



Multi-vehicle Collaborative Autonomous Control Under Difficult Communications Conditions

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The Swarming Autonomy “Theme Bug”





Our MVC Vision

**Unmanned Vehicles as a
Ubiquitous Service for the
Warfighter**



Underwater MVC Challenges

- ▶ UUVs need Collaborative MVC that is
 - » Effective under Poor Communications Environments
 - » Effective in Dynamic and/or Intractably Complex Conditions
 - » Rapid in Response to Perturbations in the Environment or the Objectives
 - » Robust and Survivable



Bottom Line

*We Have Achieved Robust
Militarily Useful Behaviors
Reactively and Emergently*



Generated Behaviors

	Fields Generated by		
	Targets	Peers	Area Effects
Patrol		✓	✓
Track & Trail	✓	✓	✓
Survey & Map	✓	✓	✓
Path Finding	✓	✓	✓
Formation Flying		✓	
Recruitment	✓	✓	✓
Comm Link		✓	
Resource Allocation	✓	✓	✓
▶ Vehicle Damage			
▶ Objective Change			
▶ Environmental Change			



Emergent Swarming





Emergent Swarming IS...

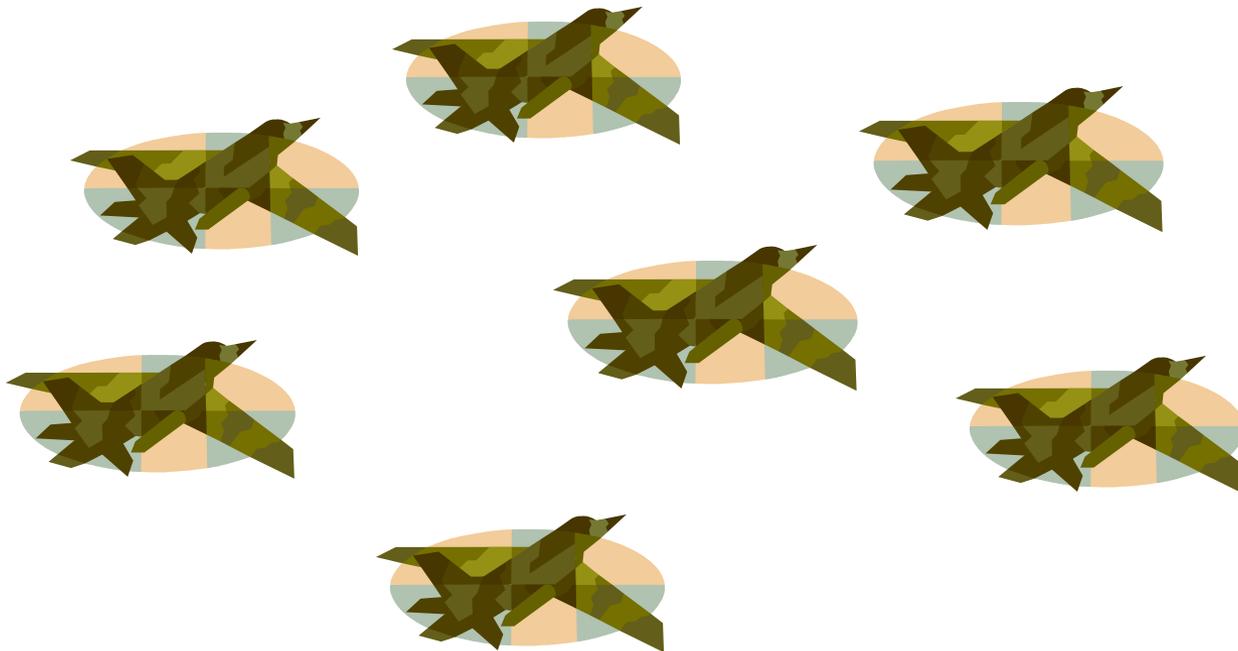
Locally-Executed Control Algorithms That Provide Globally Self-Organizing Behavior Amongst Cooperating Vehicles





Emergent Swarming IS...

