The Role of Organizational Control in Scaling AI Systems

Victor R. Lesser

Computer Science Department

University of Massachusetts, Amherst

IJCAI 2009

Pasadena, California

July 16, 2009

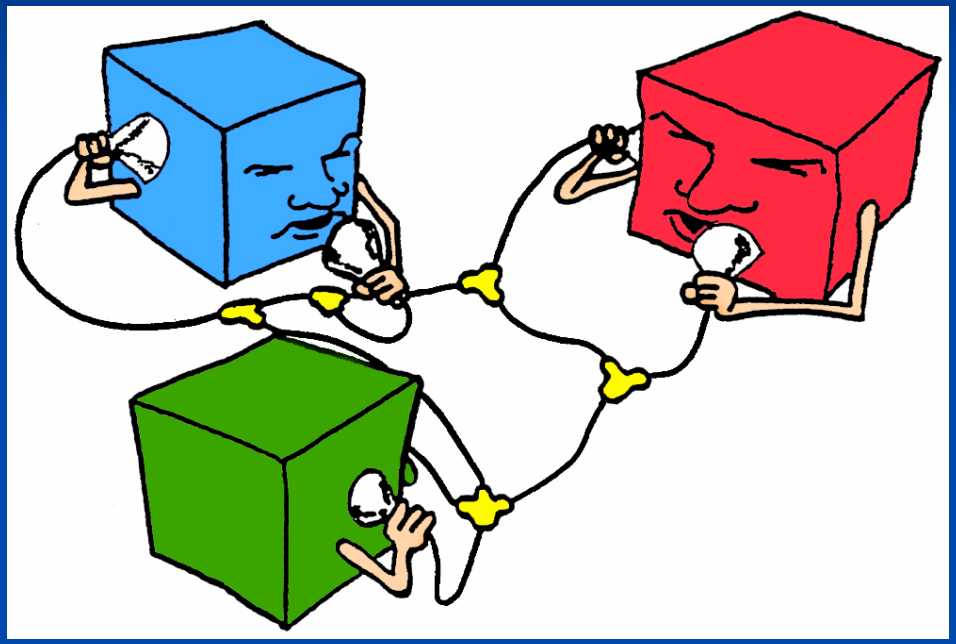
Thanks

- Raj Reddy – for his support, encouragement and mentoring
- Lee Erman – my early colleague and closest friend for over 40 years
- My wonderful graduate students – for their creativity, hard work and collegiality
  - A special thanks to my first graduate student, Dan Corkill
- Multi-Agent Systems community – who have been a welcoming home
- My wife and children – who have created a richness in my personal life

Outline

- Background
- Examples of Organizational Control
  - Distributed sensor networks
  - Distributed search in a peer-to-peer IR
  - Multi-agent reinforcement learning for distributed resource allocation
- What are the Major Research Topics
- Summary

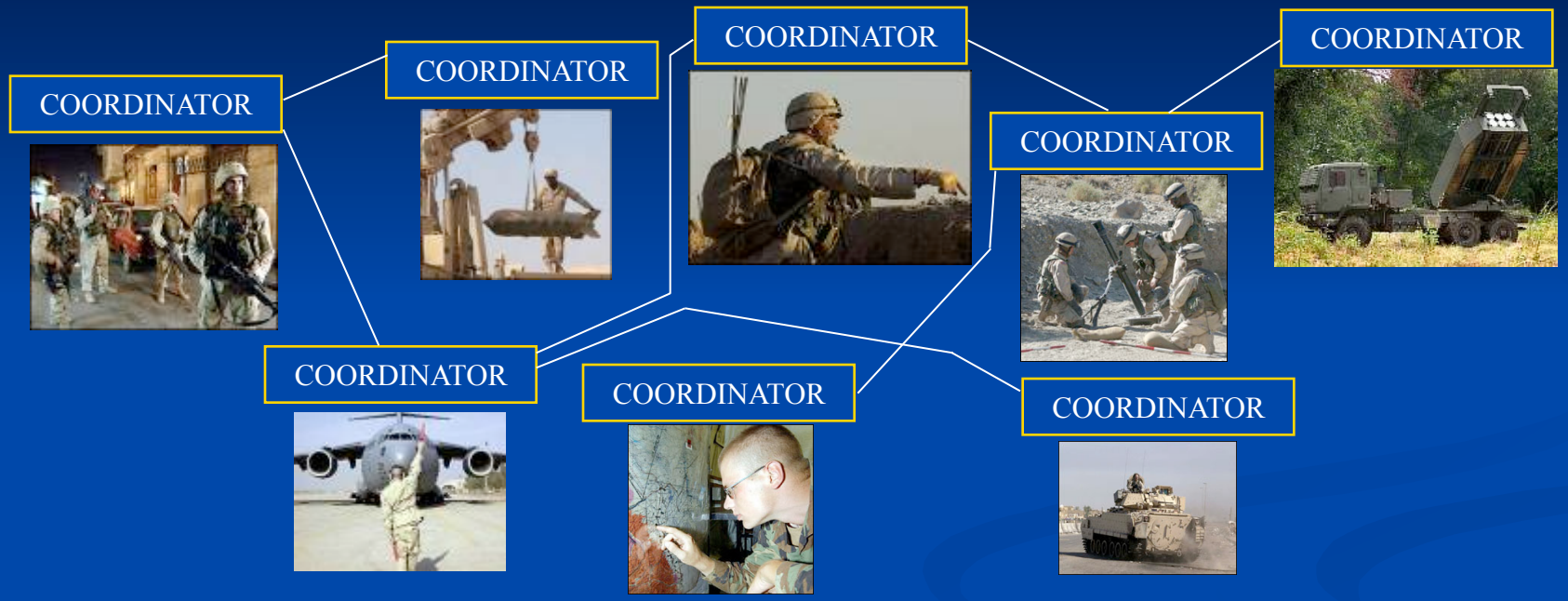
How to Construct Societies of Sophisticated AI Systems that Work Together Effectively



- Limited Bandwidth
- Lack of Global View
- Decentralized Control
- Autonomous, Asynchronous Subsystems
- Need for Cooperation

Why is this AI rather than Distributed Systems?

Example: DARPA Coordinators



Goal: enable units to adapt mission plans more rapidly, more accurately -- to be more tightly coordinated with less cognitive load.

Courtesy of Dr. Tom Wagner, Approved for public release – distribution unlimited.

Why This Model for Building Intelligent Systems vs. A Monolithic Approach?

- Geographical Distribution of Information, Resources, Expertise
  - Privacy in sharing information, fee-based services
- Modularity for Ease of Development, Debugging, Modification, Evolution

What is the Control Problem

Managing Interdependencies among Agent Activities

- What tasks to do, when, where, how
  - Limited communication and computational resources
- What information to communicate, when, to whom
  - Ubiquity of uncertainty – uncertain, out-of-date, incomplete information

How to do this in a globally optimal way

"Satisficing" vs. "Optimality"

A Model for Computation in the 21st Century

Network of cooperating, intelligent agents (people/machines)

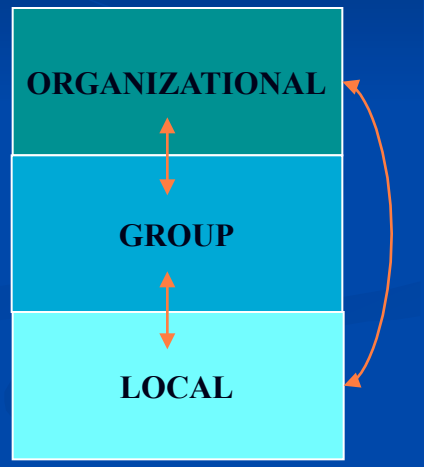
- Operate in a "satisficing" mode
  - Managing uncertainty as an integral part of network problem solving
- Highly adaptive and reliable
  - Self-aware agents
- Scaling to 100's to 1000's of agents
  - Organizational Control
  - Organizationally situated agents

What is the Lecture About

- Organizational control as one way to approach the scaling of AI Systems
  - *Organizational control is a multi-level approach in which long-term organizational goals and roles are used as guidelines for agents' detailed operational decisions*.
- Presenting interesting research topics associated with organizational control

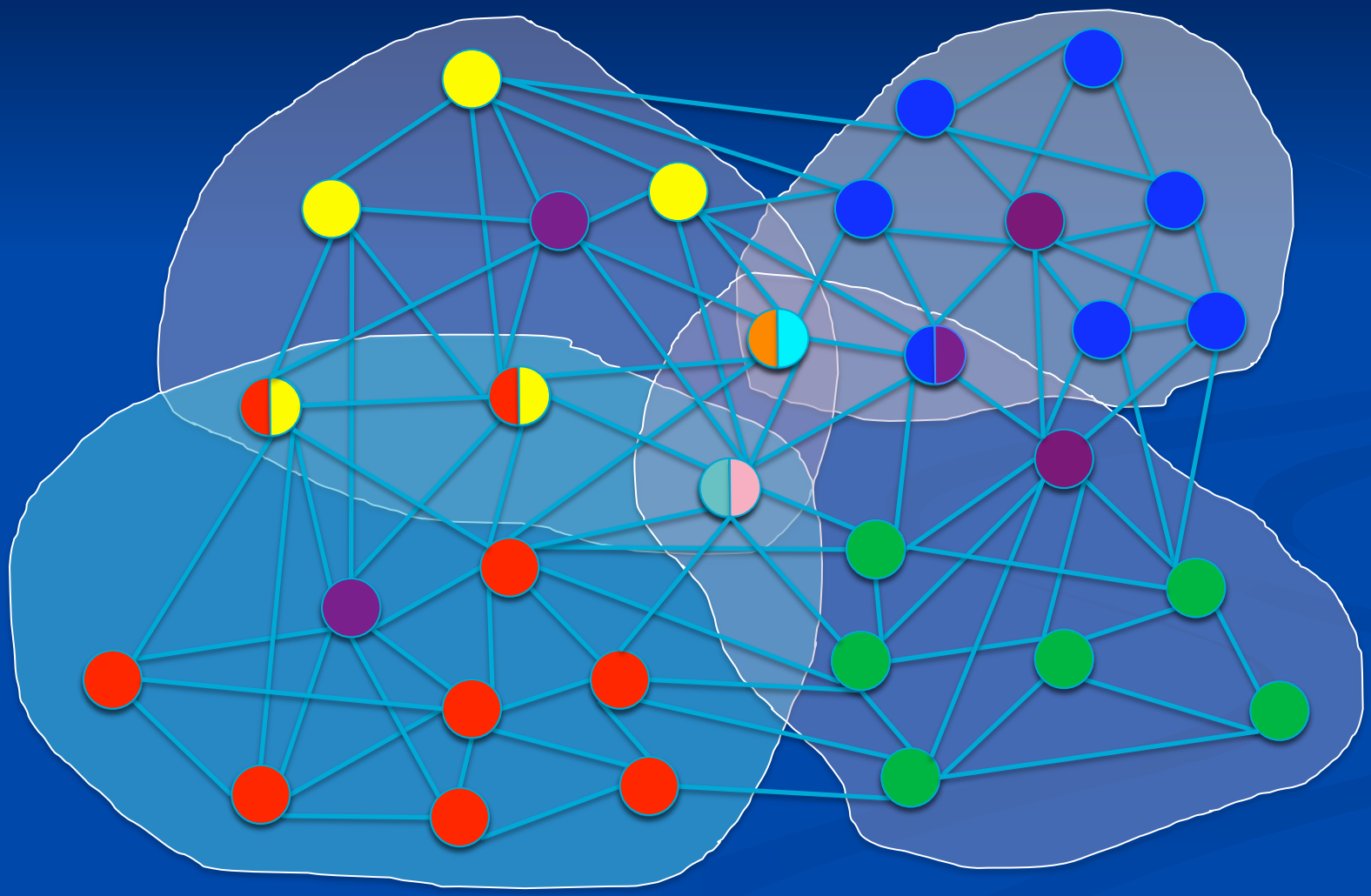
Multi-Layer Control Approach

- Organizational Control
  - Global and long-term perspective on system performance
  - Long-term (a-temporal) directives
- Operational Control
  - Limited and dynamic perspective
  - Short-term (temporal) decision in the context of organizational directives

