Command and Control of Autonomous UxV's

June 2005

Chad Hawthorne
Dave Scheidt

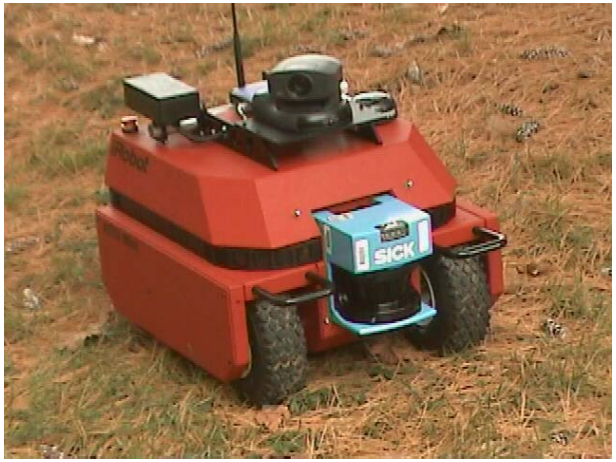
Applied Physics Laboratory

Information Technologies Group

- **University-Based Applied Research and Development Laboratory**
- **Focus on National Security**
- **Major Effort in Space Science and Technology**
- **Partner in Johns Hopkins Commitment to Education and Medicine**
- **~3,350 Staff**

Future Unmanned Battlespace

Information Technologies Group



- Thousands of UxV's and stationary unmanned sensors
- Hundreds of flavors of UxV's and sensors (heterogeneous environment)
- Significant increase in automation required
- Human operators will provide high-level goals to UxV's for autonomous operation

Challenges

- To achieve the future unmanned battlespace:
  - Autonomous vehicles
  - Sensor and UxV's coordination
  - Robust to failure (communications, hardware, peer)
  - Long operational periods
  - Decentralized control
- APL areas of work:
  - Autonomy
  - Simulation
  - Decentralized Communications
  - Command and Control

Decentralization

- New techniques in control of Unmanned Vehicles and a decentralized computing environment require rethinking of C2
  - Decentralized AI
    - Behavior Based System
    - Swarming
  - Decentralized computing environment
    - Mesh networks
    - Service Oriented Architectures
  - Decentralized Command and Control
    - Heterarchical organization

Decentralized AI

- Swarming as AI Solution
- Biological systems provide insight on problems
- Swarm of ants
  - Decentralized control
  - Massively distributed
  - Robust to failures
  - Self organizing, Self regulating

- Ants maintains own “world model”
- UxV are agents in the swarm

Swarm AI Behavior

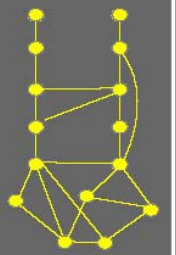
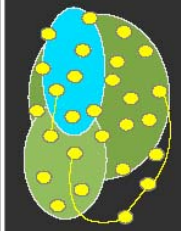
Stigmergy – “a method of communication in decentralized systems in which the individual parts of the system communicate with one another by modifying their local environment.”

Examples: Flock of Birds, Wolf Packs, Foraging Ants

Decentralized Computing

Information Technologies Group

Platform Evolution

	Client-Server	3/N-Tier	Net Apps	Net Services	Next	After that
Catch Phrase	The Network Is the computer	Objects	Legacy to the Web	The Computer Is the Network	Network of embedded things	Network of Things
System Collections Components						
Scale	100s	1000s	1000000s	100000000s	1000000000s	10000000000s
When/Peak	1984/1987	1990/1993	1996/1999	2001/2003	1998/2004	2004/2007
Leaf Protocol(s)	X	X	+HTTP (+JVM)	+XML, Portal	+RMI	Unknown
Directory(s)	NIS, NIS+	+ CDS	+ LDAP (*)	+UDDI	+ Jini	+ ?
Session	RPC, XDR	+CORBA	+CORBA, RMI	+ SOAP, XML	+ RMI/Jini	+ ?
Schematic						