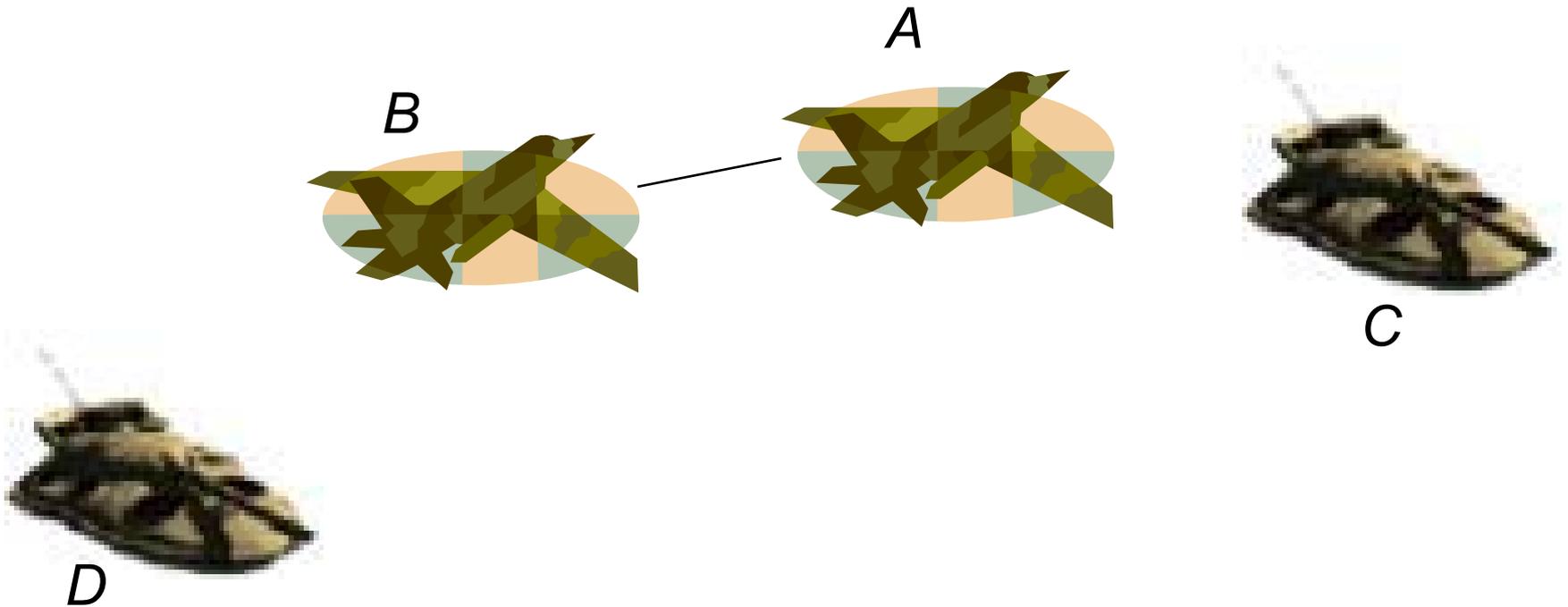
Locally Controlled:
Individual Decision Makers (Agents) on Each Platform





Emergent Swarming IS...

NOT Deliberative:

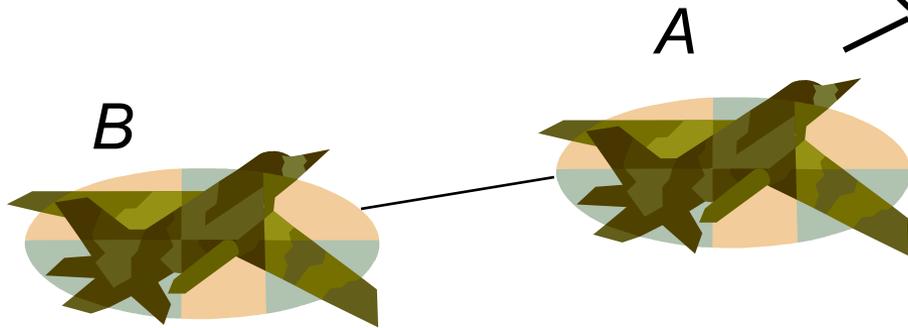




Emergent Swarming IS...