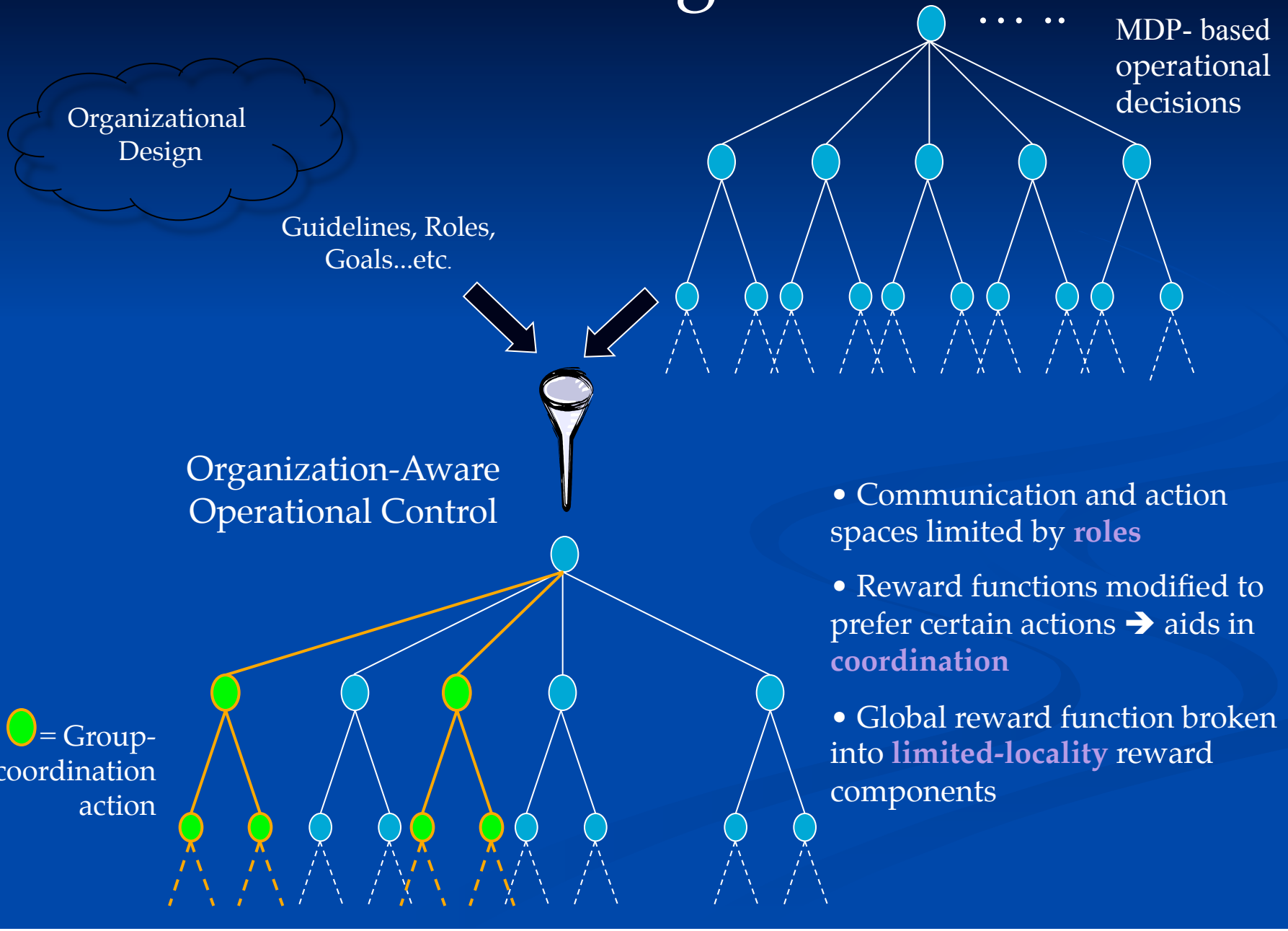


Org Control Subject to Ongoing Elaboration and Revision

Organizational Control



Network of MDP Agents



- Communication and action spaces limited by **roles**
- Reward functions modified to prefer certain actions ➔ aids in **coordination**
- Global reward function broken into **limited-locality** reward components

Why Does Organizational Control Work

- Repetitive and Nearly-Decomposable Nature of Problem Solving
- Knowledge of the Environment
  - Task Arrivals, Problem-Solving Behavior and Outcomes
- Semi-Autonomous Agents

Efficiency through Assumptions

Drivers for Organization Focus "Bounded Rationality"

- Organizational Control provides a framework for dealing with computational issues of scale
  - Decrease non-local information and reasoning necessary
  - Acting in accordance with guidelines leads to effective coordination decisions

Shift from an Agent-Centric, Operational View of Coordination to an Organization-Centric One

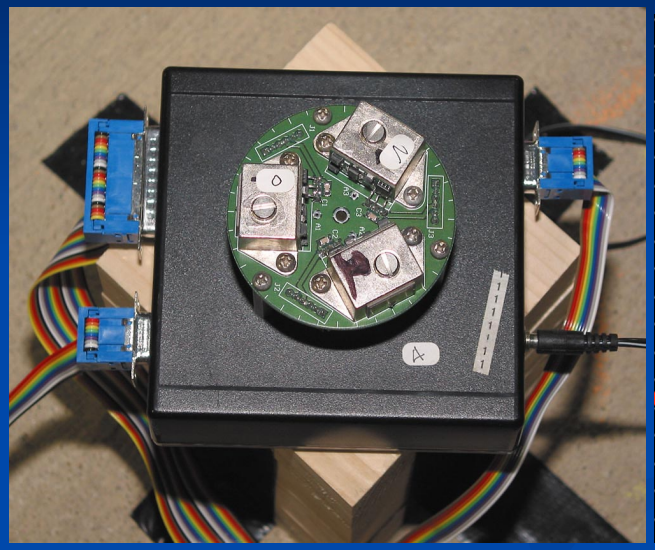
Example System – 1

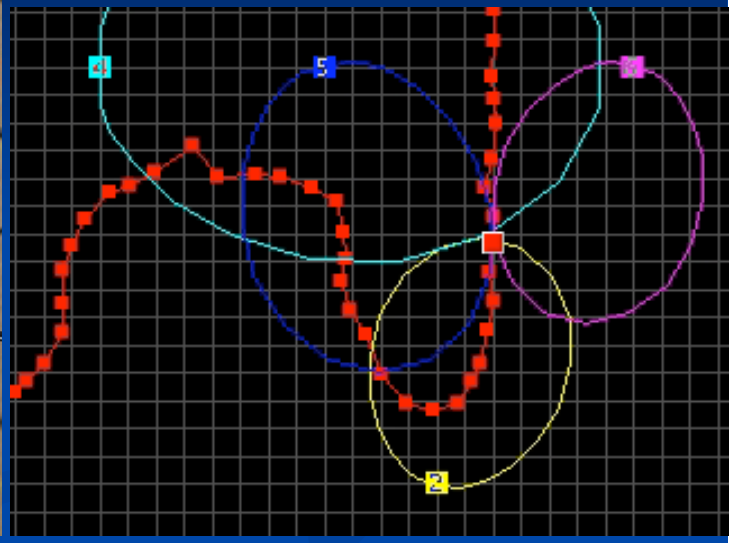
Adaptive, Real-Time Distributed Sensor Network for Vehicle Tracking (2004)

(Bryan Horling, Roger Mailler, Regis Vincent)

DARPA: Distributed Sensor Network Challenge Problem (2004)

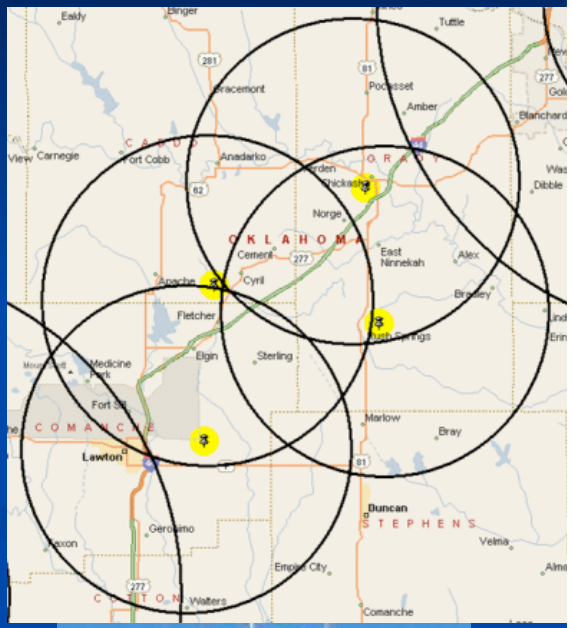
- Small 2D Doppler radar units (30's)
  - Scan one of three 120° sectors at a time
- Commodity processor associated with each radar
- Communicate short messages using one of 8 radio channels
- Triangulate radars to do tracking





CASA - Monitoring for Severe Weather (2008)

- Network of short-range (30 km), overlapping, adaptive weather-sensing radars
  - Small fielded system in Oklahoma
- Goal: Detect low-lying weather phenomena such as tornadoes within 60 second