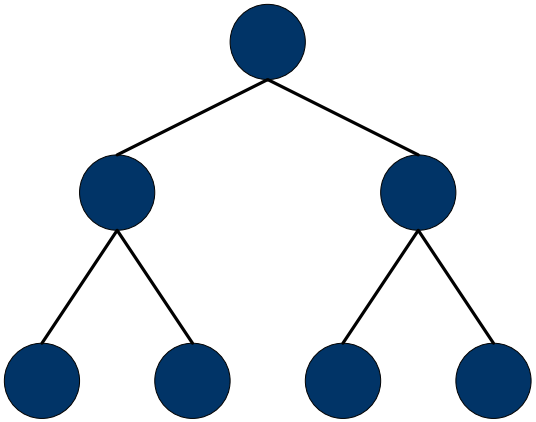
SLID 2004-0258

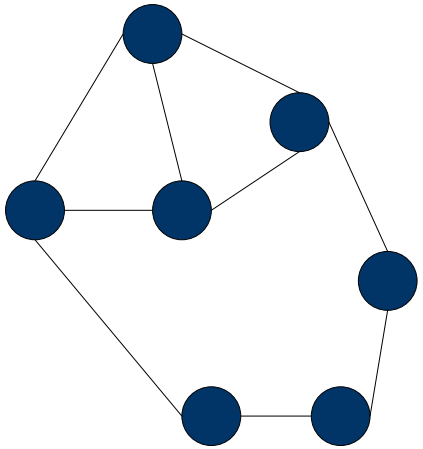
Decentralized C2

- Historical Examples
  - Napoleon during Ulm Campaign
  - Japanese in Kamikaze Attacks
  - Germans in Battle of Atlantic
- Organizations operate most efficiently when command structure match their mission environment.
  - Decentralized AI
  - Decentralized Computing

Swarming as a C2 Solution

- For C2 environment to match mission environment, we must move from Hierarchical to Heterarchical Control
- Benefits of Heterarchical C2
  - Ability to perform a task is independent the organizations size
  - The decision loop is less than that in hierarchical C2 systems
  - The group as a whole is more survivable