NOT Deliberative:

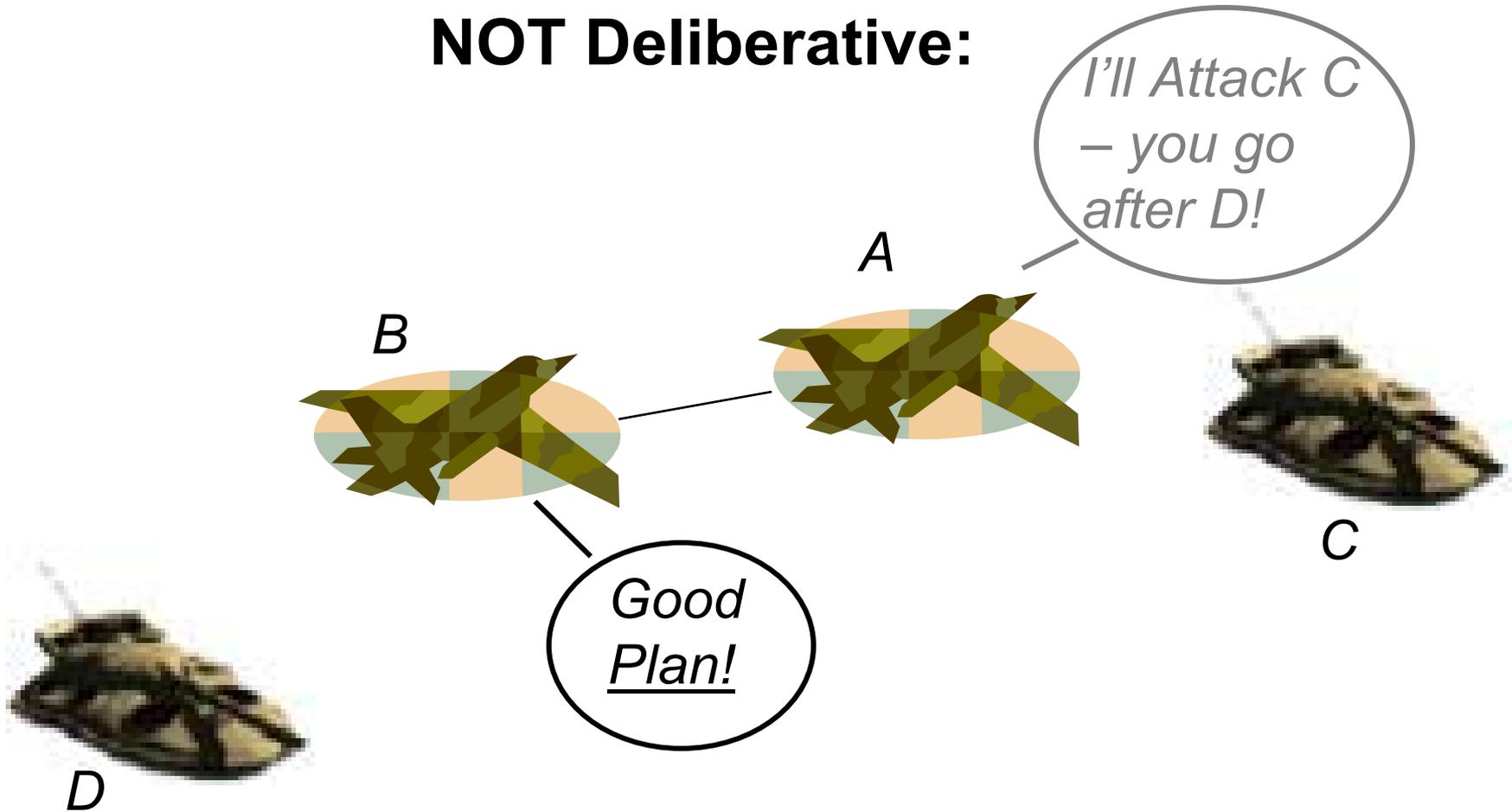
*I'll Attack C
– you go
after D!*





Emergent Swarming IS...