How to Control the DSN

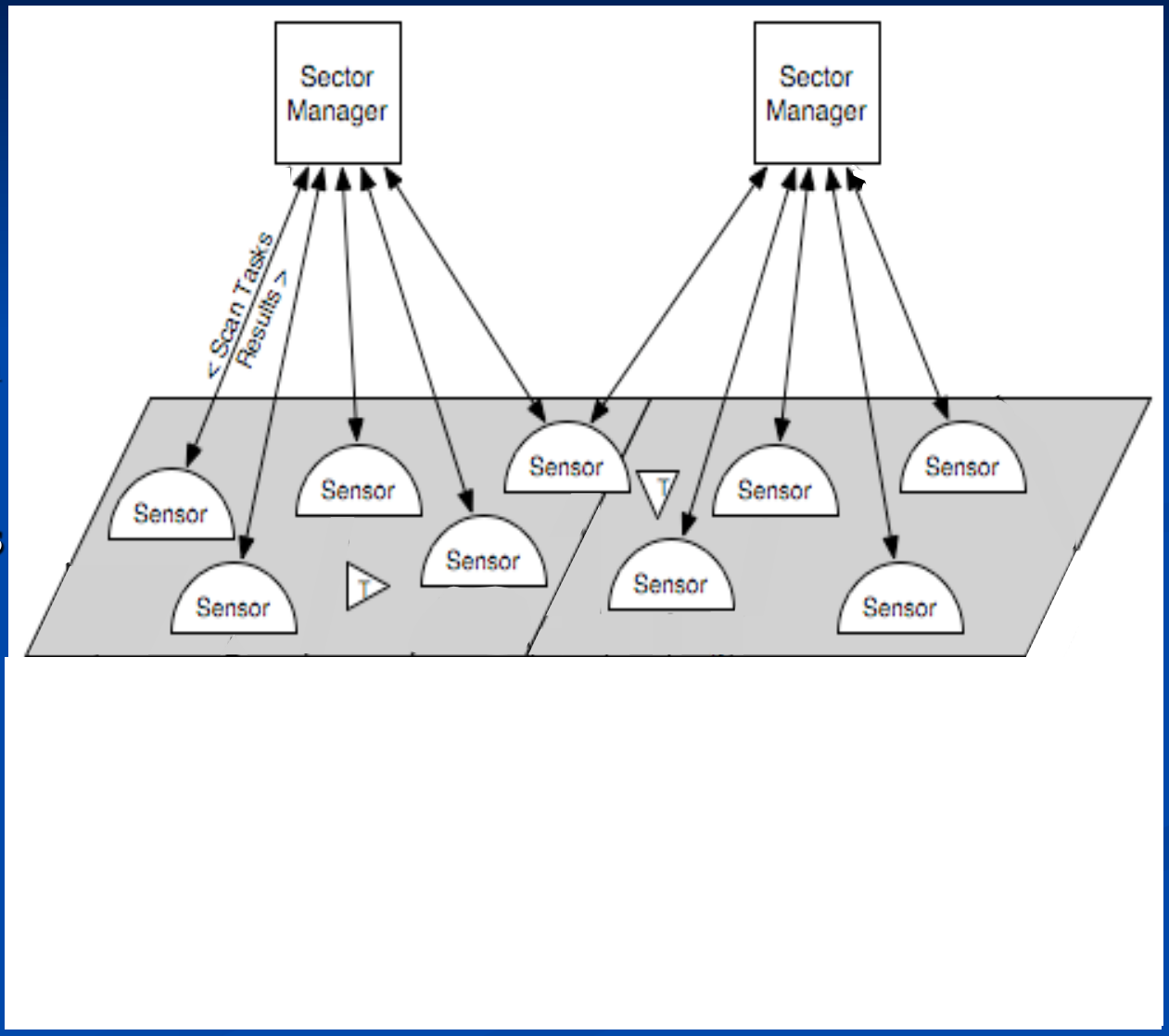
- **Scalability**: Hundreds of sensors, multiple targets, constrained communication

- *What if there were no (formal) organization?*
  - *Who decides if a target is new?*
  - *Who tracks a target?*
  - *How do trackers obtain sensor information?*

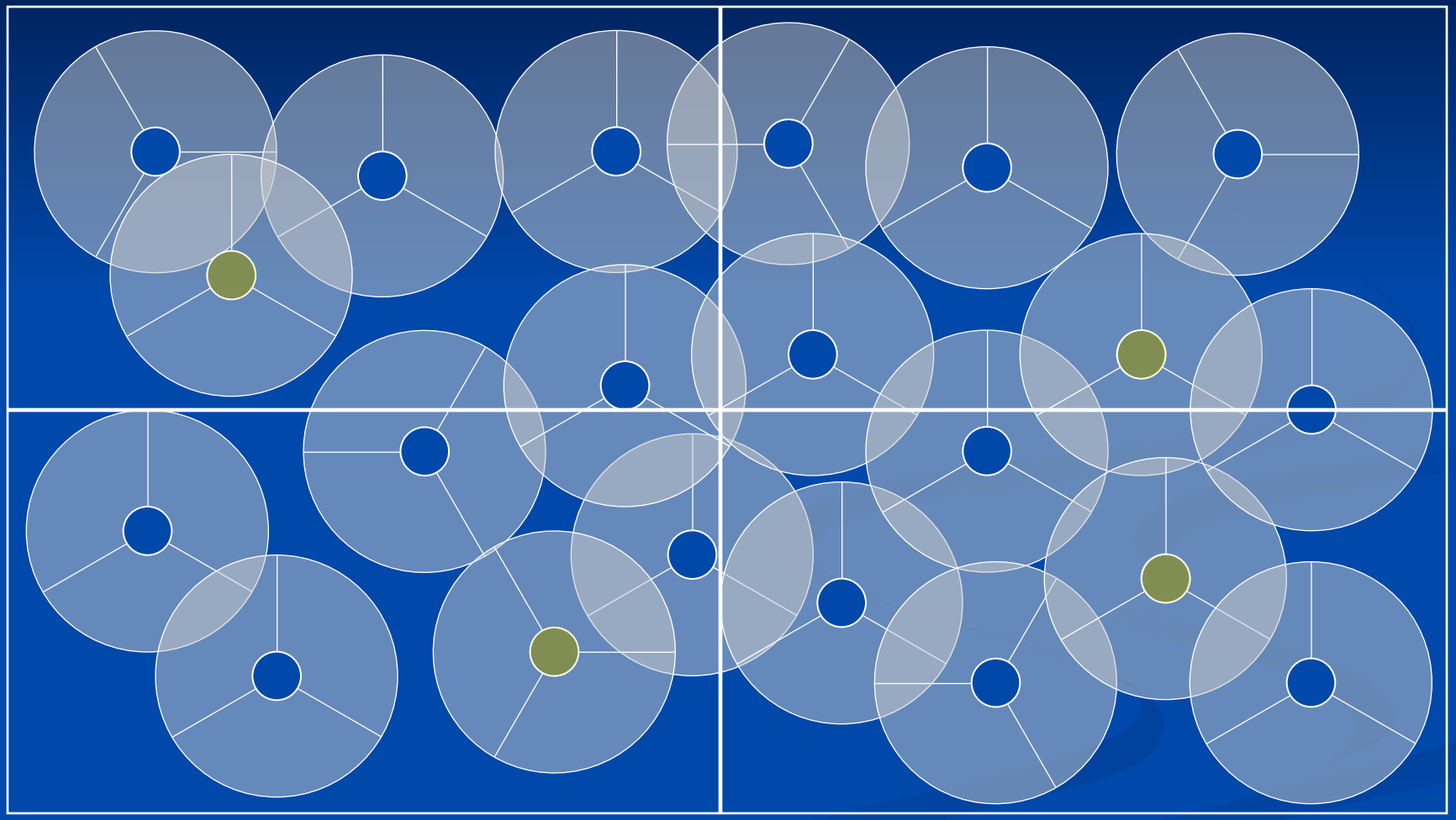
- These operational control decisions could be made individually by each agent, but through organization can be made easier

DSN Organizational Control

- **Partitioned Environment**
  - Sectors
  - Constrains info. propagation
  - Reduces information load
  - Exploits locality
- **Agents assigned roles**
  - Sensor (Scan/Track)
    Sector Manager
    Track Manager
  - Limits sources of information
  - Facilitates data retrieval

