Task Allocation: Role Assignment

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Outline

- Multi-robot dynamic role assignment
Task Allocation Based On Roles

- Usually, a task is decomposed into roles either by a general autonomous planner, or by the designer.

- Roles are defined by action strategies for achieving part of the application.

- Roles can then be dynamically assigned to robots in a similar way as in the auction-based approaches.

- To determine which mapping is the best, some types of utility estimation are used.
Presentation

“Dynamic Role Assignment for Cooperative Robots”, by Chaimowicz, Campos and Kumar, ICRA’02.
Basic Idea

- Each robot performs a role that determines its actions during cooperation

- Robots dynamically exchange roles
  - Perform tasks more efficiently
  - Adapt to unexpected events
  - Improve performance
Roles and Role Assignment

- We model roles and role assignment as discrete modes and mode switching in a hybrid automata.

- The parallel compositions of automata define cooperation.

- Can better describe each robot’s behaviors.
Simulated Cooperative Transportation Task

- A group of robots must find and cooperatively transport several objects scattered in the environment

- Loosely coupled
  - Search area independently

- Tightly coupled
  - Robots manipulate objects in cooperation
Definition of Role

- A role is a **function** that one or more robots perform during the execution of a cooperative task.
- Each robot performs a role while certain **internal and external conditions** are satisfied.
- A role depends on **internal robot state** and on **information about the environment and other robots** and defines a set of controllers that control robot in that moment.
Hybrid Systems

- Formally, a role can be described as a control mode in a hybrid automaton

\[ F = \{ Q, X, E, f, \text{Inv}, G, \text{Init}, R \} \]

- **Q**: set of discrete states (control modes)
- **X**: continuous states (variables)
- **E**: control switches
- **f**: a differential equation, flows
- **Inv**: stay in a control mode while its invariant is satisfied
- **G**: control switch when its guard is satisfied
- **R**: reset statement, change value of variable during a discrete transition
Hybrid Automaton & Roles

- **Continuous variables:**
  - Internal states and sensory information
  - Updated according to dynamic equations within each mode

- **Discrete transitions:**
  - Role assignments

- **Inv and G define when to assume a new role**

- **Cooperation:**
  - A parallel composition of several automata, one for each robot
Three Types of Role Assignments

- **Allocation:**
  - Robot assumes a new role

- **Reallocation:**
  - Robot interrupts the performance of one role and starts or continues the performance of another role

- **Exchange:**
  - Two robots synchronize themselves and exchange roles
When To Change Roles?

- **Allocation**: Robot completes current role
- **Reallocation**: Use a function that measures utility of performing a given role. When $(utility_{new} - utility_{now}) > threshold$, change role. Threshold must consider overhead of changing roles.
- **Exchange**: Both parties agree and synchronize
Cooperative Transportation

- A group of $n$ robots must find $m$ objects that are scattered in an area and transport them to a goal location

- Object $\{k, v\}$
  - Requires $k$ ($k>1$) robots
  - Has an importance value $v$

- Task characteristics:
  - Loosely coupled
  - Tightly coupled
Bidding Process

- Attach leader broadcasts messages
- Robots bid for tasks
- Higher utility values are recruited
- When a robot assumes the approach or attach roles, it makes a commitment to the leader
- If it were reallocated to another role, it must inform the leader
Control Modes and Transitions

Diagram showing the transitions between control modes: Explore, Approach, Attach, Lead, Transport.

- Explore to Approach
- Approach to Transport
- Transport to Attach
- Attach to Lead
- Lead to Explore
- Explore to Attach (dashed line)
- Approach to Explore (dashed line)
- Transport to Approach (dashed line)
- Attach to Transport (dashed line)
Choice of Utility Function

- Determines task performance

Examples:
- Minimize execution time
- Maximize the value in a shorter time
Snapshot of Simulator
Experiment Setup

- 20 holonomic robots
- 30 objects randomly distributed
- $V = \{1 \ldots 5\}$
- $K = \{2 \ldots 5\}$
- Assume robots know their positions and error-free communication

\[ \mu = \begin{cases} 
0, & r = \text{Explore}, \\
\infty, & r = \text{Transport}, \\
\frac{v^2}{k_w+1} + \frac{1}{f(d)}, & \text{otherwise.} 
\end{cases} \]
Determining Threshold

- Varying thresholds were used
Percentage of Total Value Transported
Discussion on Paper 1

- When and why do robots take different roles?

- How do we evaluate the overhead of changing roles during execution?

- How’s this cooperative transportation task different from foraging task?

- Compare the swarm with explicit collaboration here.

- Can we use subtasks instead of roles?
Student Presentation

“Multi-Robot Dynamic Role Assignment and Coordination Through Shared Potential Fields”, by Vail and Veloso, *ICRA’03*.

Presented by Liang Zhang.
Robocup Background

- [www.robocup.org/](http://www.robocup.org/)

- Research goals:
  - Cooperative multi-robot and multi-agent systems in dynamic adversarial environments
  - All robots in this league are fully autonomous

- Ultimate goal:
  - By 2050, develop a team of fully autonomous humanoid robots that can win against the human world champion team in soccer
Current Robot League

- Humanoid
- Middle Size
- Simulation
  - 2D and 3D
- Small Size
- Standard Platform
Humanoid League

- **Robots:**
  - Kid-size: 30-60cm height
  - Teen-size: 100-160cm height
  - Adult-size: ?

- **Research issues:**
  - Dynamic walking, running, and kicking the ball while maintaining balance; visual perception of the ball, other players, and the field; self-localization, and team play

- [http://www.youtube.com/watch?v=wpNaANCq0NM&feature=related](http://www.youtube.com/watch?v=wpNaANCq0NM&feature=related)
Middle Size League

- Two teams of mid-sized robots with all sensors on-board
- Field: 18m by 12m, up to 6 robots
- Relevant objects are distinguished by colors
- Real size soccer
- Wireless communication

- No external intervention by humans is allowed, except to insert or remove robots in/from the field

- http://www.youtube.com/watch?v=cXSGTkI390w
Small Size League

- Two teams of 5 robots each
- Each robot must conform to the dimensions specified
  - 18cm diameter circle, 15cm height
- Field
  - Green carpet, 6.05m by 4.05m
  - Orange golf ball
- Robots
  - Local on-board vision
  - Global vision with overhead camera and off-field PC
- Communication is wireless with FM transmitter/receiver units

http://www.youtube.com/watch?v=jQXPy9rsaAA
Standard Platform League

- All teams use identical robots
- Concentrate on software development
- Replaced four-legged league (Sony’s AIBO robots), now based on Nao humanoids

- [http://www.youtube.com/watch?v=RerTewzPzfY](http://www.youtube.com/watch?v=RerTewzPzfY)
Multi-Robot Soccer

One principle difference from everything we’ve studied thus far:

- Adversarial environment

- What is the impact of this characteristic?
Techniques Involved in Robot Soccer?
Discussion on Paper 2

- How should a group of robot divide tasks among its members?

- Should the robots just rely on their local knowledge?

- Is it wasteful to broadcast position estimates instead of a real valued bid?

- What happens if an agent fails or the environment changes so that a different robot is more suitable for the task?