# Practical Implemented Examples

# Example: CEBOT

- The original example of reconfigurable teams
- Cellular Robot (CEBOT); Japan

# Implementations

- **Examples:** MIT (Parker, Mataric video), Cornell (Donald et al video), Alberta (Kube)

# Example: Nerd Herd

- A collection of 20 coordinated small wheeled robots (Mataric 1994, MIT/Brandeis/USC) (video)
- **Basis behaviors:** homing, aggregation, dispersion, following, safe wandering
- Organized in Subsumption style
- **Complex aggregate behaviors:** flocking, surrounding, herding, docking
- Complex behaviors result from combinations or sequences of basis set

# Example: Alliance

- L. Parker MIT/ORNL
- Heterogeneous teams
- Adds a layer of motivations to subsumption, for switching behavioral sets on and off
- Motivational behaviors *take inputs from other robots'*, i.e., serve for group communication; relies on broadcast
- Combines impatience and acquiescence for team coordination
- Impatience is a scalar value that grows as a robot waits for another robot to complete a task that is a prerequisite for its own next action
- Acquiescence is a binary predicate that determines if a robot will give up its task to another robot
- **Tasks include** box-pushing, hazardous waste clean-up, janitorial service (simulation), bounding overwatch (simulation)

# Example: Stagnation

- R. Kube and Zhang - U of Alberta
- Aimed at **reducing stagnation**
- Stagnation occurs when cooperation within the group is poor
- Specific anti-stagnation strategies are implemented on each robot
- Each decides between the **strategies to recover** when stagnation is detected
- No explicit communication
- **Task**: box pushing

# **Example:** Stagnation

## Box Pushing Task

- Arbitrary object geometry
- Arbitrary numbers of robots
- Arbitrary initial configuration
- Homogeneous or heterogeneous teams
- Different approaches to communication:
    - no explicit communication
    - minimal communication
    - global communication (broadcast)

# Types of Pushing Tasks

- Homogeneous:
  - collection of wheeled robots
  - a pair of 6-legged robots
- Heterogeneous:
  - wheeled and legged
  - different types of sensors
- Applications
  - removing barriers
  - help in disaster scenarios
  - moving wounded

# Communication

- Communication:
  - Enables synchronization of behaviors across the group
  - Enables information sharing & exchange
  - Enables negotiations
- Communication not necessary or essential for cooperation
- Louder is not necessarily better

# Communication Cost

- Communication is not free
  - Hardware overhead
  - Software overhead
- For any given robot task, it is necessary to decide:
  - whether communication is needed at all
  - what the range should be
  - what the information content should be
  - what performance level can be expected

# What to Communicate?

- **State** (e.g., I have the food, I'm going home)
- **Goal** (e.g., go this way, follow me)
- **Intentions** (e.g., I'm trying to find the food, I'm trying to pass you the ball)
- **Representation** (e.g., maps of the environment, knowledge about the environment, task, self, or others)

# Learning to Communicate

- Besides deciding all these factors a priori, communication can also be learned
- Example: Bert & Ernie (Yanko & Stein '93)
- spin or go behaviors; associated messages/labels

# Kin Recognition

- Kin recognition is the ability to recognize “others like me”
- In nature, it usually refers to the members of the immediate family (shared genetic material); can be used for sharing of food, signaling, altruism
- In robotics, it refers to recognizing other robots (and other team-members) as different from everything else in the environment

# Kin Recognition Importance

- Without kin recognition, the types of cooperation that can be achieved are greatly diminished
- Kin recognition does not necessarily involve recognizing the identities of others, but if those are provided, more sophisticated cooperation is possible (dominance hierarchies, alliances, etc.)
- Ubiquitous in nature, but not simple to implement on robots!

# Applications

The combination of distributed sensing (over a group of robots) and coordinated movement result in a large number of practical applications:

- convoying (highways, transportation)
- landmine detection
- reconnaissance & surveillance
- blanket coverage
- barrier coverage
- sweep coverage
- map making

# Multi-Robot Learning

- What can be learned in a group?
  - distributed information (e.g., maps)
  - tasks/skills by imitation
  - social rules (e.g., yielding, communicating)
  - models of others
  - models of the interactions
  - with the environment
  - with others

# Why is it difficult?

- As we saw, learning is hard
- It is even harder with groups of robots dynamic, changing, non-stationary environment
  - huge state space
  - even greater uncertainty
  - incomplete information (sensors, communication)

# Reinforcement Learning

Reinforcement learning is a popular approach

Several problems must be overcome

- giant state space (RL requires building a table of states or state-action pairs)
- credit assignment across multiple robots (who is to credit/blame?)
- greediness of the approach (maximizing individual reward may not optimize global performance)

Multi-robot scenarios can also speed up RL

Communication is a powerful tool for

- increasing observability
- minimizing the credit assignment problem
- sharing reward to minimize greediness

Direct observation is useful, too

- using observation of another agent as a source of information and reinforcement

# Coevolution Approaches

- Designing controllers for a group of robots can be done automatically, by using evolutionary methods
- Coevolution is the most powerful method
- Two populations compete and the winners of both sides are used to produce new individuals, then compete again
- Models natural ecological evolution

# Imitation Learning

# Imitation Learning

Imitation is a powerful mechanism for learning in a group

- It involves
  - having motivation to imitate (find a teacher)
  - finding a good teacher
  - identifying what to imitate and what to ignore
  - perceiving the teacher’s actions correctly

# Representation in Imitation

The observed action must be encoded in some internal representation, then reconstructed/reproduced

This requires:

- finding a suitable encoding that matches the observed behavior
- encoding the observed behavior using that mapping

# Reproduction of Action

Reproducing an observed action requires

- being motivated to act in response to an observation
- selecting an action for the current context
- adapting the action to the current environment

=> Imitation is a complex form of learning, but a powerful one, because it provides an initial policy for the learner

# Case Study: UGV Demo

Task: battlefield scouting using multiple autonomous mobile ground vehicles (UGVs)

Equipped with behavior-based controllers

Involved tele-operation and autonomy

Arbiter for behavior coordination

Formation behaviors

User interface (MissionLab)

Team tele-autonomy

- operator as a behavior
- operator as a supervisor

# From Natural to Artificial Systems

- ❖Summary
- ❖Questions
- ❖Webnotes: http://www.cpsc.ucalgary.ca/~pango/533/

# Sources

**Maja Mataric,**
**Rob Cranston,**
**Walter Proseilo,**
**Chau Trinh,**
**Owen Pang**