The ALLIANCE Architecture for Multi-Robot Control*

NASA Surface Systems Quarterly Meeting

Panel on: "Multi-Robot Control Architectures: Commonalities and Differences"

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March 23-24, 2000
Arcadia, CA

*Research sponsored in part by the Engineering Research Program of the Office of Basic Energy Sciences, U. S. Department of Energy. Oak Ridge National Laboratory is managed by UT-Battelle, LLC, for the U. S. Department of Energy under contract DE-AC05-00OR22725.

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What do we mean by “multi-robot control”?

- Coordinated, cooperative control at the level of the *group task*
  - Example group tasks:
    - Open-pit excavation/mining
    - Object transport/pushing
    - Ground leveling/clearance (i.e., site preparation)
    - Surveillance/reconnaissance
    - Object collection (e.g., moving rocks or pucks to goal)
    - Formation-keeping
    - Construction

- Software approaches defining the control of the individual robot in a team, enabling the team to cooperate and coordinate to accomplish the given group task.

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Two Classes of Multi-Robot Control: Swarm vs. "Intentional" Cooperation

- Large numbers (20+)
- Homogeneous
- Individual has little capability
- As a group, generate "intelligent" cooperative behavior
- Largely ignores issues of efficiency
- ***Relies on sufficiently large number of robots and sufficient available time to converge to desired solution***

e.g. Theraulaz *et al. '90*,
Beni and Hackwood '91,
Deneubourg *et al* '92,
Mataric '92,
Drogoul and Ferber '92,
Stilwell and Bay '93,
Kube '97,
Recent NASA excavation effort (Wilcox, *et al.*)

- Smaller numbers (2-10)
- Often heterogeneous
- Individual can accomplish meaningful task alone
- Redundancy, complementarity in individual capabilities
- Often deal with time or energy constraints
- ***Requires more directed, complex mechanisms for generating cooperative control***

e.g. Cohen *et al. '90*,
Asama *et al.* '92,
Noreils '93,
Wang '93,
Parker '94 ,
Other recent NASA efforts (Schenker, Kortenkamp/Simmons, Rock)

The control approaches to solve these two classes are distinct.

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The ALLIANCE Architecture for Multi-Robot Control (Parker '94)

- Principally aimed at generating fault-tolerant, adaptive action selection in (possibly heterogeneous) multi-robot teams
- Fully distributed control technique; no centralized control
- Defines control of individual robot to enable cooperation with other robots
- Behavior-based; defines "behavior sets" as groups of behaviors corresponding to high-level task-achieving functions
- Hybrid approach (behaviors + reasoning)
- Utilizes motivational behaviors, impatience, and acquiescence to enable fault tolerant, adaptive multi-robot action selection
- Uses broadcast communication as substitution for action recognition
- No requirement for negotiation
- Incorporates mechanisms for multi-robot learning and automatic parameter tuning
- Demonstrated to generate fault tolerant, adaptive allocation due to:
  - Robot failures
  - Sensor/actuator uncertainties
  - Dynamic environment
  - Mission changes
  - Dynamic team composition
  - Human interference with robots
  - Learned experiences
  - Communication failure

