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Command and Control of Autonomous UxV's

June 2005

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Report Documentation Page				Form Approved OMB No. 0704-0188	
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1. REPORT DATE JUN 2005		2. REPORT TYPE		3. DATES COVERED 00-00-2005 to 00-00-2005	
4. TITLE AND SUBTITLE Command and Control Autonomous UxV's				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Johns Hopkins University, Applied Physics Laboratory, 11100 Johns Hopkins Road, Laurel, MD, 20723				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution unlimited					
13. SUPPLEMENTARY NOTES The original document contains color images.					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES 17	19a. NAME OF RESPONSIBLE PERSON
a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified			



Applied Physics Laboratory

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- **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

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- 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



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- 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



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- 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

- Swarming as AI Solution
- Biological systems provide insight on problems
- Swarm of ants

Decentralized control

Massively distributed

Robust to failures

Self organizing, Self regulating



U F Ent Dep, James L. Castner

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



Swarm AI Behavior



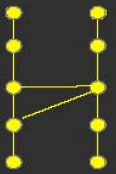
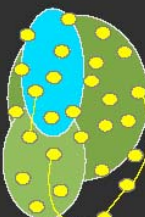
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Stigmergy – “a method of communication in decentralized systems in which the individual parts of the system communicate with one another by modifying their local environment.”

Examples: Flock of Birds, Wolf Packs, Foraging Ants



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	10000000s	100000000s	1000000000s
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

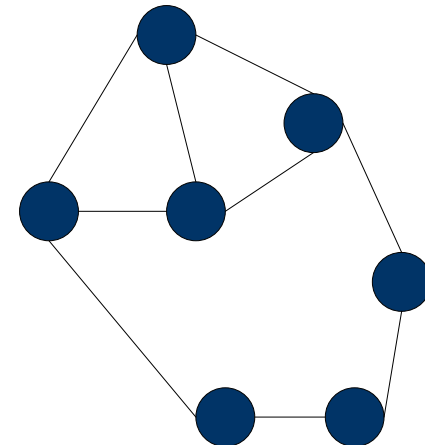
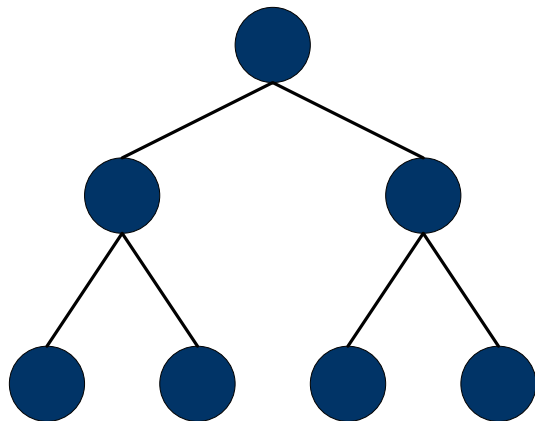


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- Historical Examples
 - Napoleon during Ulm Campaign
 - Japanese in Kamikaze Attacks
 - Germans in Battle of Atlantic
- Organizations operate most efficiently when command structure match their mission environment.
 - Decentralized AI
 - Decentralized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