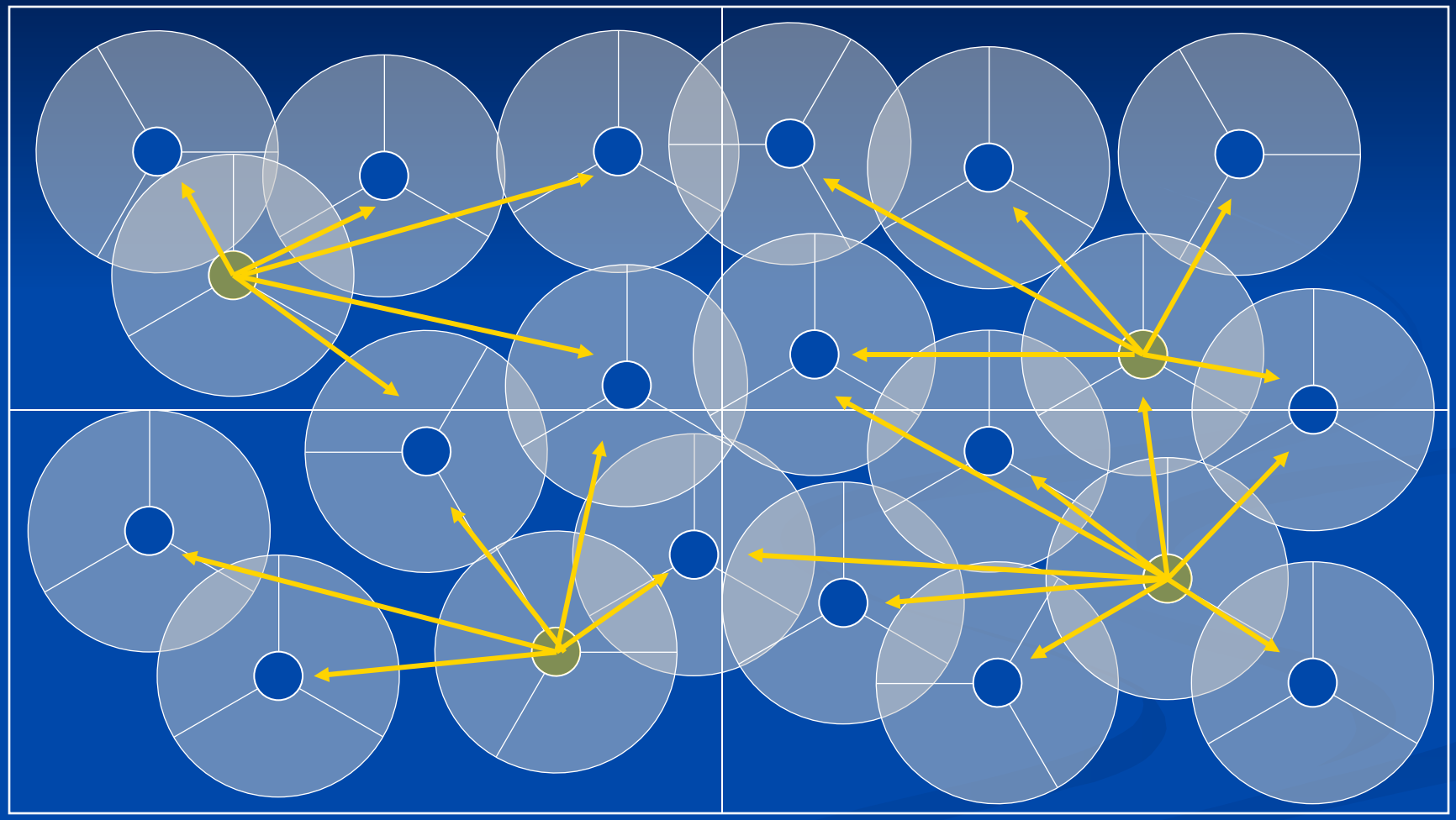


Partitioning of Nodes



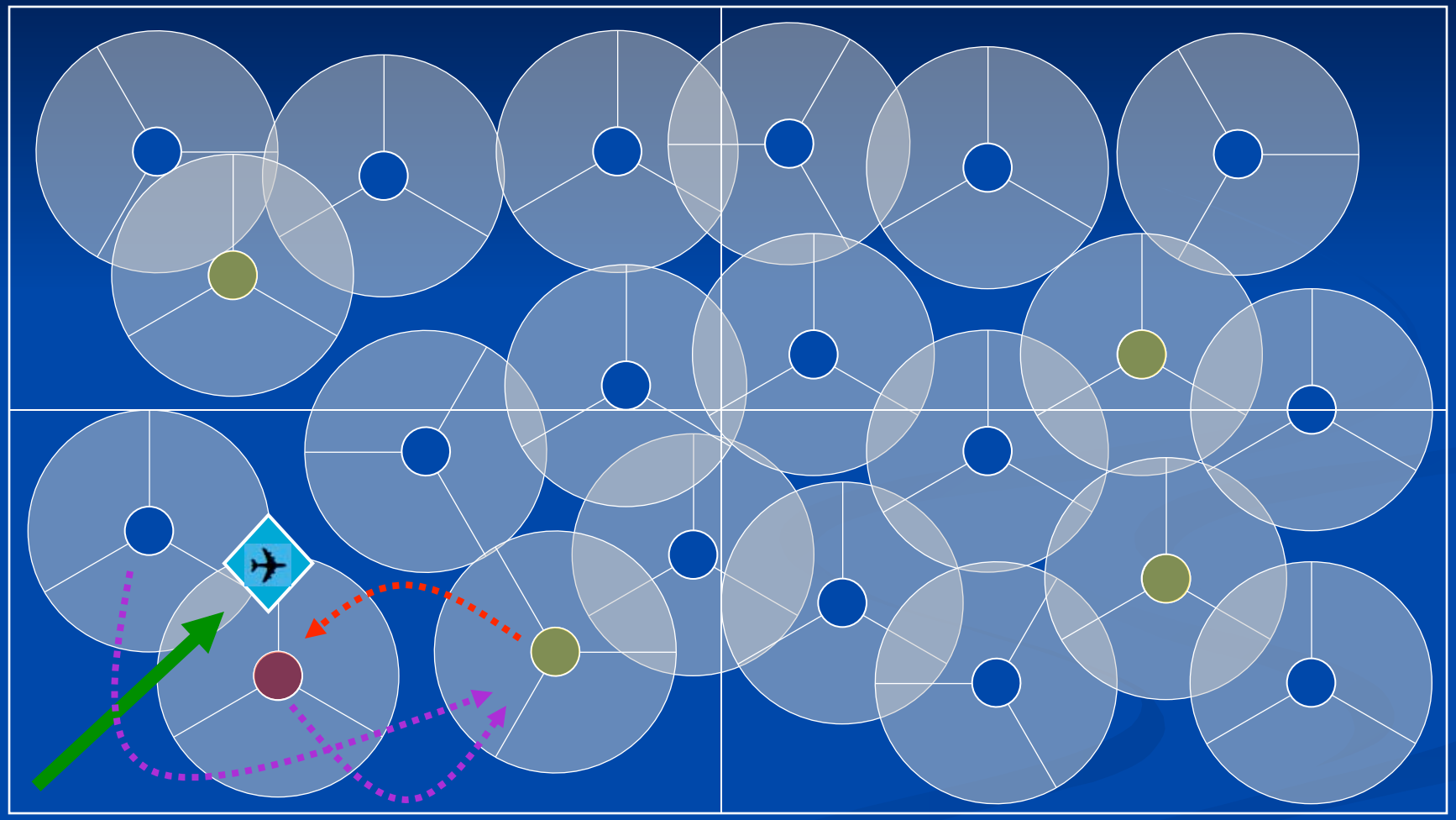
- The environment is first partitioned into sectors.
- Sector managers are then assigned.

Competition for Sensor Agents



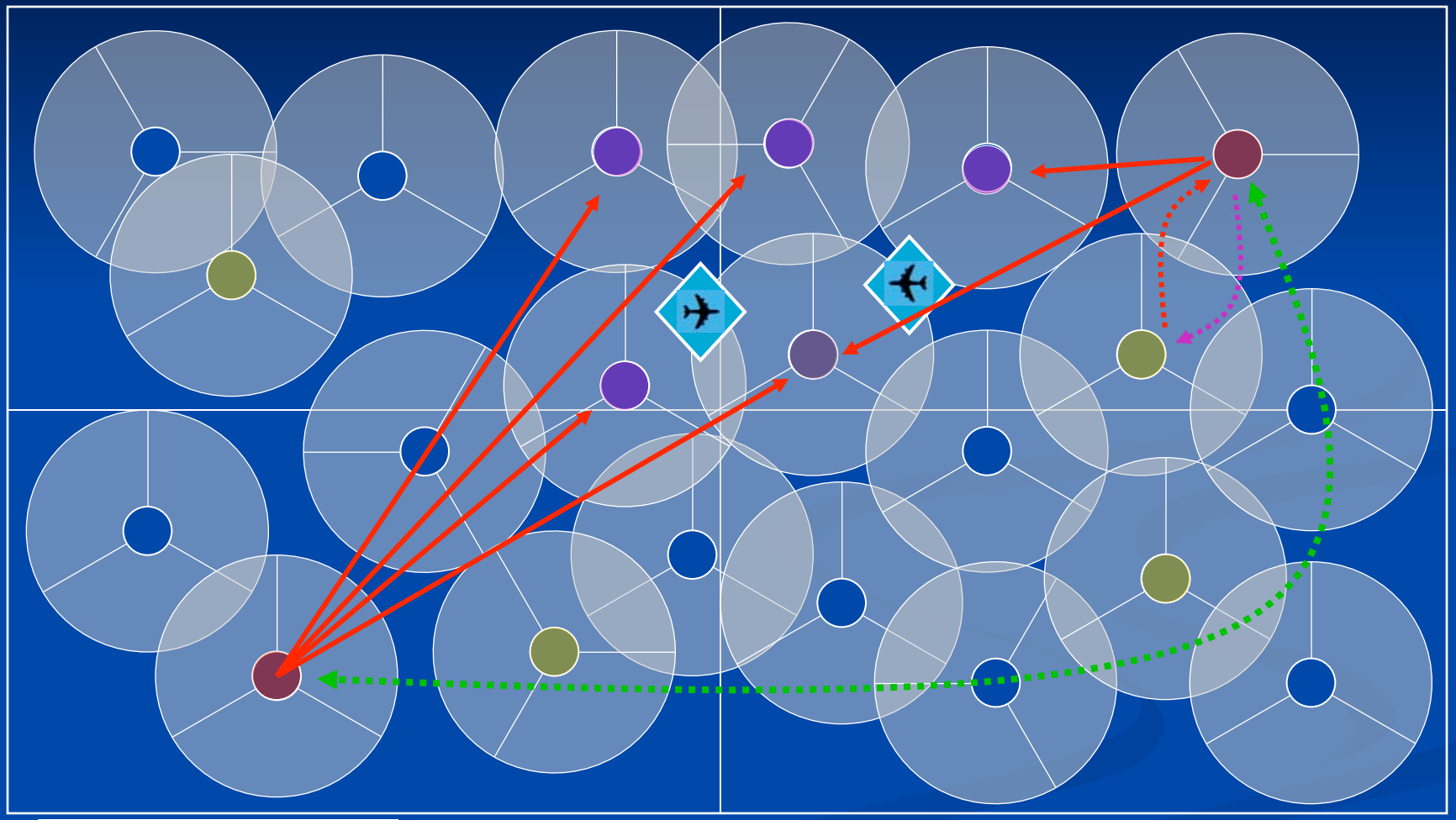
- Sector members send their capabilities to their managers.
- Each manager then generates and disseminates a scan schedule.

Track Manager Selection



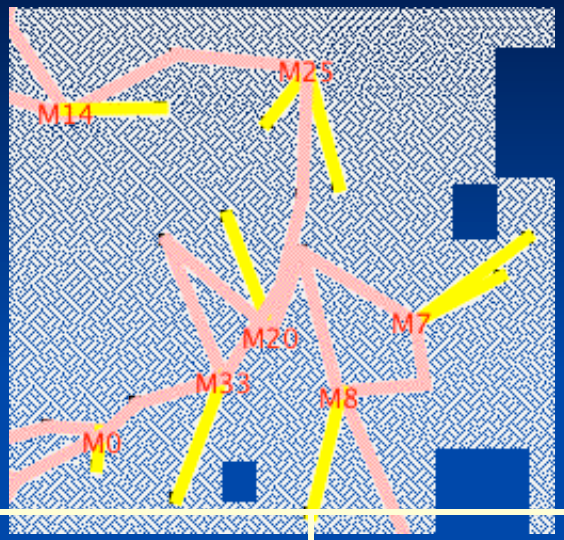
- ***Nodes*** in the scan schedule perform scanning actions.
- Detections reported to ***Manager*** and a ***Track Manager*** selected.

Managing Conflicted Resources



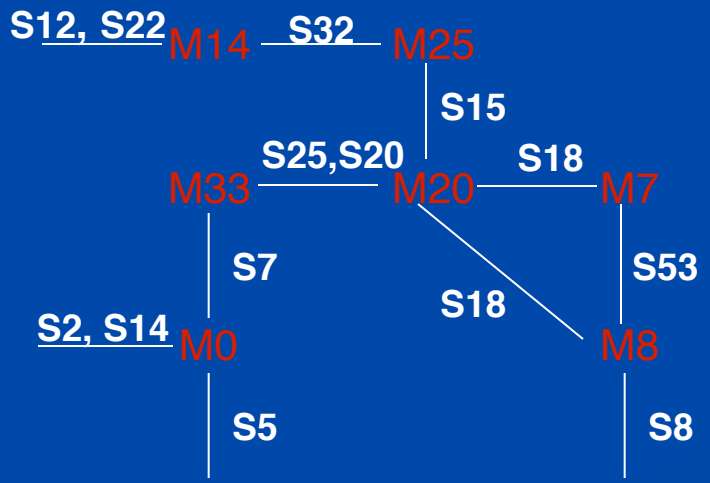
- ***Track Manager*** discovers and coordinates with ***tracking nodes***.
- New tracking tasks may conflict with existing tasks at the ***node***.

