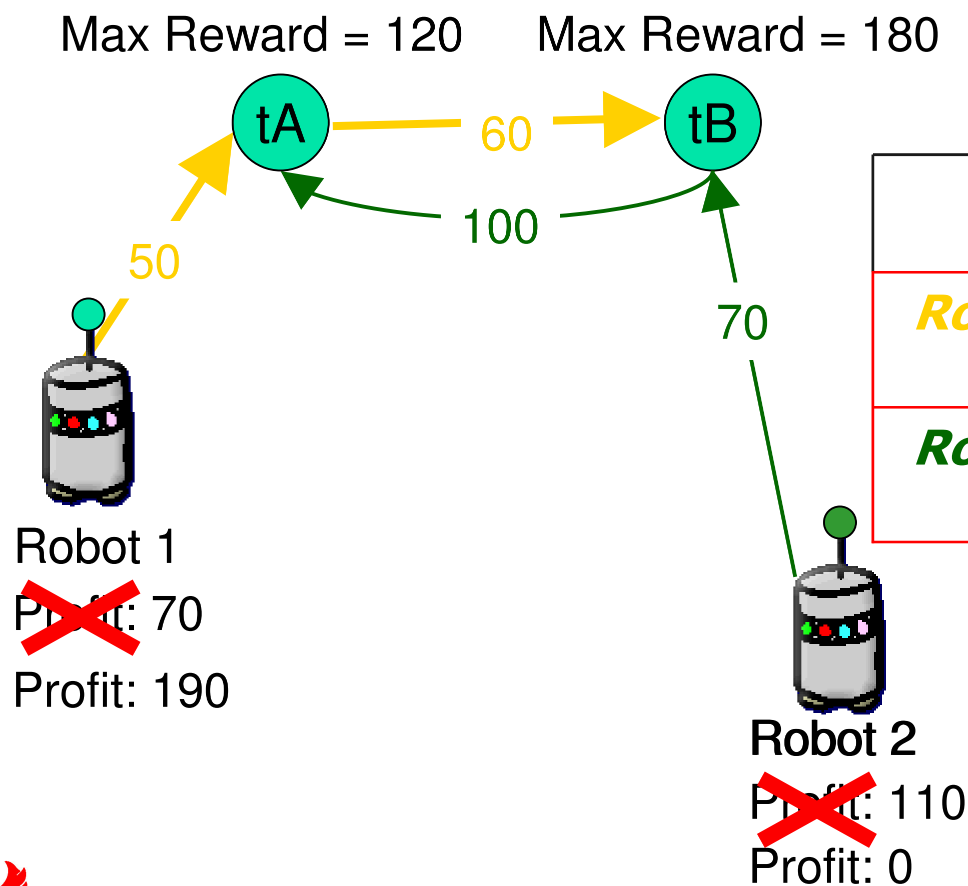


Bids Placed for Tasks

	tA	*tB*
Robot 1	**50** ✓	**100**
Robot 2	**No bid**	**70** ✓

System cost: 50+70=120

A Simple Example:



Bids Placed for Tasks

	tA	***tB***	***tA+tB***
Robot 1	**50**	**100**	**110** ✓
Robot 2	**No bid**	**70**	**170**

