Multi-Robot Planning, Execution, and Some Learning II

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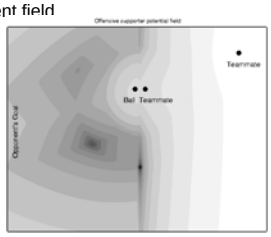
Simmons and Veloso, PEL 2010

Given Common World Model, Multi-Robot Coordination

1. Role assignment
   - Primary attacker, offensive supporter, defensive supporter
2. Strategic positioning
   - Environment driven gradient field



Roles

- Role : Specific set of behaviors that one member of the team will execute
  - Responsible for completing a task
  - Respond to a specific set of contengencies
- Roles can have overlapping responsibilities
- The assignment of roles to robots can be static or dynamic

Assigning Roles in Soccer

- Communicate sensor and state information
- Generate shared world model
  - Global coordinates
  - Subjective representations
  - etc…
- Assign roles
- Act on those roles

Roles from CMPack'03

- Primary attacker:
  - The robot that is closest to the ball
  - Task is to move the ball down the field and shoot on the opponent goal
- Offensive supporter
  - Stay ahead of the ball
  - Move in response to the position of the primary attacker
    - Stay out of the way of primary attacker
    - Try to line up for interceptions
- Defensive supporter
  - Stay in the defensive side of the field
  - Move in response to the position of the ball
    - Stay between ball and goal
- Goalie
  - Stay in the goalbox
  - Guard the goal box against incoming shots
  - Clear the ball up field

Ordered Role Assignment

Given:
- An ordered list of *n* roles: *r1,…rn*
  - Primary attacker, defensive supporter, offensive supporter
- A list of *n* robots: *R1,…,Rn*
- A value for a role, function of a robot: $Bid_{ri}(Rj)$
- An initially empty assignment:
  assigned(*Ri*)=0, for all *i*

Compute role assignment:
- For i=1,…,n
- Assigned (*Rj*)=*ri*, s.t.
  $Bid_{ri}(Rj) > Bid_{ri}(Rk)$, for all *k!=j*

Role Assignment Bidding

- Order of role assignment
  - *Goalie is always fixed!*
  - Primary attacker
  - Defensive supporter
  - Offensive supporter
- Selecting the primary attacker
  - Bidding function

$$Bid_{attacker}(R) = \underbrace{\frac{\theta_{goal}(R)}{\pi}}_{\text{Angular component}} + \underbrace{(1 - \min(1, d_{ball}(R)))}_{\text{Distance component}}$$

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Role Assignment Issues

- Content of communication
  - Each robot communicates the values for each other's bids based on the data
- Latency of communication
  - Hysteresis – robots hold roles
- Cost and frequency of communication
  - On demand vs. continuous

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Positioning

- Potential functions
  - Used by offensive and defensive supporter
- Sum of several linear components of two types:
  - Constraints about the task (e.g. do not block shots)
  - Dynamic obstacle information, (e.g. repulsion from walls and other robots)
- Different components are used by different roles

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Example Ball Component

$$P_{ball} = \left\| c_2 - d_{ball} \right\| \cdot k_2$$

- Guides the offensive supporter to a position that is an equilibrium distance, c_2, away from the ball.
- Potential increases linearly with a slope of k_2 as the robot moves away from the equilibrium distance.

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Potential fields (Vail & Veloso)

All	$P_{wall} = \max(0, c_1 - k_1 \cdot d_{wall})$
All	$P_{ball} = \left\| c_2 - d_{ball} \right\| \cdot k_2$
All	$P_{teammate} = \max(0, c_3 - k_3 \cdot d_{teammate})$
Offensive	$P_{forward_bias} = \max(0, k_4 \cdot d_{behind_ball})$
Defensive	$P_{defensive_bias} = k_5 \cdot d_{from_goalline}$
Offensive	$P_{ball_corridor} = \left\| c_6 - d_{shot_path} \right\| \cdot k_6$
Defensive	$P_{block_goal} = d_{block_path} \cdot k_7$
Offensive	$P_{side_bias} = \max\left(0, k_8 \cdot offset_{robot} \cdot \frac{offset_{ball}}{0.5 * width_{field}}\right)$

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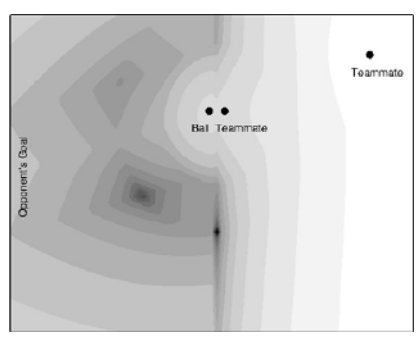
Offensive Supporter



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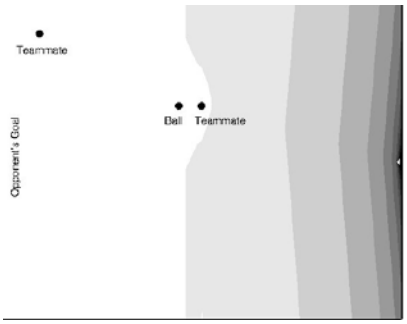
Defensive Supporter



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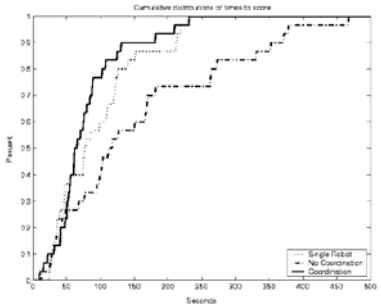
Controlled Experiment



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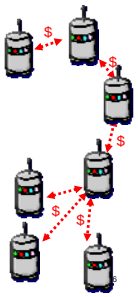
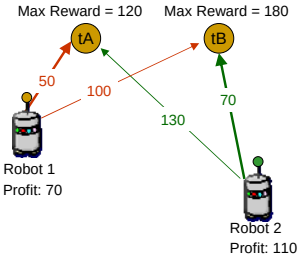
Market-Based Approaches

- 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

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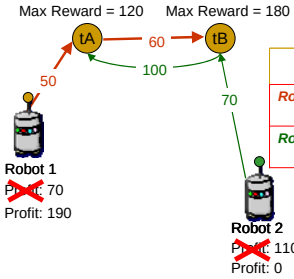
A Simple Example:



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

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Why Multiple Robots?

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

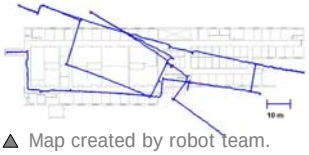
Why Not Multiple Robots?

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

Tasks for Multi-Robot Teams

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

Loosely-coordinated



Map created by robot team.

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Tasks for Multi-Robot Teams

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

Tightly Coordinated

Robotic Construction.

Box Carrying

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

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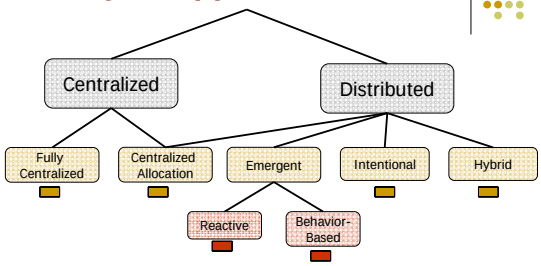
Taxonomy of Approaches



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Summary - Distributed Planning

- Centralized control
  - Centralized evaluation and role assignment
  - Distributed bidding plus centralized role assignment
- Distributed control
  - Communication towards common world model
  - Distributed role assignment based on *common* world model

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