SPAM: Mediation-Based Negotiation

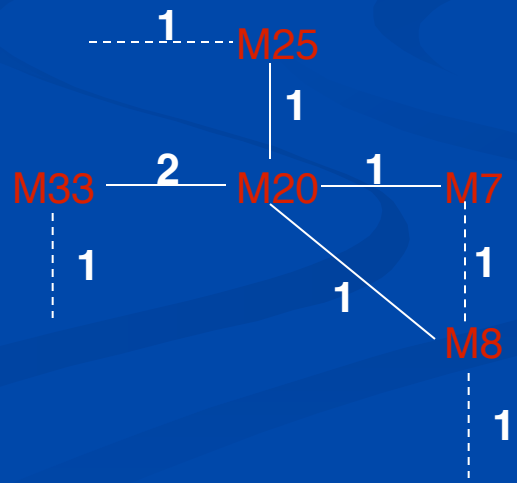


World View-Multi-Linking of Resource Allocations

Interdependency Graph

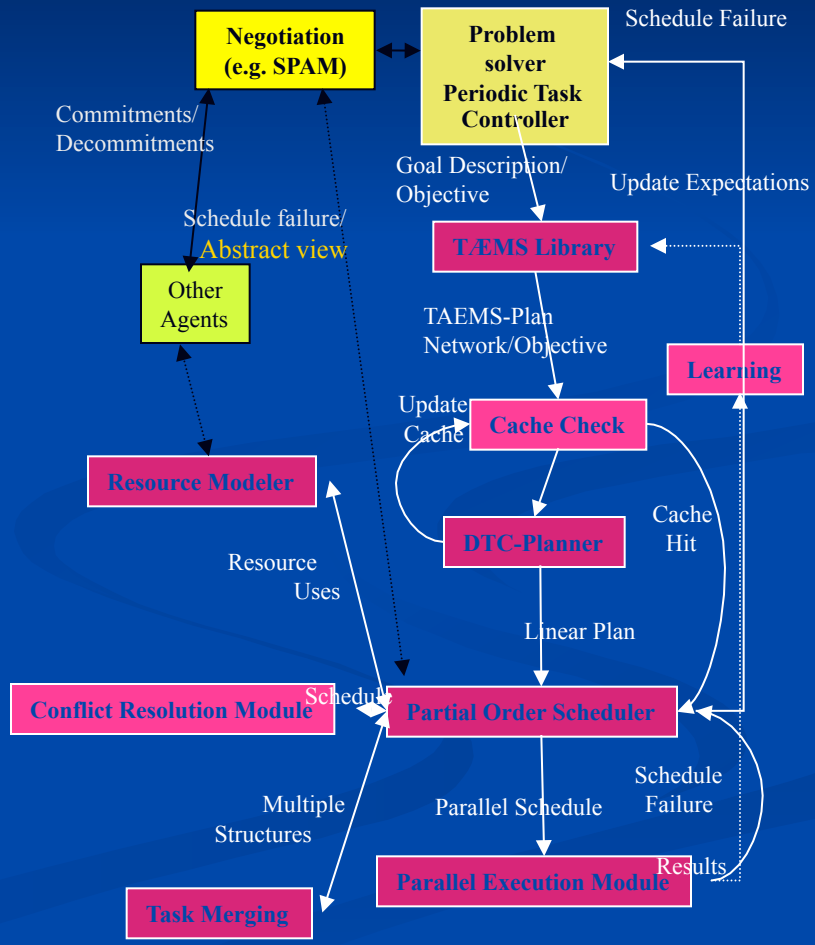


Mediator View



SRTA: Soft Real-Time Agent Architecture

- Mapping Org and Dynamic Coordination Guidelines into Operational Decisions
  - Guidelines into detailed resource allocations
  - Resolve conflicts locally not resolved

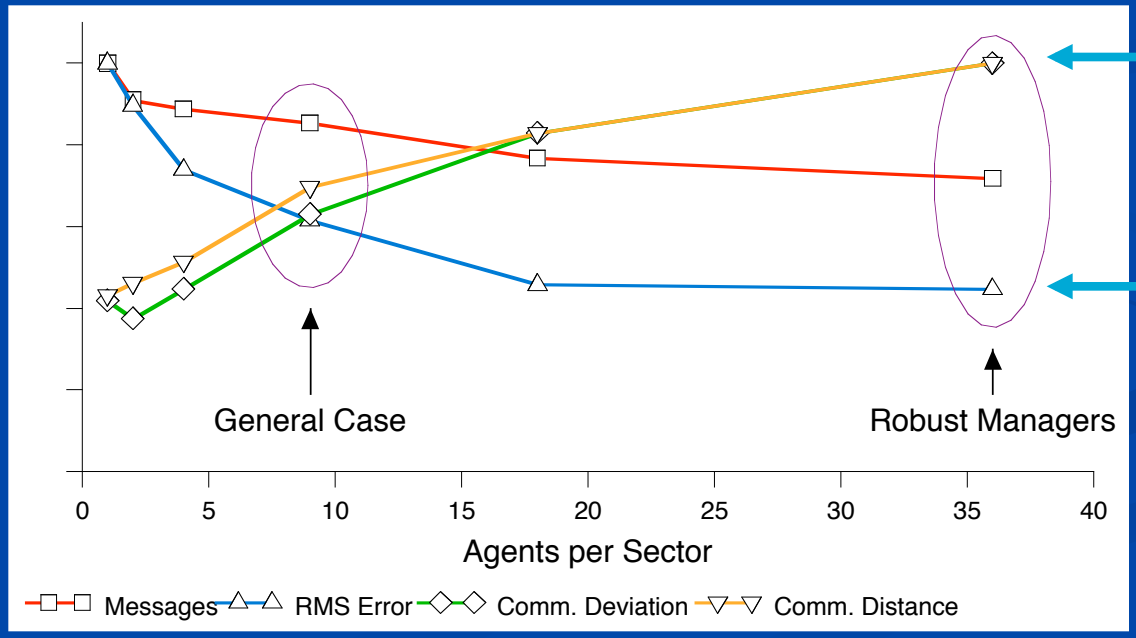


What Does Organizational Control Accomplish

- Managing Resource Contention
  - Sensors, processors, communication
- Centralizing Information in Sector Manager
  - Handling data correlation with multiple tracks
- Fault Tolerance
- Communication Locality for Tracking

Organizational Trade-Offs

- How big should sectors be?
- Empirical evidence: between 5-10 sensors
- This would vary, depending on sensor and environmental characteristics



Deviation
(high = bad)

RMS Error
(low = good)

Some Additional Thoughts

- Org Control is tightly integrated with control capabilities of agents
  - Semi-autonomy of local decision making
- This is a small part of the story
  - Re-organization based on sensor / communication failure, changing task environment
  - More complex control hierarchy needed where there is more long-distanced interdependencies

Example System - 2

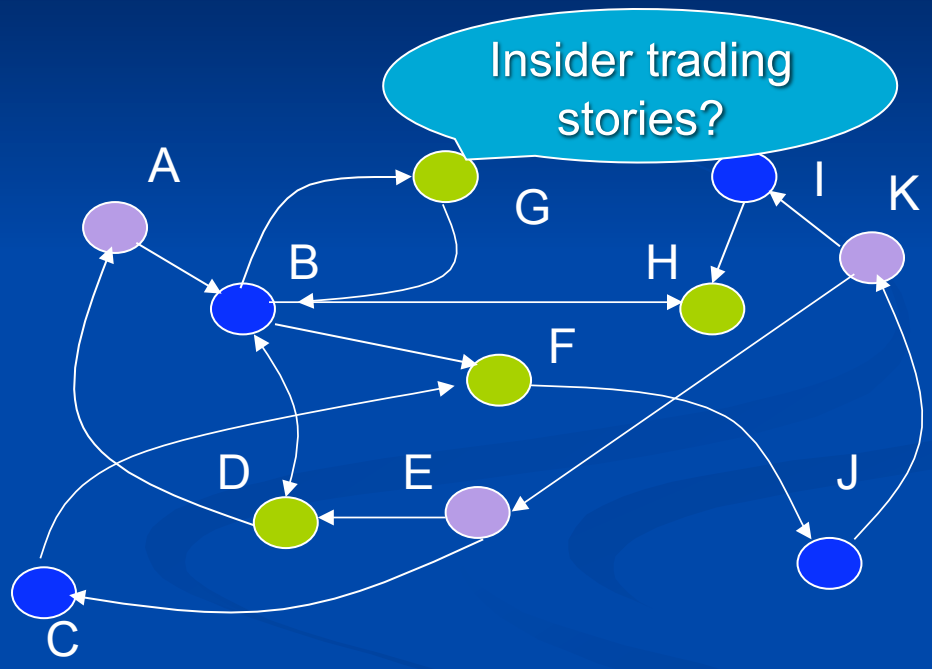
Information Retrieval in a Peer-to-Peer Network (2007)

(Haizheng Zhang, Bryan Horling)

Information Retrieval in a Peer-to-Peer Network

Problem Description:

Minimize communication and processing costs to acquire a sufficient set of relevant documents



Challenges:

- Content distribution is arbitrary
- Agents limited view of content distribution
- Queries arrive concurrently at different agents

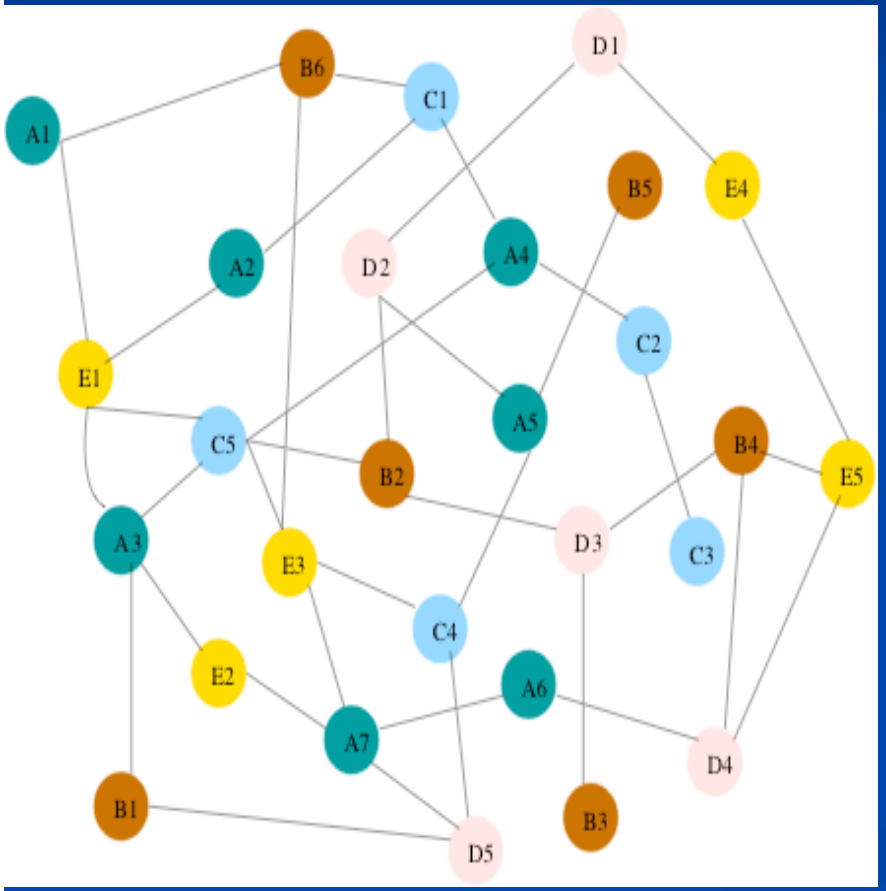
American Patent DB
Wall Street Journal
Associated Press News