~~System cost: 50+70=120~~

System cost: 50+60=110

Market-Based Approaches

Dias and Stentz

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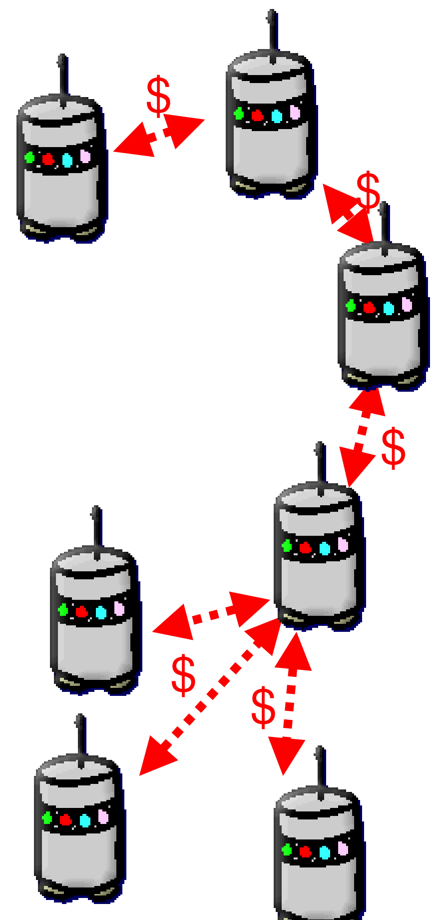
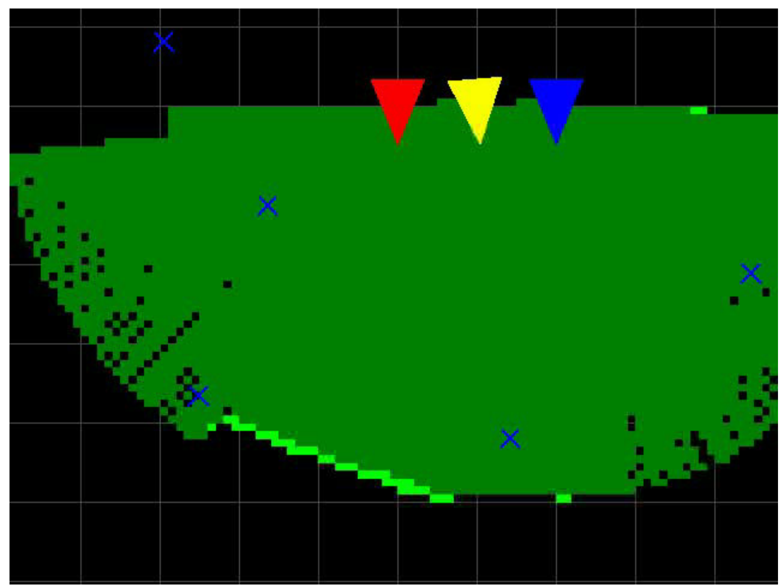


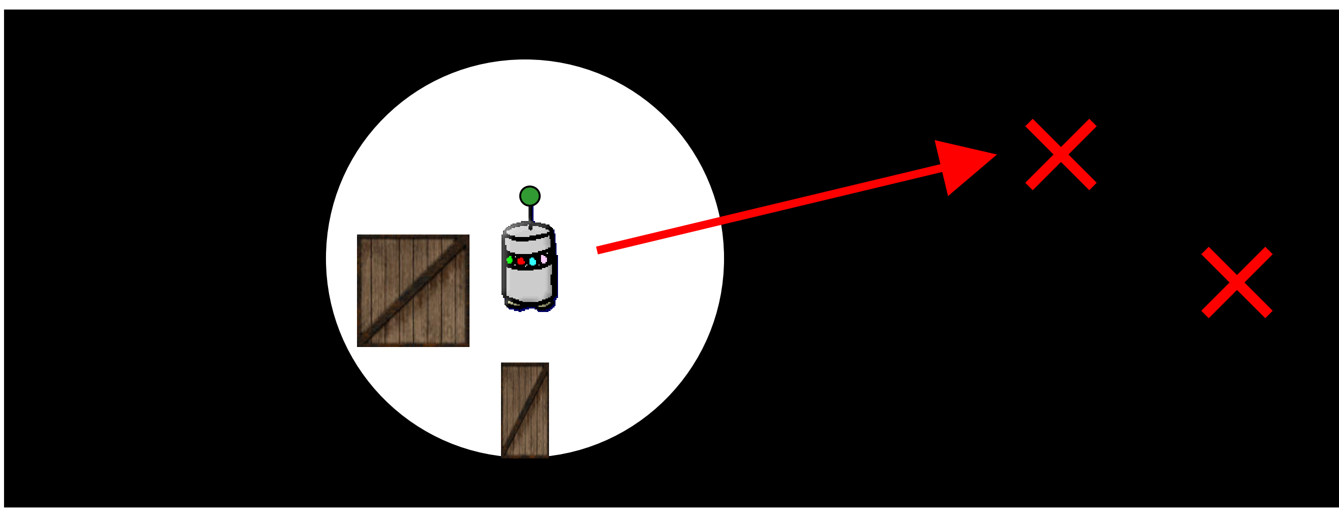
Implementation (Zlot, et al)