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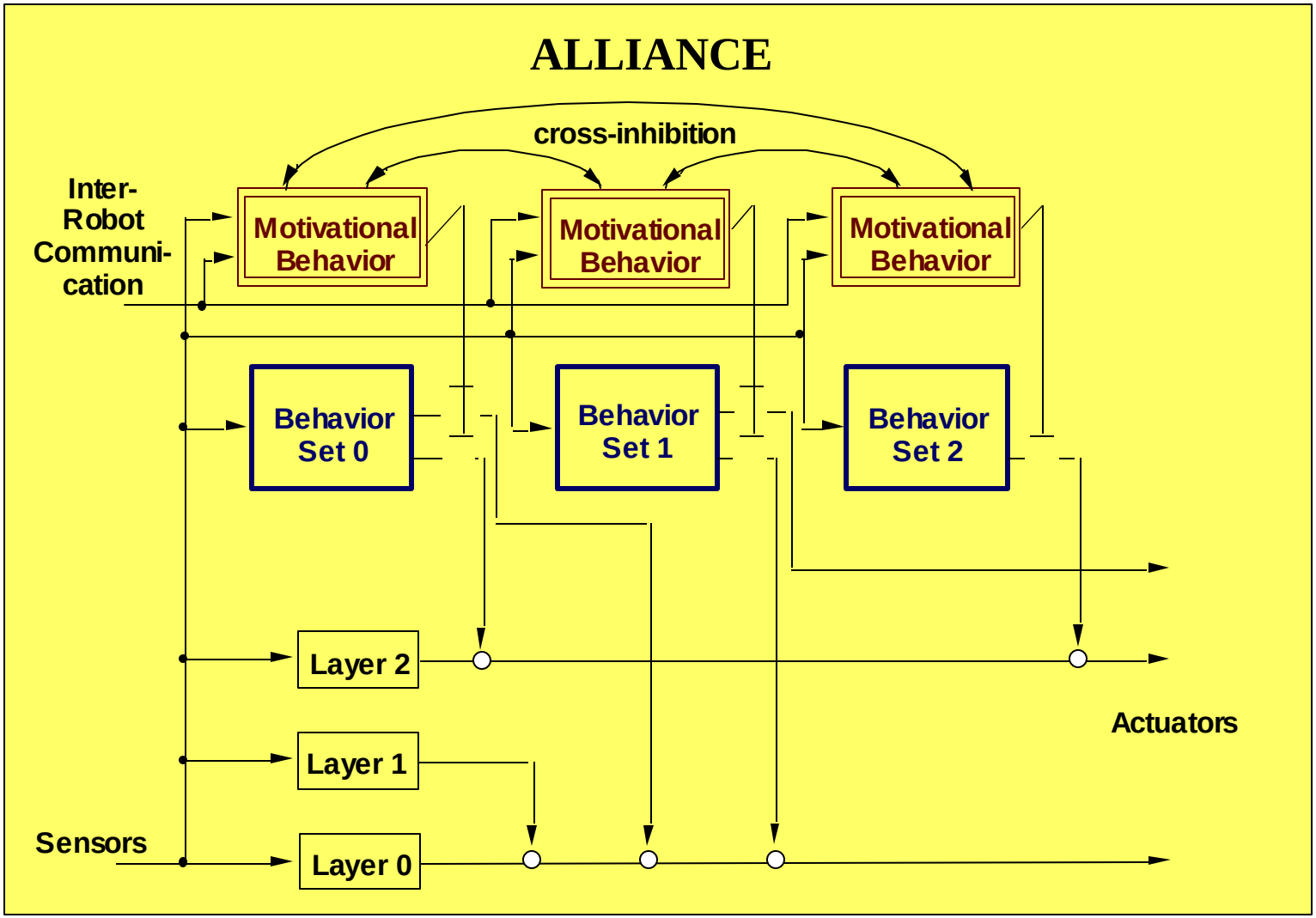
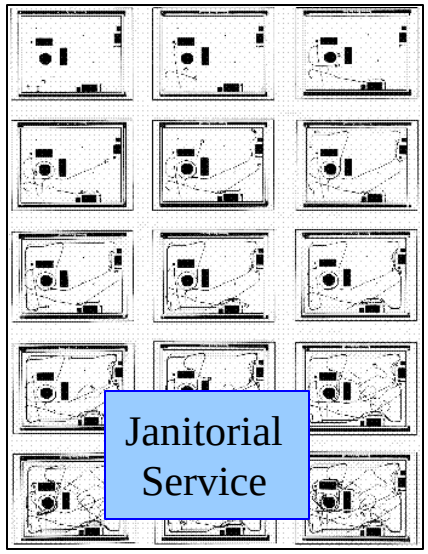
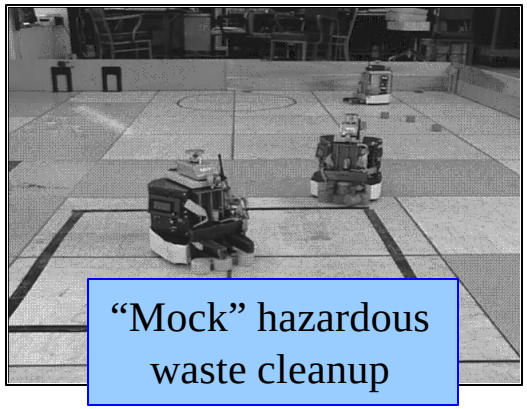
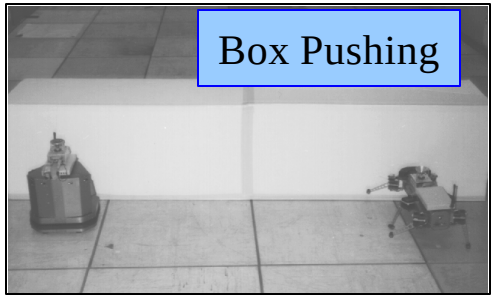
ALLIANCE: An Architecture for Heterogeneous Cooperative Control