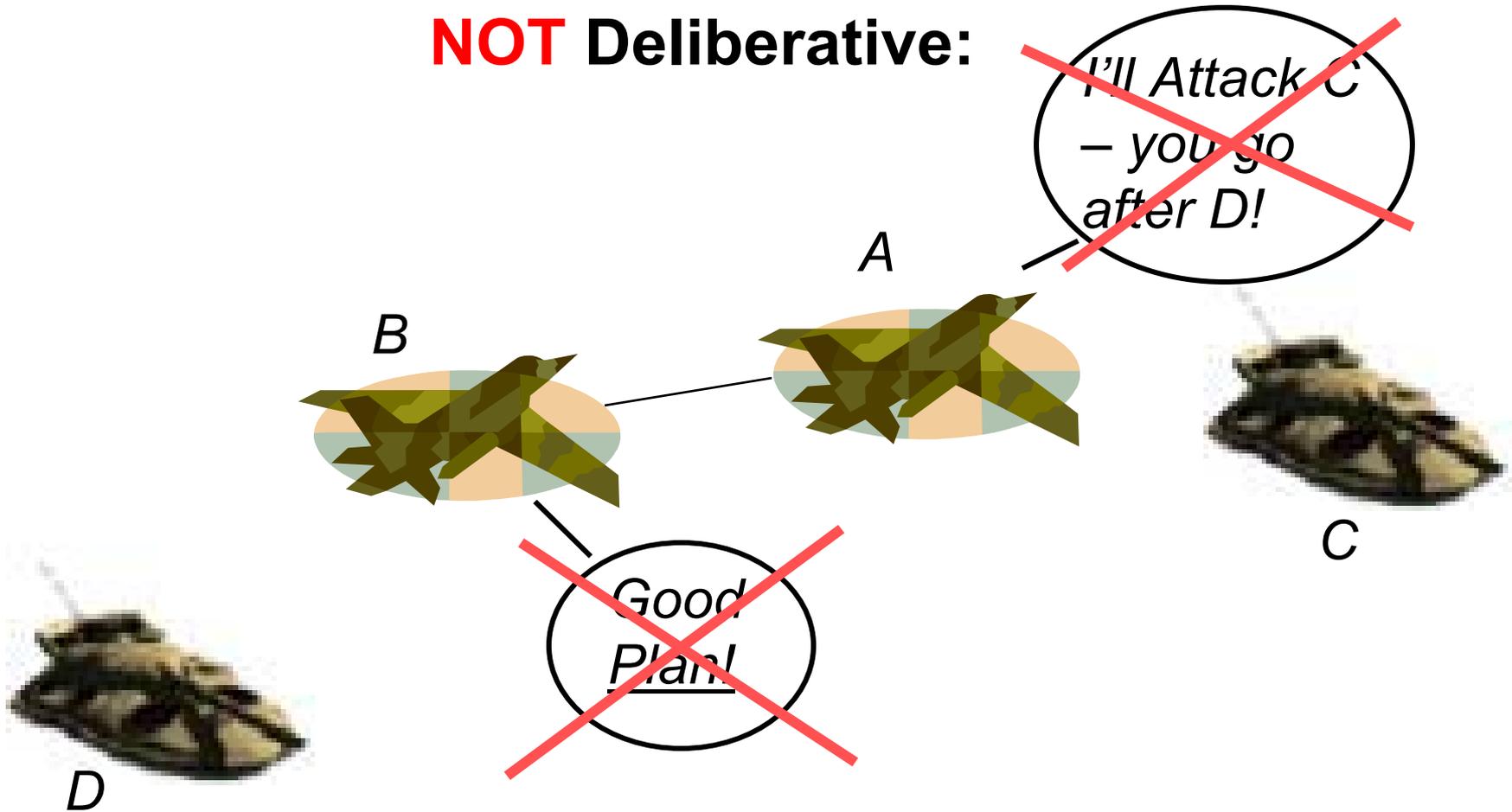
NOT Deliberative:





Emergent Swarming IS...