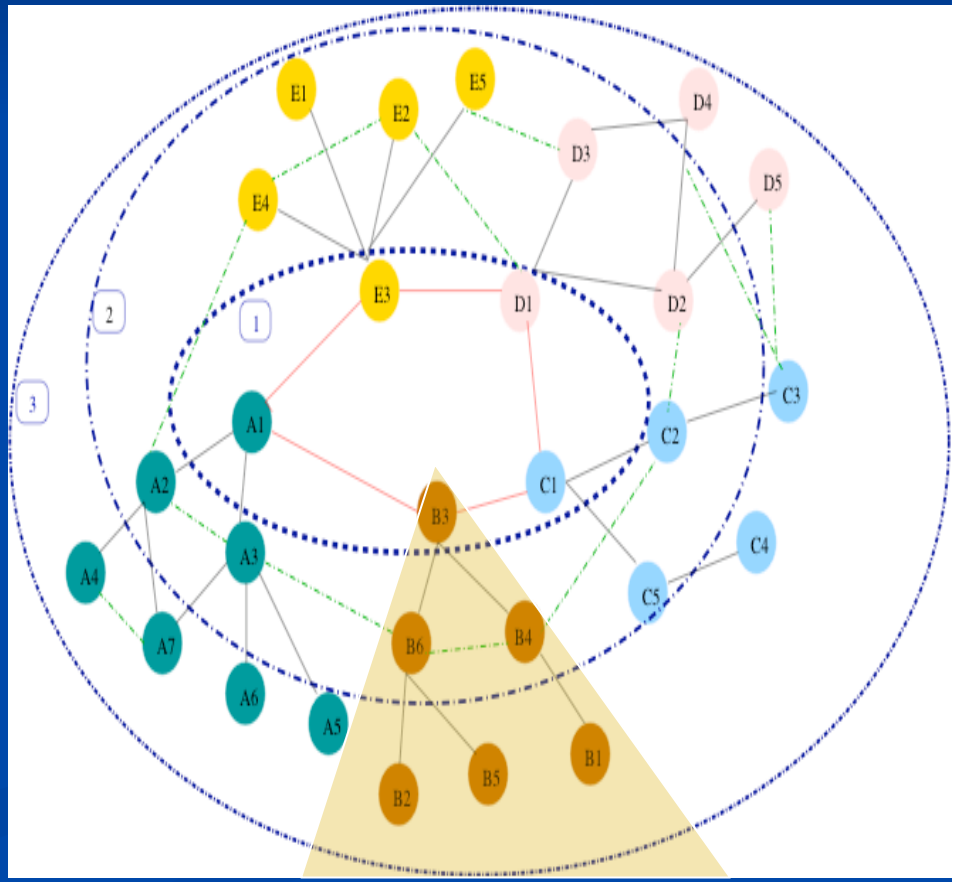
Organization for Peer-to-Peer Content Retrieval

Virtual Overlay

Initial and Unstructured Peer-to-Peer Network

Nearly-Decomposable Hierarchy of Content Mediators

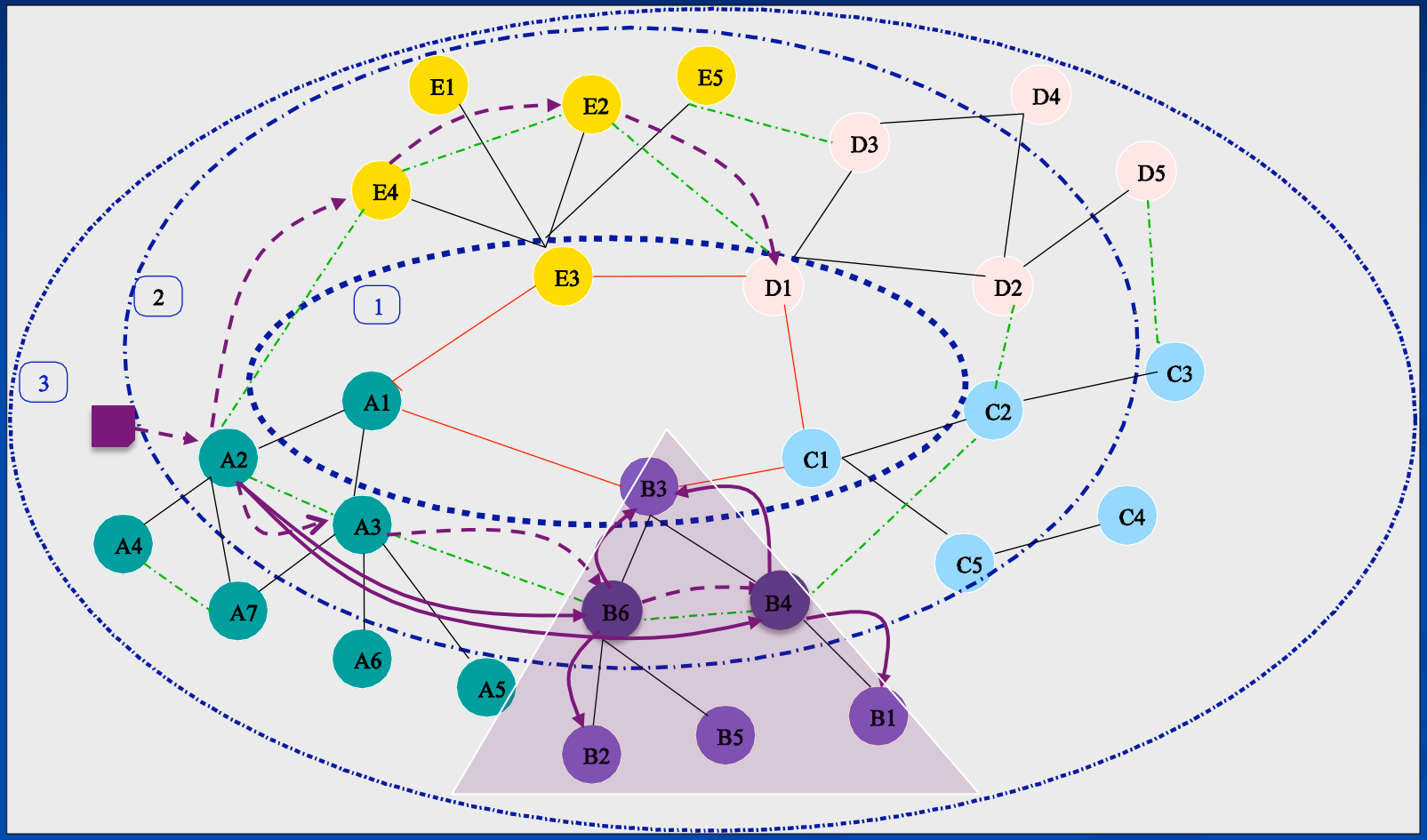




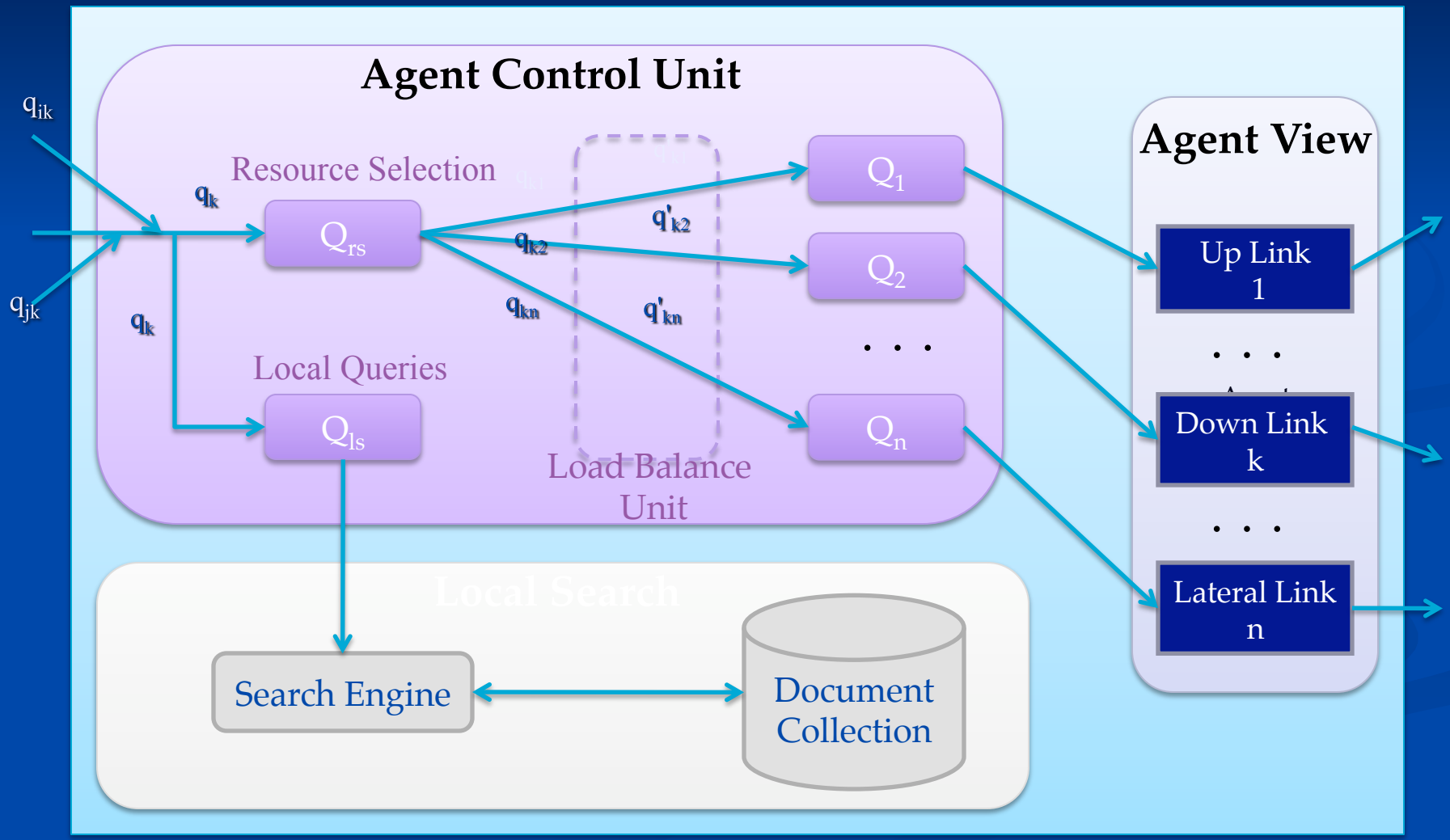
Content-Based Hierarchical Agent Organizations

- Group agents of similar content
  - Limit subset of agents to be probed
  - Add lateral links to quickly locate diverse content
- Incremental construction of the organization as new agents join network
- A two-phase search algorithm
  - Locate relevant hierarchical agent clusters
  - Perform searches in clusters