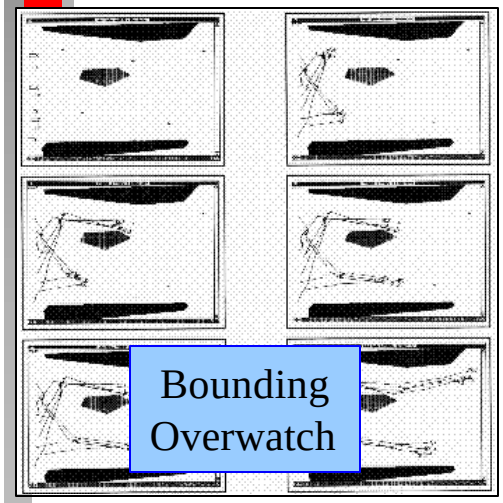


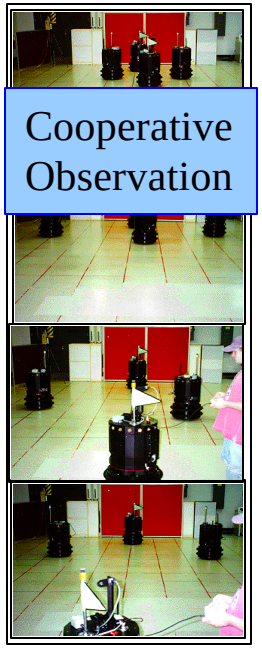
Many Proof-of-Principle Demonstrations of ALLIANCE Architecture











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ALLIANCE Compared to New NASA Surface Systems Architectures (con't.)

- Primary uniquenesses of ALLIANCE:
  - Focuses on fault tolerance in autonomous robot action selection
  - Philosophy: vast majority of current applications for multi-robot teams do not require extensive task planning (exception: large-scale construction). Thus, need for high-overhead task planning, etc., is minimal. Focus instead is on generating adaptive, fault tolerant control for a given cooperative task, rather than for general, multi-purpose robots.
  - Provides mechanisms for multi-robot learning and automatic parameter tuning
- What ALLIANCE *does not* do:
  - Provide mechanisms for "traditional AI" planning
  - Provide mechanisms for injecting human advise and control (although this is currently being added into ALLIANCE)
  - Provide solutions to low-level, closed-loop, tightly-coupled coordinated control (e.g., for the purpose of cooperative object transport)
    - NOTE: If a closed-loop solution can be generated separately, it can perhaps be implemented under the ALLIANCE framework, depending on the nature of the solution.

