A Taxonomy of Multirobot Systems

---- Gregory Dudek, Michael Jenkin, and Evangelos Milios

in

“Robot Teams: From Diversity to Polymorphism”

edited by Tucher Balch and Lynne E. Parker


presented by: Lan Lin

for CS594: Distributed Intelligence for Autonomous Robotics

March 11, 2003

© Lan Lin March 11, 2003
A Quick Overview

• Why a Taxonomy Is Important
• Dimensions of Robot Collective Taxonomies
• A Taxonomy of Robot Collectives
• Case Studies
• Summary and Conclusions
Some Issues

• Multiple Robots vs. A Single Robot
  – distinguish between \( \{r_i\} \) and \( R \)
  – cost, scalability, robustness, reliability, performance

• Intra-collective Communication
  – required for cooperative intelligent behavior
  – difficult in terms of efficiency, fault tolerance, and cost
  – design options less extensively examined
Tasks → Team Organization

- Expendability of Collective Elements
  - mine deployment, carrier deck foreign object disposal, etc.

- Computational Reasons
  - tasks (spatially disparate) that require synchronization (inter-robot communication)
  - tasks (simple, highly parallel) that are traditionally multiagent
  - tasks that are traditionally single-agent
  - tasks that may benefit from multiple agents

© Lan Lin March 11, 2003
Tasks (con’d)

- Communication Mechanism is Critical
- Requirements at Odds with One Another
  - practicality, efficiency, reliability
- Different Collective Architectures Proposed
  - how to compare
- Factors that Influence Collective Processing Ability
  - # of units, unit sensing, limits on communication
Dimensions

• Dudek and Cao Independently Proposed the Classification
• Five Research Axes (defined by Cao)
  – Group Architecture
    • Centralized / Decentralized
    • Differentiation-heterogeneous vs. Homogeneous
    • Communication Structures (interaction via environment, via sensing, and via communications)
    • Modelling of Other Agents
  – Resource Conflicts
  – Origins of Cooperation
  – Learning
  – Geometric Problems
Dimensions (con’d)

• Other Efforts Along the Line
  – subdivision of collectives (Yuta and Premvuti)
  – in terms of a particular task (Arkin)
  – task features and rewards (Balch)
  – survey and identification of open questions (Parker)
  – degree of heterogeneity and communication with a focus on learning (Stone and Veloso)
Taxonomy
(proposed by Dudek)

• Size of the Collective
  – SIZE-ALONE 1 robot
  – SIZE-PAIR 2 robots
  – SIZE-LIM multiple robots
  – SIZE-INF $n > 1$ robots

• Communication Range
  – COM-NONE no direct communication
  – COM-NEAR communicate with others sufficiently nearby
  – COM-INF communicate with any other robot
Taxonomy (con’d)

- Communication Topology
  - TOP-BROAD broadcast
  - TOP-ADD address
  - TOP-TREE tree
  - TOP-GRAPH graph

- Communication Bandwidth
  - BAND-INF free communication
  - BAND-MOTION same order of magnitude in cost compared with motion
  - BAND-LOW very high cost
  - BAND-ZERO no communication

© Lan Lin March 11, 2003
Taxonomy (con’d)

• Collective Reconfigurability
  – ARR-STATIC static arrangement
  – ARR-COMM coordinated arrangement
  – ARR-DYN dynamic arrangement

• Processing Ability of Each Collective Unit
  – PROC-SUM non-linear summation unit
  – PROC-FSA finite state automaton
  – PROC-PDA push-down automaton
  – PROC-TME Turing machine equivalent
Taxonomy (con’d)

• Collective Composition
  – CMP-IDENT *identical*
  – CMP-HOM *homogeneous*
  – CMP-HET *heterogeneous*

• Values of the Taxonomy
  – provides description of systems and results in the literature
  – maps out the space of possible designs
<table>
<thead>
<tr>
<th>Axis</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collective Size</td>
<td># of autonomous agents in the collective</td>
</tr>
<tr>
<td>Communication Range</td>
<td>the maximum distance between two elements for possible communication</td>
</tr>
<tr>
<td>Communication Topology</td>
<td>of the robots within communication range, those who can be communicated with</td>
</tr>
<tr>
<td>Communication Bandwidth</td>
<td>how much information can be transmitted to each other</td>
</tr>
<tr>
<td>Collective Reconfigurability</td>
<td>the rate at which the organization of the collective can be modified</td>
</tr>
<tr>
<td>Processing Ability</td>
<td>computational model used by an individual</td>
</tr>
<tr>
<td>Collective Composition</td>
<td>elements homogeneous or heterogeneous</td>
</tr>
</tbody>
</table>
Case Studies

• Turing Equivalence of a Collective of Finite Automata
  – (SIZE-INF, COM-NEAR, TOP-ADD, BAND-INF, ARR-STATIC, PROC-FSA, CMP-HET)

• Exploration
  – using an occupancy-grid-based map (Burgard)
    • (SIZE-LIM, COM-NEAR, TOP-ADD, BAN-INF, ARR-COMM, PROC-TME, CMP-HOM)
  – using a topological map
    • (SIZE-LIM, COM-NEAR, TOP-ADD, BAND-INF, ARR-COMM, PROC-TME, CMP-HOM)
Case Studies (con’d)

– using a metric map (Dudek)
  • (SIZE-LIM, COM-NEAR, TOP-GRAPH, BAND-INF, ARR-COMM, PROC-TME, CMP-HOM)

• Material Transport
  – a box-pushing system with n » 1 robots (Kube and Zhang)
    • (SIZE-INF, COM-NONE, NA, NA, NA, PROC-FSA, CMP-HOM)
  – homogeneous and heterogeneous robot teams in box-pushing under ALLIANCE (Parker)
    • (SIZE-LIM, COM-NEAR, TOP-BROAD, BAND-INF, ARR-COMM, PROC-TME, CMP-HOM)
Case Studies (con’d)

– box-pushing with legged robots (Mataric)
  • (SIZE-LIM, COM-NEAR, TOP-ADD, BAND-INF, ARR-COMM, PROC-TME, CMP-HET)

– a multiple mobile robot system for coordinated material transportation (Hirata)
  • (SIZE-LIM, COM-NEAR, TOP-BROAD, BAND-LIM, ARR-STATIC, PROC-TME, CMP-HET)

• Coordinated Sensing (Jenkin and Dudek)
  – (SIZE-LIM, COM-NEAR, TOP-BROAD, BAND-LIM, ARR-COMM, PROC-TME, CMP-HOM)
Case Studies (con’d)

- Robot Soccer
  - (SIZE-LIM, COM-INF, TOP-BROAD, BAND-MOTION, ARR-DYN, PROC-TME, CMP-HOM)

- Moving in Formation
  - a collection of control laws (Desai)
    - (SIZE-LIM, COM-NEAR, TOP-ADD, BAND-INF, ARR-COMM, PROC-TME, CMP-HET)
  - leader-follower experiments (Dudek)
    - (SIZE-LIM, COM-NEAR, TOP-BROAD, BAND-LIM, ARR-COMM, PROC-TME, CMP-HET)
Conclusions

• A Taxonomy Provides a Common Language

• Serves Dual Functions
  – allowing concise description of key characteristics of different collectives
  – describing the extent of the space of possible designs
Thanks!!  😊

Questions?