A Taxonomy of Multirobot Systems

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

in

"Robot Teams: From Diversity to Polymorphism"

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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

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* } a property of the size of the task
  - 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*

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

Summary of Taxonomy Axes

(Table 1.1 on Page 14)

Axis	**Description**
Collective Size	# of autonomous agents in the collective
Communication Range	the maximum distance between two elements for possible communication
Communication Topology	of the robots within communication range, those who can be communicated with
Communication Bandwidth	how much information can be transmitted to each other
Collective Reconfigurability	the rate at which the organization of the collective can be modified
Processing Ability	computational model used by an individual
Collective Composition	elements homogeneous or heterogeneous

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)

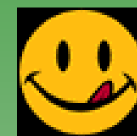
Case Studies (con'd)

- 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?