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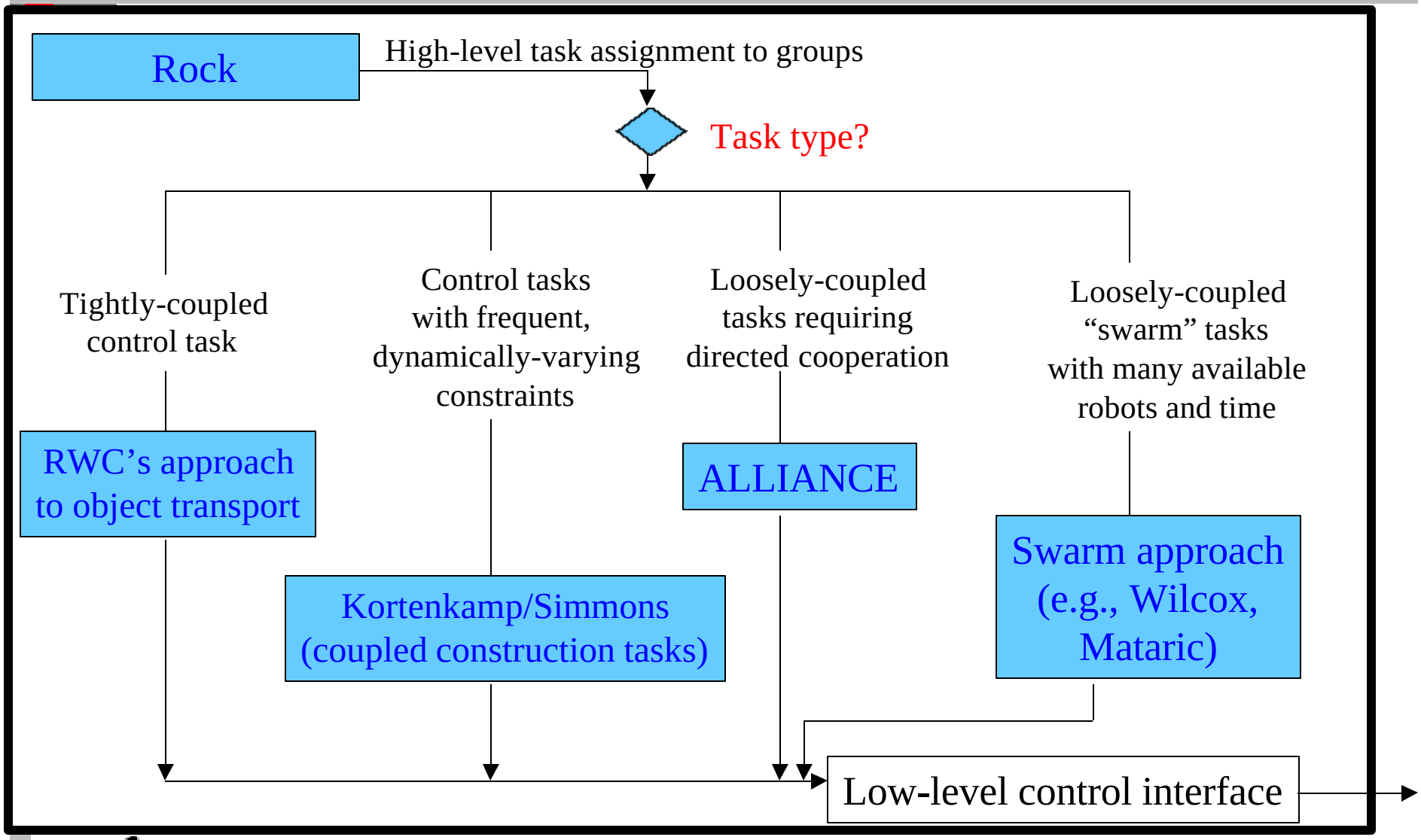
Comparing Architectures: Commonalities and Differences



Overall design: objective of CAMPOUT (RWC)

Recognizing a "Good" Multi-Robot Control Architecture

- Applicable to a wide range of application domains
- Provides appropriate abstractions for the application
- Robust in light of real-world issues, including:
  - Communications loss
  - Noisy sensors and effectors
  - Robot failures
  - Dynamic and/or uncertain environment
  - Drift in robot capabilities
  - Dynamic team composition
  - Heterogeneous robot capabilities
- Easy to use

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Remaining Issues: Solvable

- Reliable response to communications failures
- Interacting in a 3D world, including altering environment
- Need for complete, light-weight, system for multi-robot control including capabilities for:
  - Online mission specification
  - Easy injection of human-in-the-loop control
  - Generic solutions to robust coordinated control
  - Autonomous adaptation to off-normal events
- Scaling up to larger numbers (10+) of heterogeneous ("non-swarm") robot teams -- "System of systems"
- Multi-robot learning

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Remaining Issues: Unsolvable?
(at least in the near term)

- Efficient (vs. *reliable)* response to communications failures
  - Requires passive action recognition or passive determination of intentions
  - Requires a great deal of reasoning, common sense, etc.

May be difficult to build into a "real-time", online system in the near future

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