- Want robots to explore and map unknown area (FRC Highbay)
- Have team of Pioneer DX-II's



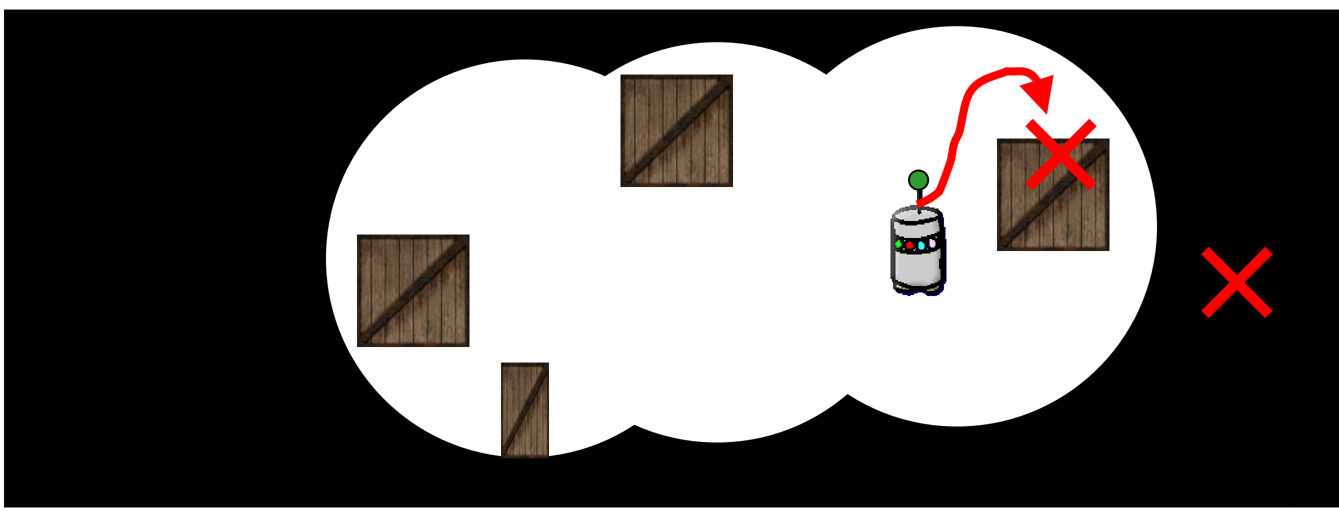
Perception:

- Unknown environment: How to estimate costs?
- Do your best: assume something about the environment. (its clear)
- LEARN!



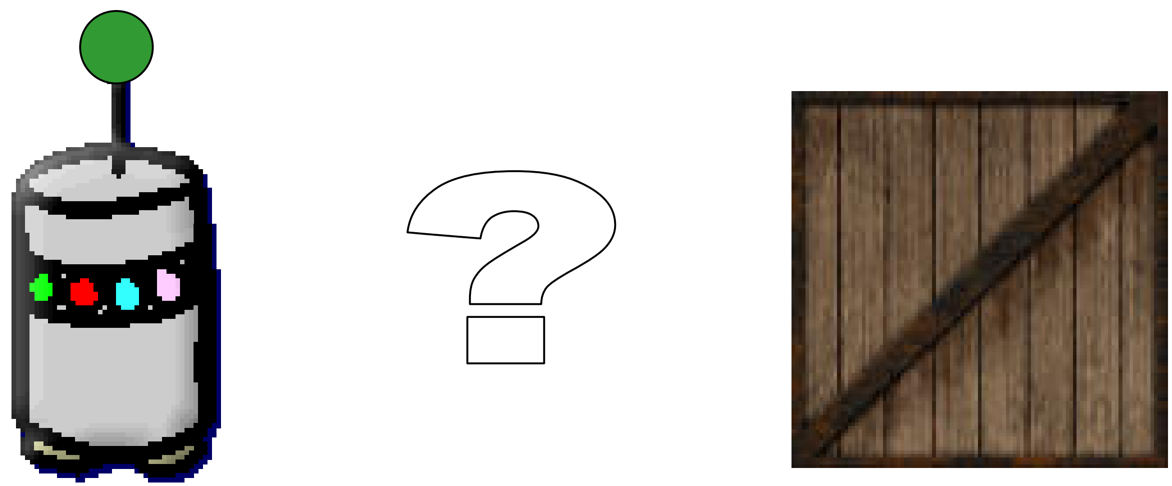
Perception:

- Unknown environment: Some cities may be inside obstacles!
- Constantly update map information
- Constantly find new paths to city
- If no path, city is unreachable.



Perception

- What is an obstacle and what is a teammate?
- Share your (x,y) location
- Set teammates' positions as free space



Replanning: Reallocation of Cities

What happens when 1) robots miscompute costs 2) robots malfunction/die?

- Subcontract expensive cities to other teammates
- Completely offload cities to other teammates

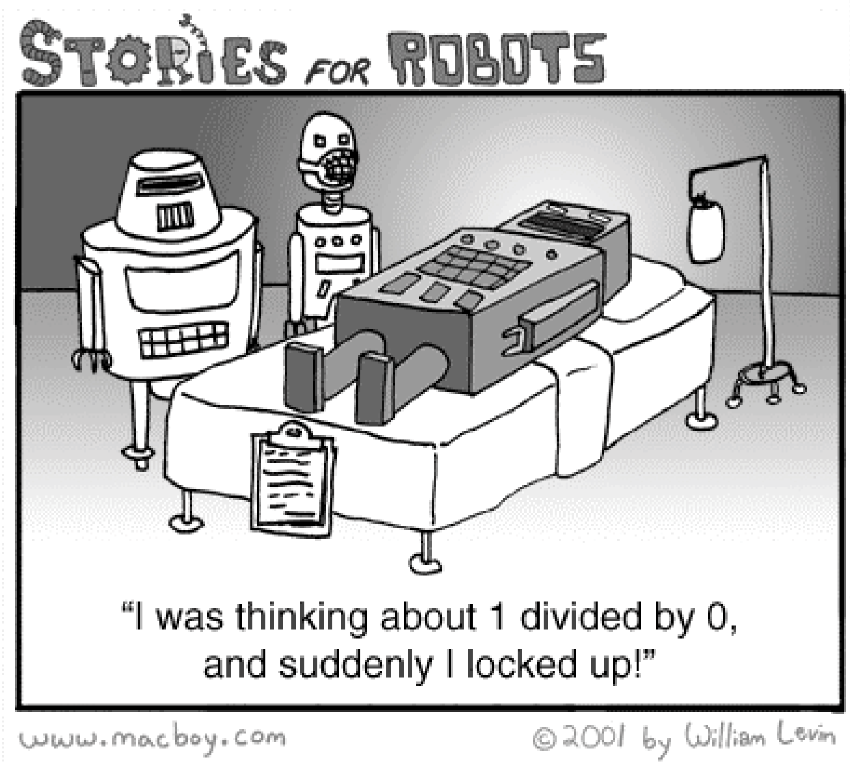
Communication

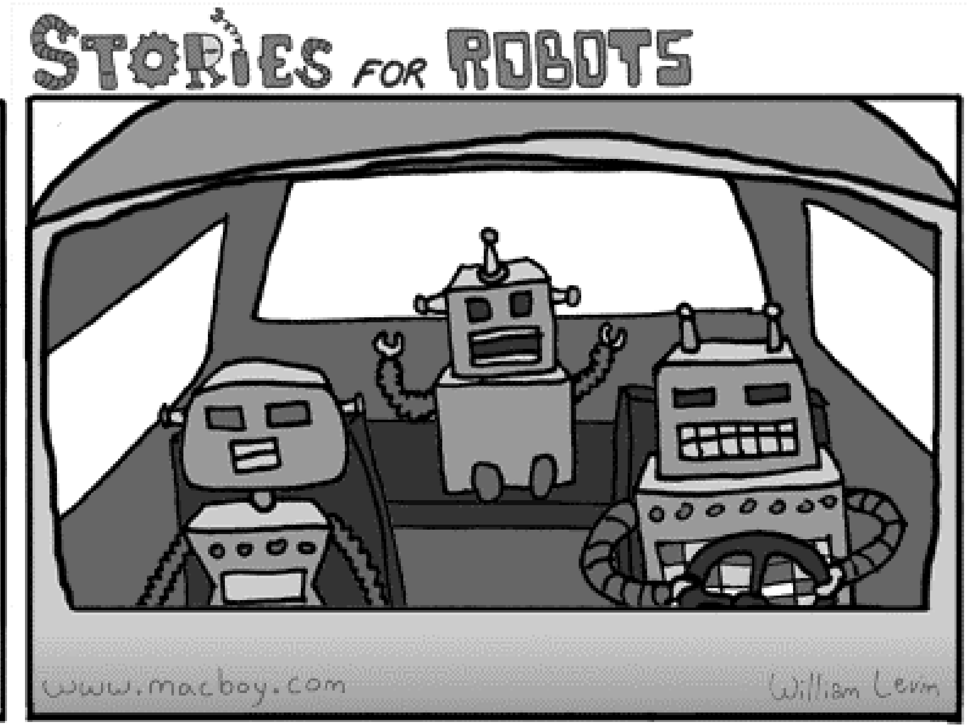
- Original allocation of tasks
- Current position (x,y,t) to everybody
- New auctions for tasks (city location, bids, winner, etc.)
- Completion of subcontracted tasks to original owner

In Action…

QuickTime™ and a
YUV420 codec decompressor
are needed to see this picture.