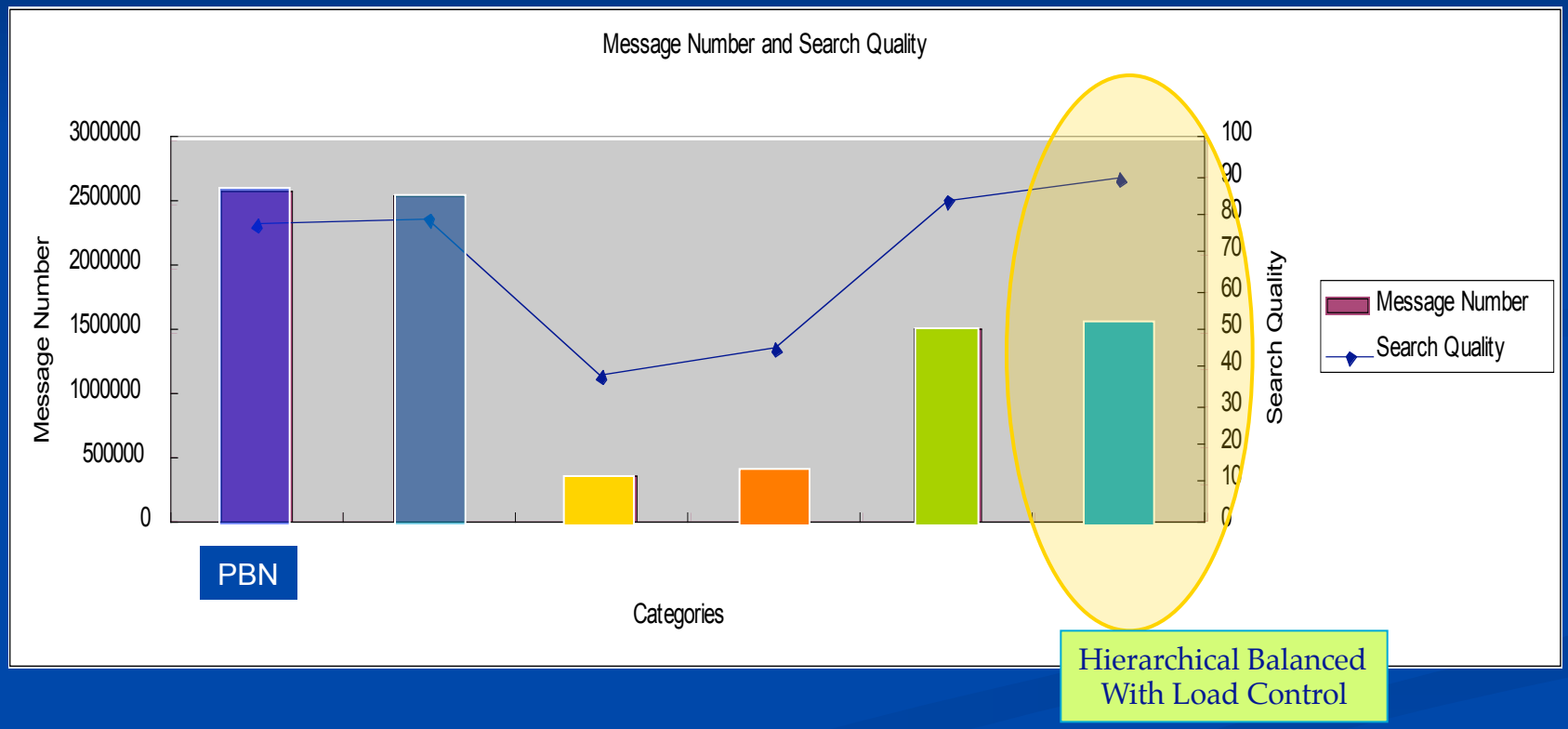
Two-Phase Search Protocol



Internal Agent Structure



Experimental Results (TREK 921 Nodes)



Search Quality versus Number of Messages

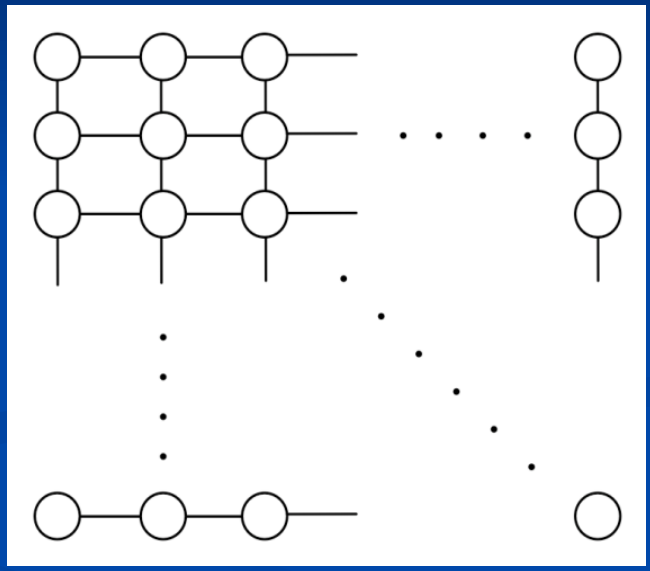
Example System - 3

Distributed Resource Allocation for Computational Services (2009)

(Chongjie Zhang, Sherief Abdallah)

Example System - 3

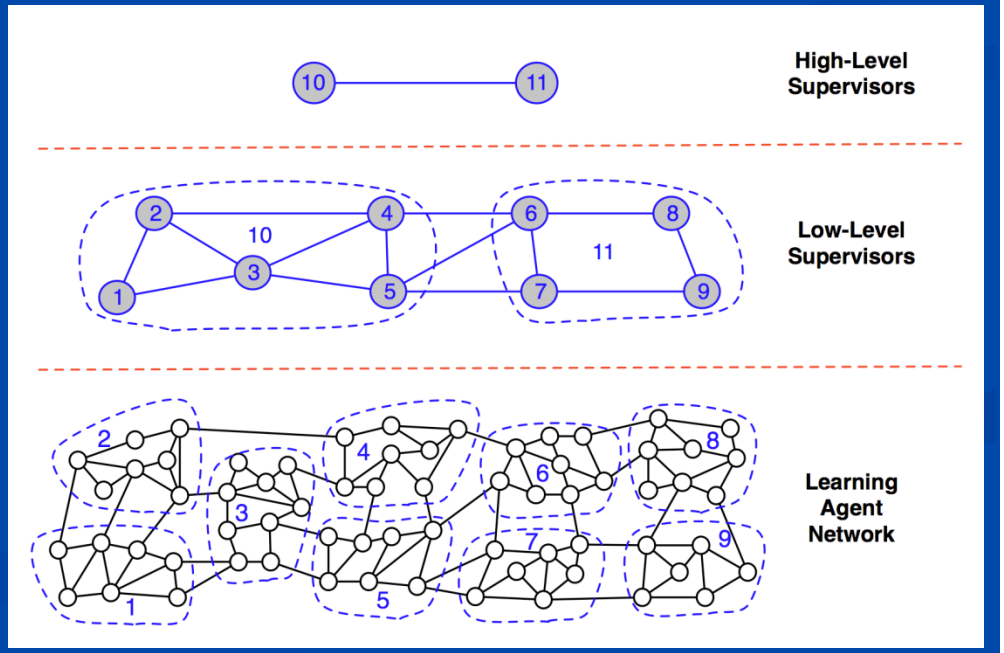
- Distributed Resource Allocation for Computational Services



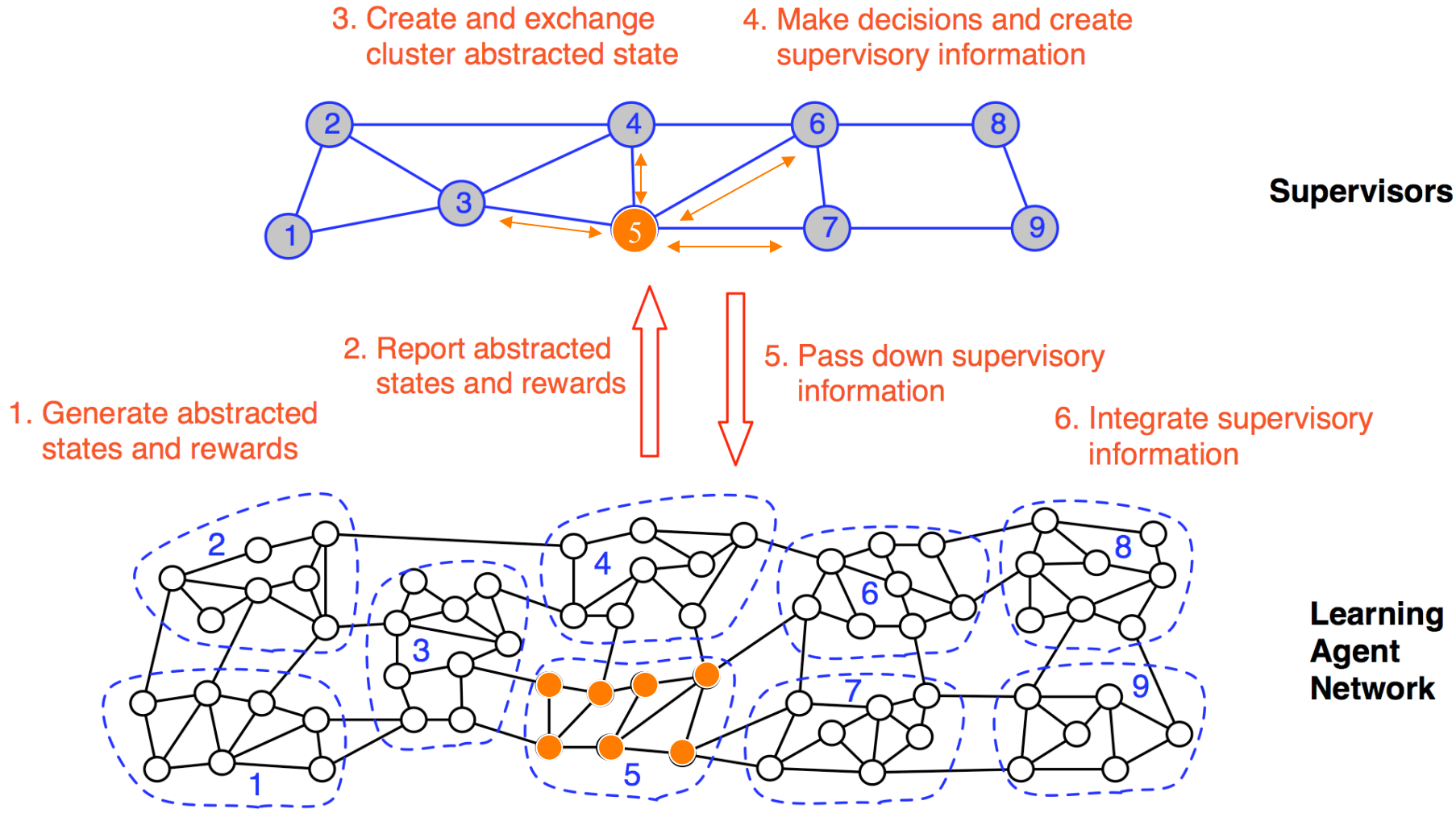
Chongjie Zhang, Sherief Abdallah, 2009

Integrate Organizational Control into Multi-Agent Learning

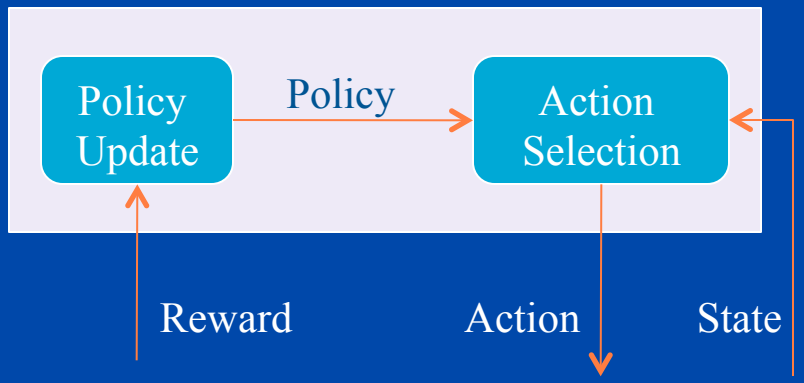
- Convergence in large-scale settings is challenging — speed, likelihood and quality.
  - Non-stationary learning environment
  - Partial view and no global reward signal
  - Communication delay