Protect Moving Convoy

Deny Access to Basin



Warfighter Ground Station



Patrol Roads in Area of Interest

Identify Mines in Surf Zone

Protect HQ



Human On the Loop

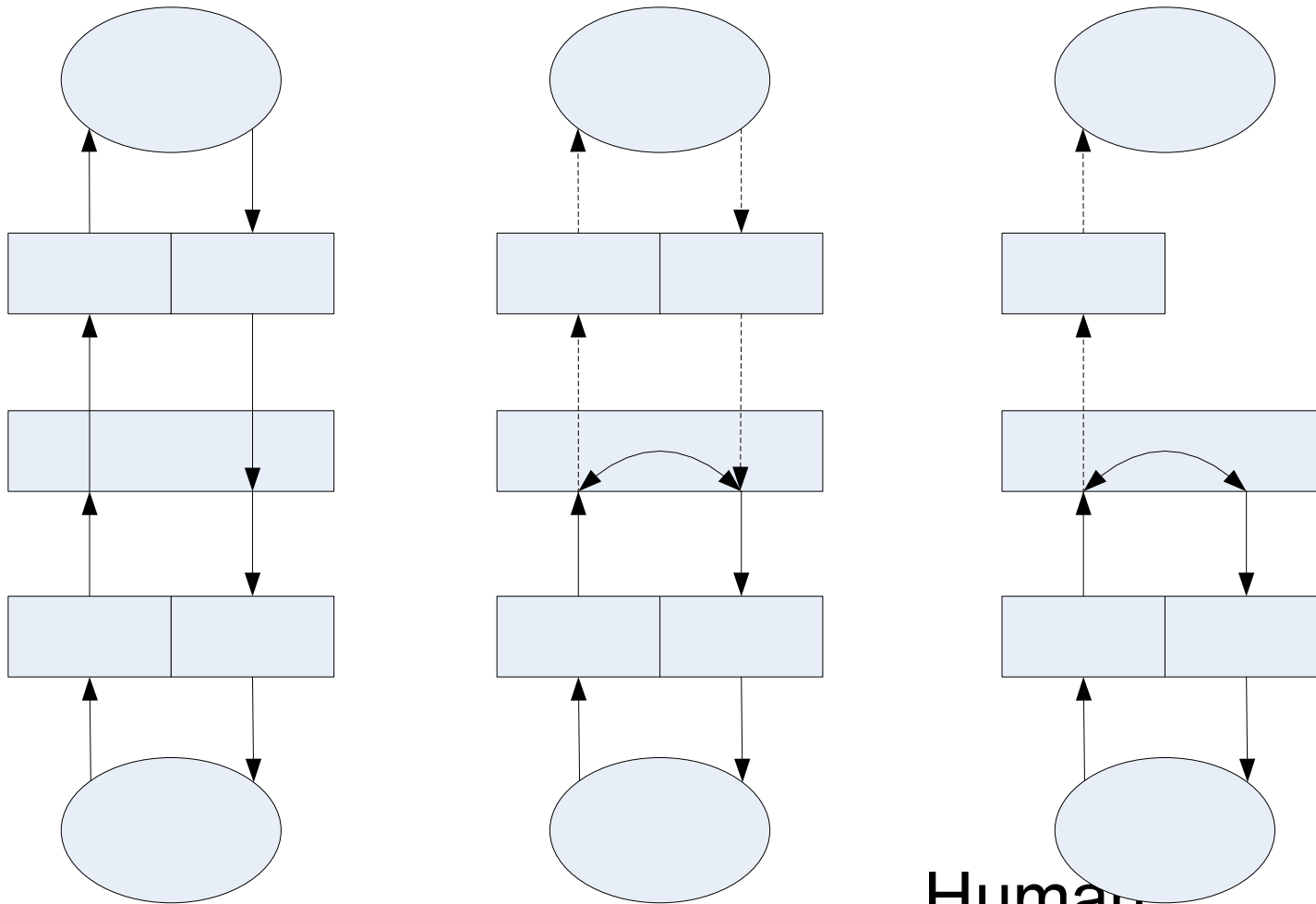


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Automation

Human On the Loop

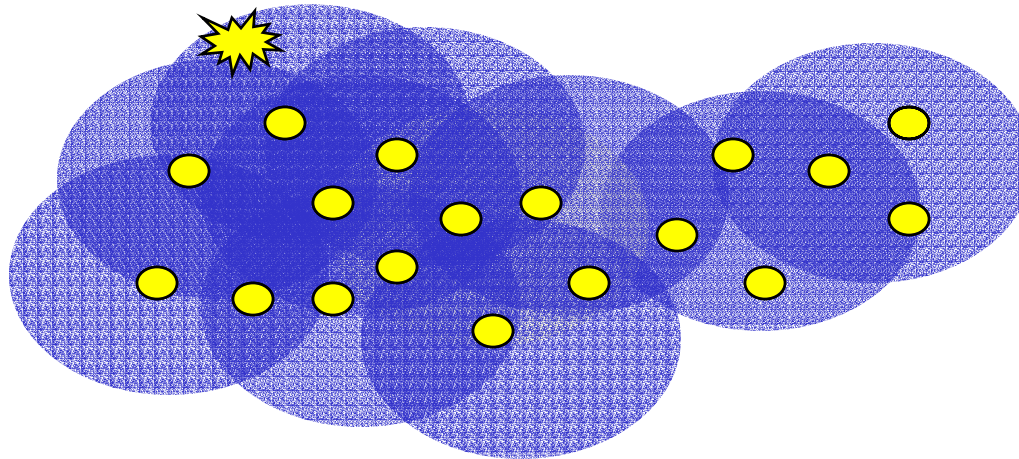
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Human
Operator

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

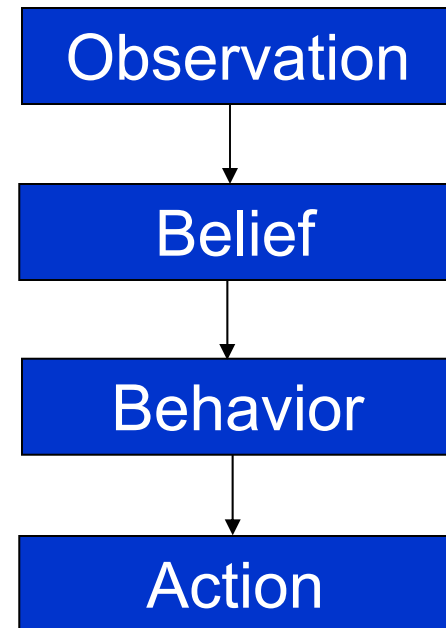


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- Modeled after insect behavior
 - Observations about the world are translated into beliefs (pheromones)
 - Collection of beliefs constitute world model.
- Heterogeneous Swarm of Vehicles
 - Real and simulated robots working in concert
- Opportunistic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



- 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



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- 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