Break for five…





10 PRINT "ARE WE THERE YET?"
20 GOTO 10

The Coordination Spectrum

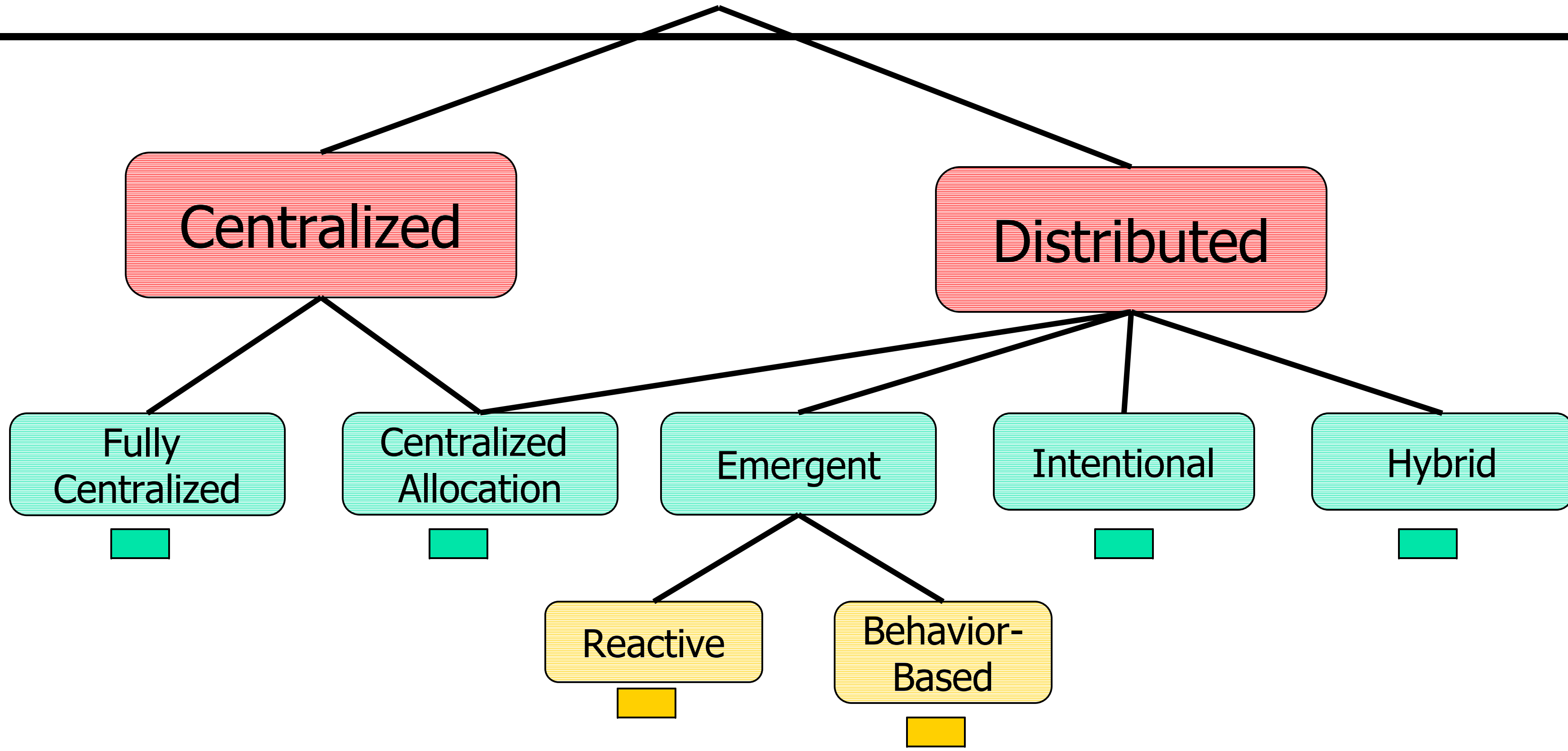
Loosely-Coordinated

- Decomposable into subtasks
- Independent execution
- Minimum interaction
- Task decomposition and allocation strategies.

Tightly Coordinated

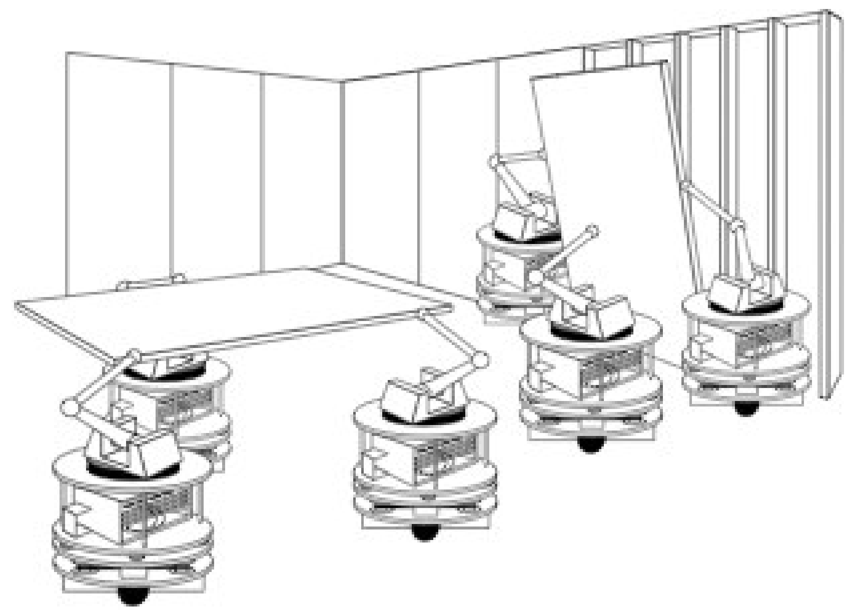
- Tasks not decomposable
- Coordinated execution
- Significant Interaction

Taxonomy of Approaches



Fully Centralized

- Single agent plans for entire team
- \+ Potential to be optimal
- \+ Implicitly encodes coordination
- \- Usually computationally intractible
- \- Single point of failure
- \- Slow to respond to changes