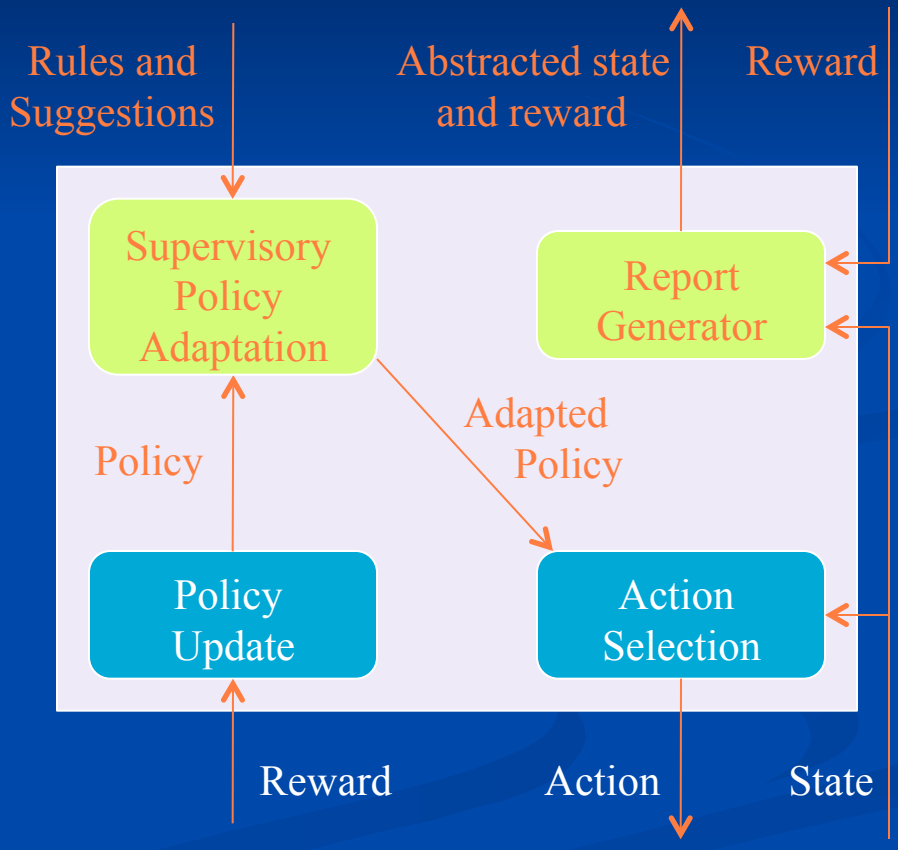
Organization-Based Control Framework



Integrate Supervisory Information into Multi-Agent Learning

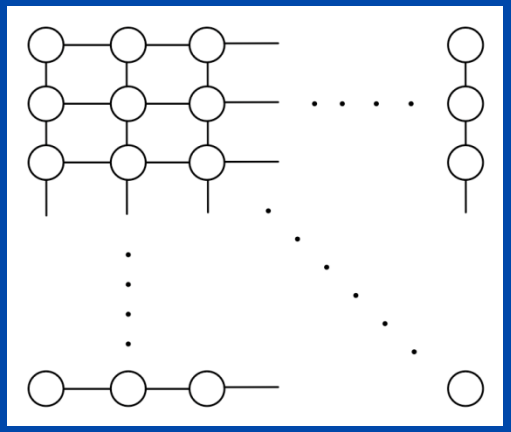


(a) Multi-Agent Reinforcement Learning (MARL)

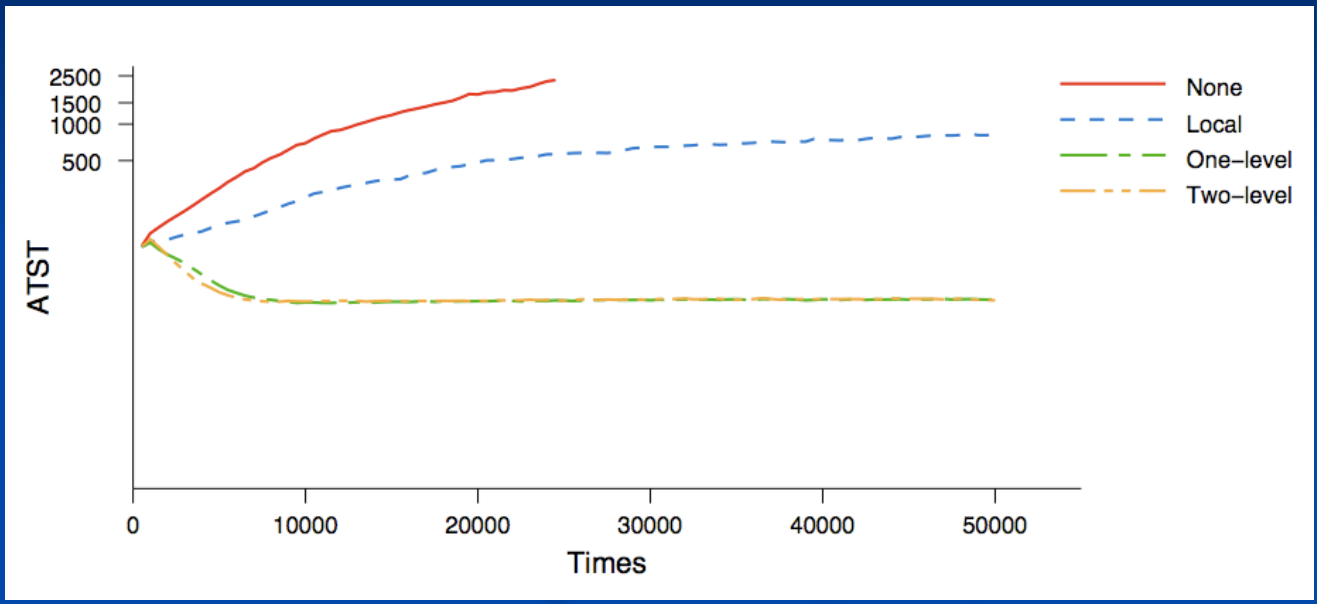


(b) MARL under Supervision

Experiments: Distributed Task Allocation Problem (729 agents)



27 X 27 Agent Network



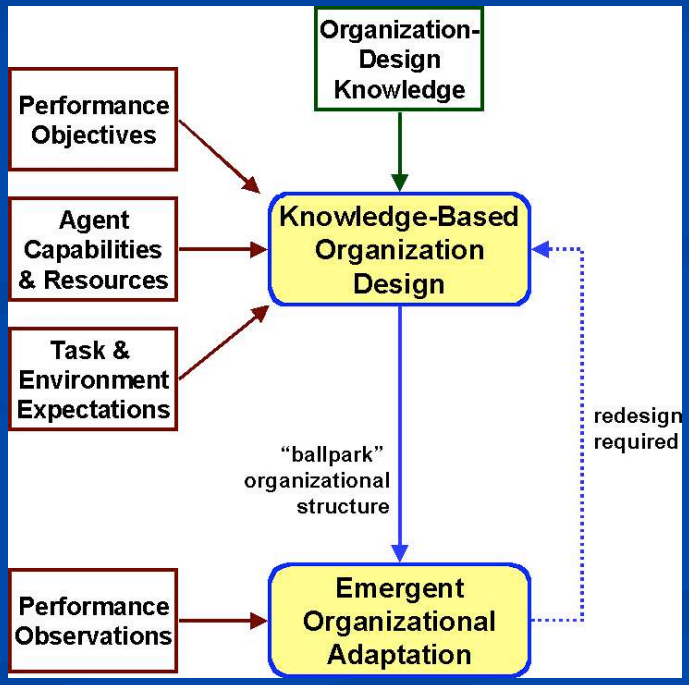
Supervision	ATST	AMSG	TOC
None	N/A	N/A	N/A
Local	N/A	N/A	N/A
One-level	33.41 ± 0.66	10.21 ± 0.25	7500
Two-level	34.08 ± 0.62	10.60 ± 0.22	6000

What Do These Examples Tell Us

- Organizational Control can be used in scaling of very different types of AI problem solving
- Flexibility and adaptability of control decisions at all levels is important
- Very early in our understanding of how to effectively exploit this approach

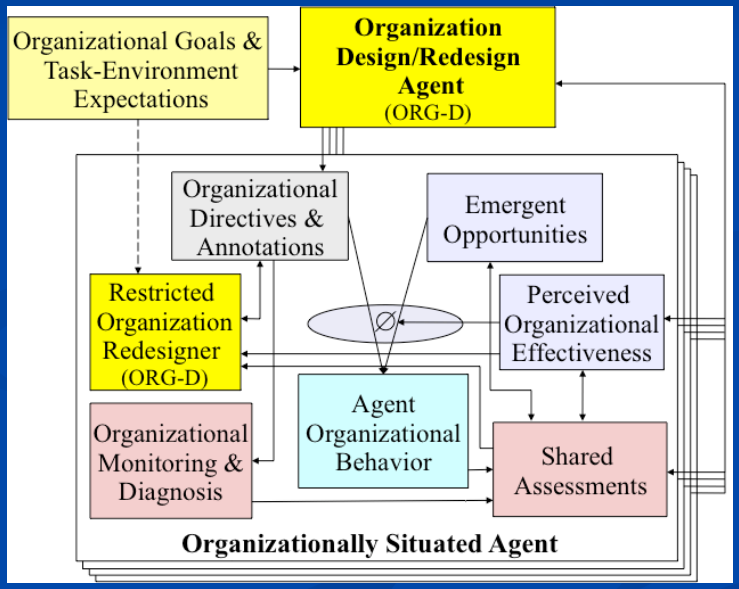
How to Create an Organization

- Top-Down
- Emergent / Self-Organizing
- Some Combination



What Constitutes an Organization

- What is the Role of Institutional Mechanisms
  - Computational artifacts for control
- What Type of Agents
  - Cooperative
  - Self-interested
  - Semi-cooperative



- What is an Organizationally Situated Agent

MAS and Human Organizations

- Relationship between MAS and Organizational Structuring from a business/ sociological perspective?

- Are emotions effective computational mechanisms?
  - Skepticism – limits effect of info distraction
  - Boredom – avoid over-learning of routine tasks
  - Self-interest – decision making without global impact

Can you Automate the Organizational Design Process?

- Theory behind organizational design
  - The nature of sub-problem interdependencies
- Designing for multi-attributed nature of organizational performance
  - Reliability, fail-softness, adaptability
- Predicting the performance of a computational organization
- Specialness of the search process for finding a good organization
  - Repetitiveness of structure

The Human in the Loop

- How can computational organizations be controlled by people
- How can human and computational organizations interact
- What is the implication for how we see ourselves and others

Summary

- Organizational Control is important in how we think about scaling AI systems
- Organizational Control is an intrinsically interesting problem that deserves our intellectual attention