High-Level Goals

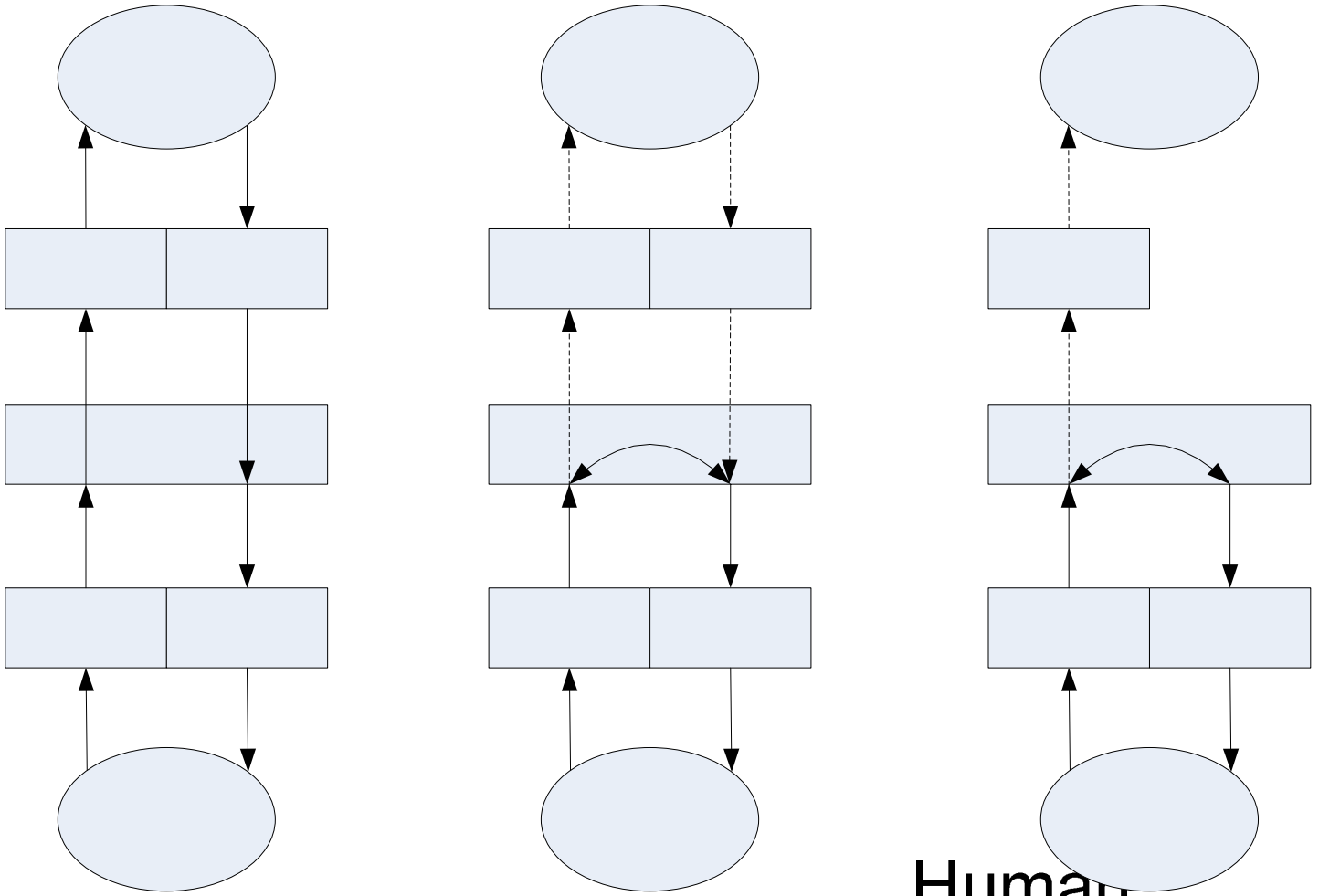
Warfighter Ground Station

Human On the Loop

Information Technologies Group

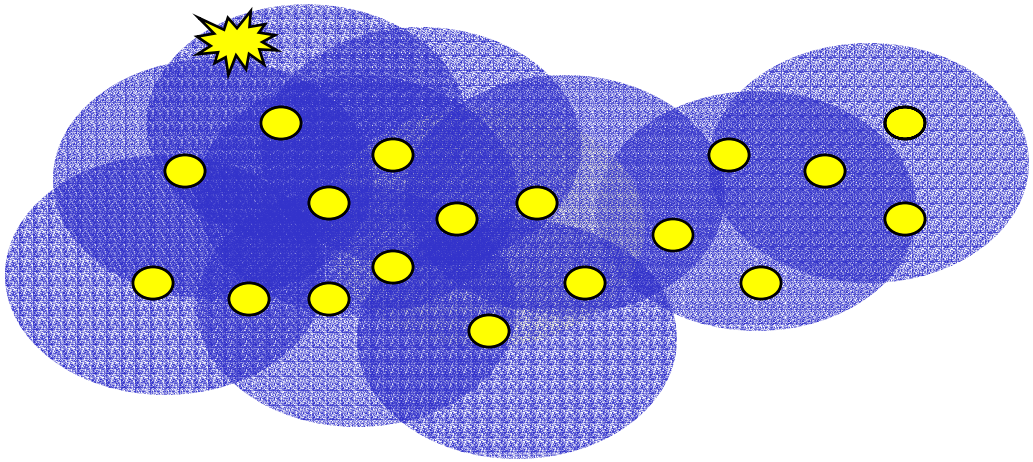
Automation

Human On the Loop



Propagation Network

- Platform Independent
  - UGV, UAV, Windows Laptop, Handheld
  - Humans or sensors can provide input to network
  - Supports multiple operators simultaneously
  - Future embedded devices….
- Decentralized
- Robust in an unreliable environment



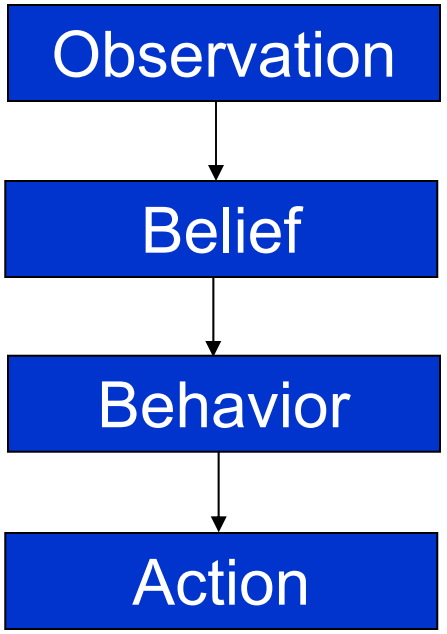
JHU/APL Robotics Algorithm and Communications Environment

Information Technologies Group

- Modeled after insect behavior
  - Observations about the world are translated into beliefs (pheromones)
  - Collection of beliefs constitute world model.
- Heterogeneous Swarm of Vehicles
  - Real and simulated robots working in concert
- Opportunistic Communications
- Heterarchical C2 environment

Software Architecture

- Variation on classic AI paradigm of: Sense, Plan, Act
  - Sensor-based Observations are used to generate…
  - Belief about the current state of the world which in turn is used to devise an appropriate...
  - Behaviors to satisfy group goals and objectives. Behaviors are then used to generate…
  - Actions which translate into real world movements of the robot.



Conclusions

- Large Scale deployment of Unmanned Vehicles will require a rethinking of C2
- C2 environment should match mission environment
  - Heterarchical vs. Hierarchical Organization
  - Decentralized AI
  - Decentralized Computing Environment
  - Decentralized Command and Control