Centralized construction; Khatib et al 1996

Centralized Allocation

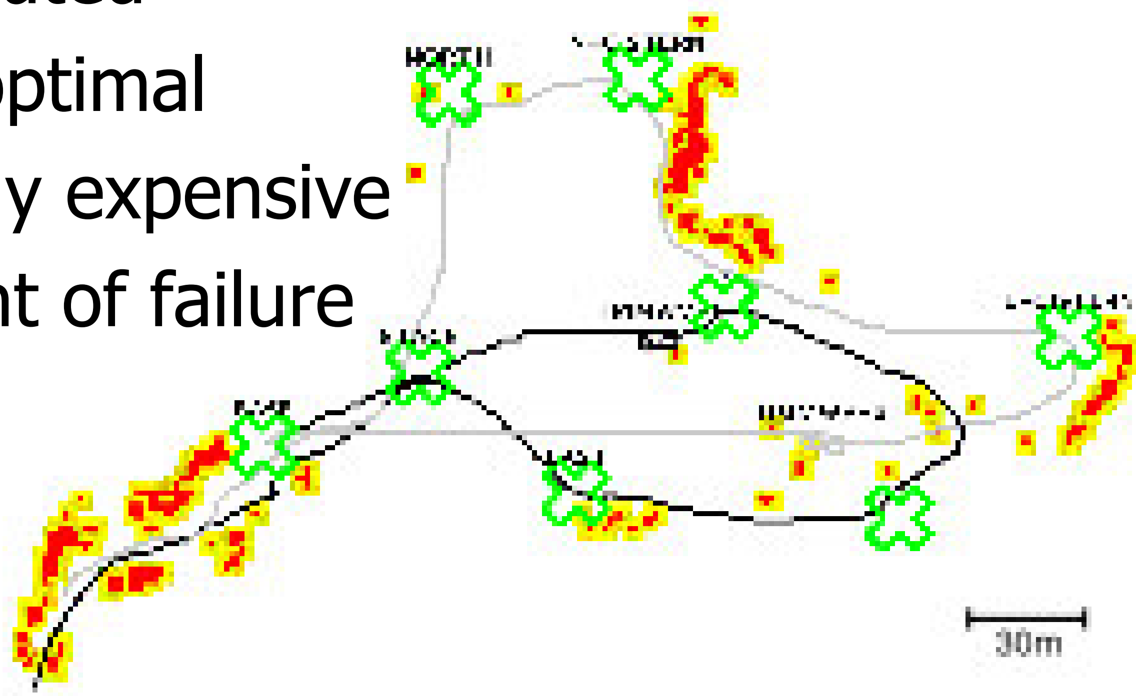
- Single agent assigns tasks to teammates
- Teammates complete tasks individually

\+ Execution is distributed

\+ Allocation can be optimal

\- Still computationally expensive

\- Still has single point of failure



GRAMMPS
Brummitt and Stentz; 1996

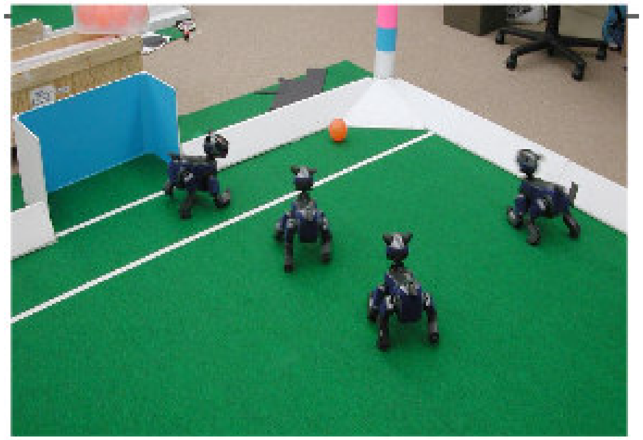
Reactive

- Robots have a tight sense-act loop
- \+ Extremely fast
- \+ Very simple
- \- Cannot handle complex tasks

Caloud et al; 1990

Behavior-based

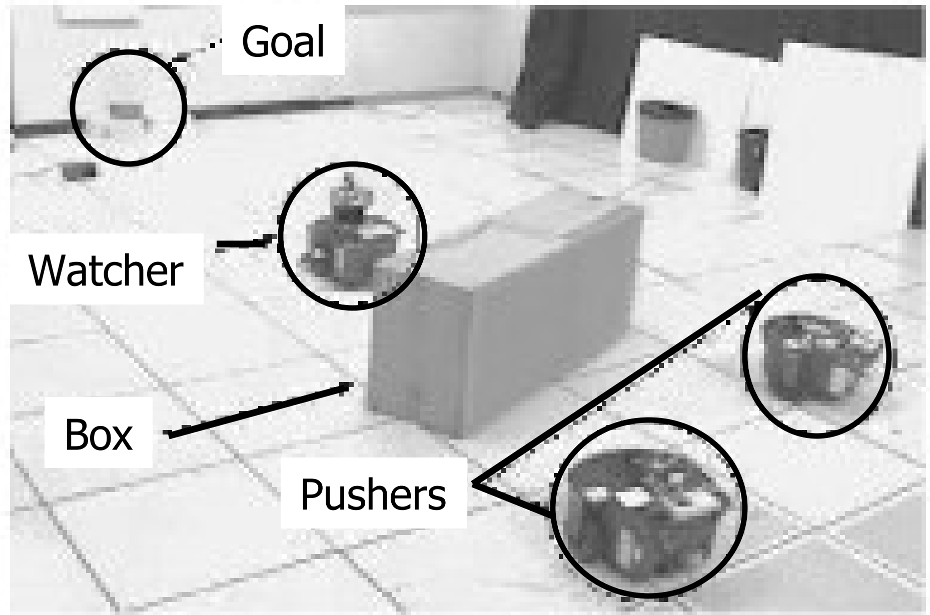
- Use state information to choose actions
- \+ Fast, simple
- \+ Robots can contribute to multiple tasks
- \+ More expressive than reactive
- – Still cannot plan



CMPack 2002

Intentional

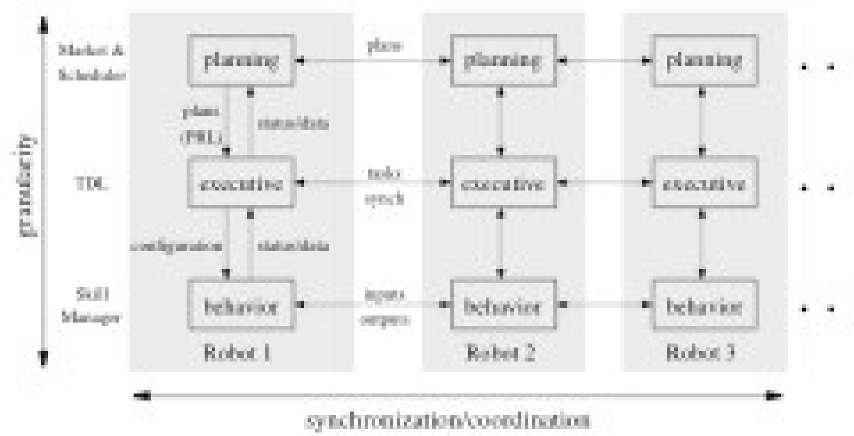
- Communication with the intent to coordinate
- \+ Facilitates planning, scheduling
- \+ Better solutions
- \- Slow in time-critical situations
- \- Very dependent on communication



MURDOCH; Gerkey and Mataric

Hybrid

- Emergent approach in larger intentional approach
- \+ Allows better planning/distribution of resources
- \+ Can have tight coordination
- \- Cannot have complex interactions



Trestle; Simmons et al ▶

Loosely Coordinate Teams

- Behavior-based (Parker's ALLIANCE)
- Central Task Allocation (Caloud)
- Intentional - Market Systems (Dias and Stentz's Traderbots, Gerkey and Mataric's Murdoch, Zlot's Task Trees)

Tightly-Coordinated Teams

- Fully centralized (Khatib et. Al.)
- Reactive (Chaimowicz et. Al.)

Guess the Strategy

QuickTime™ and a
YUV420 codec decompressor
are needed to see this picture.

To Remember…

- Wide range of tasks and purposes for teams
- Robot teams are problems as well as solutions
- Type of team depends on many factors (tasks, robots, time constraints)
- Perception, communication, exectution issues
- Lots of research in this area!