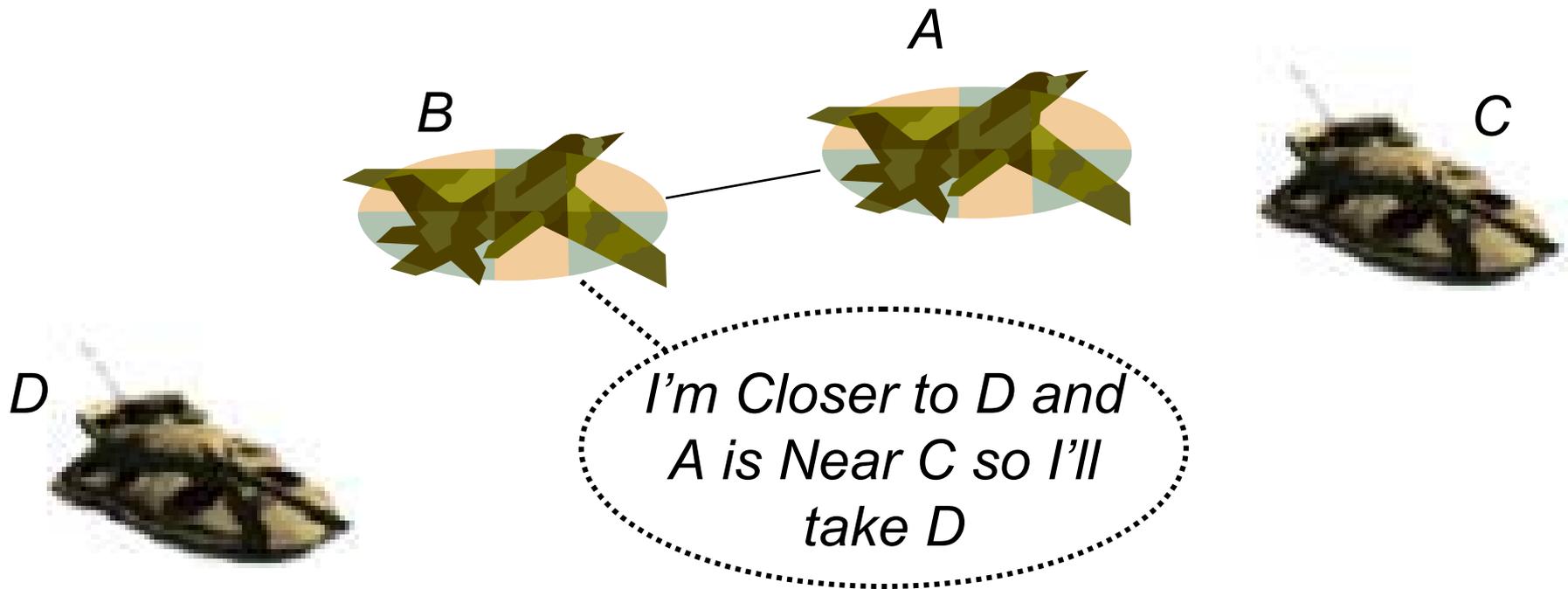
NOT Deliberative:





Emergent Swarming IS...

NOT Deliberative:



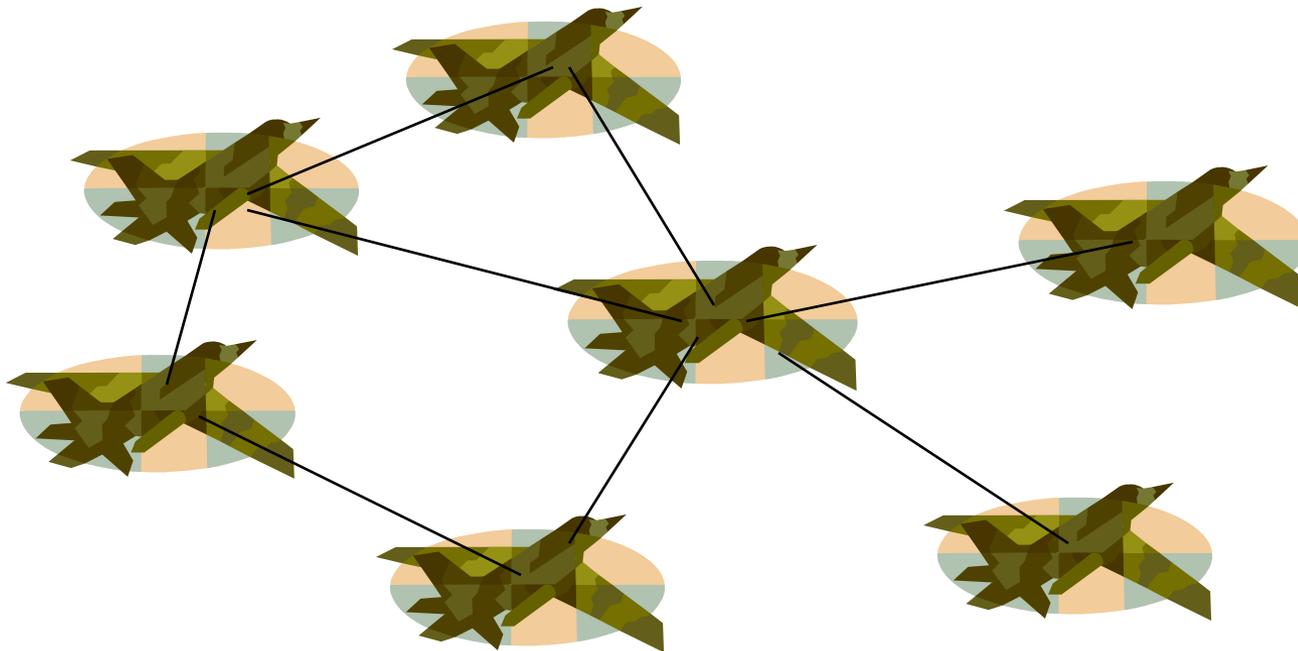
Coordination *Emerges* from Sympathetic Decision Processes and Shared Knowledge



Emergent Swarming IS...

Heterarchical:

An Unstructured Network of Cooperating Peers
No dedicated leaders* ever!



(*single points of vulnerability)



With a Flat Communications Topology any one Swarming Element can be Sufficient to Communicate any End User/Decision Maker





There's no single point of vulnerability, and no particular pre-determined critical path to get information back to the operator.



Find the Enemy!



The nature of the swarming system is such that it can adapt and reshape itself until the requirements are met. This isn't commander Cicada – just the Cicada that was handy and happened to be close enough to relay the relevant information.

We hear
and Obey!





Swarming Models

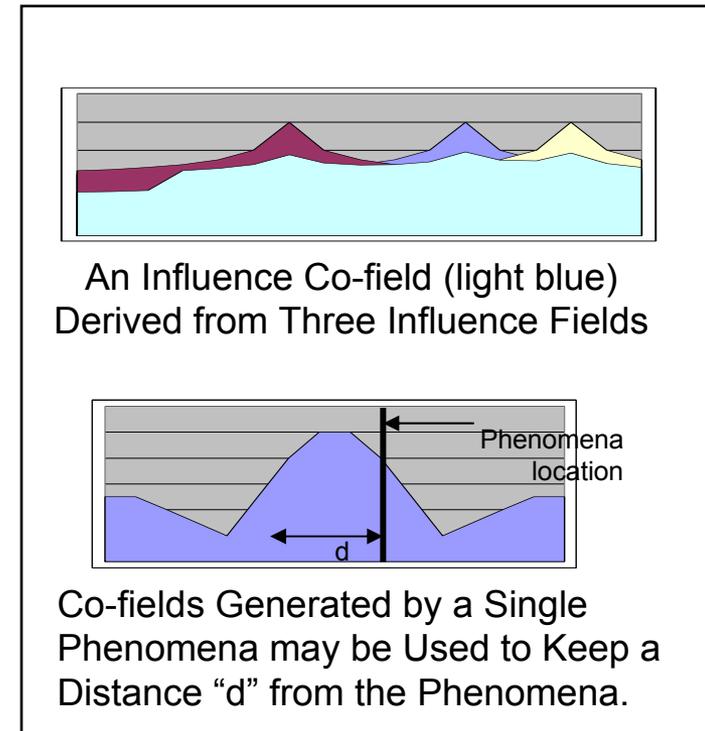
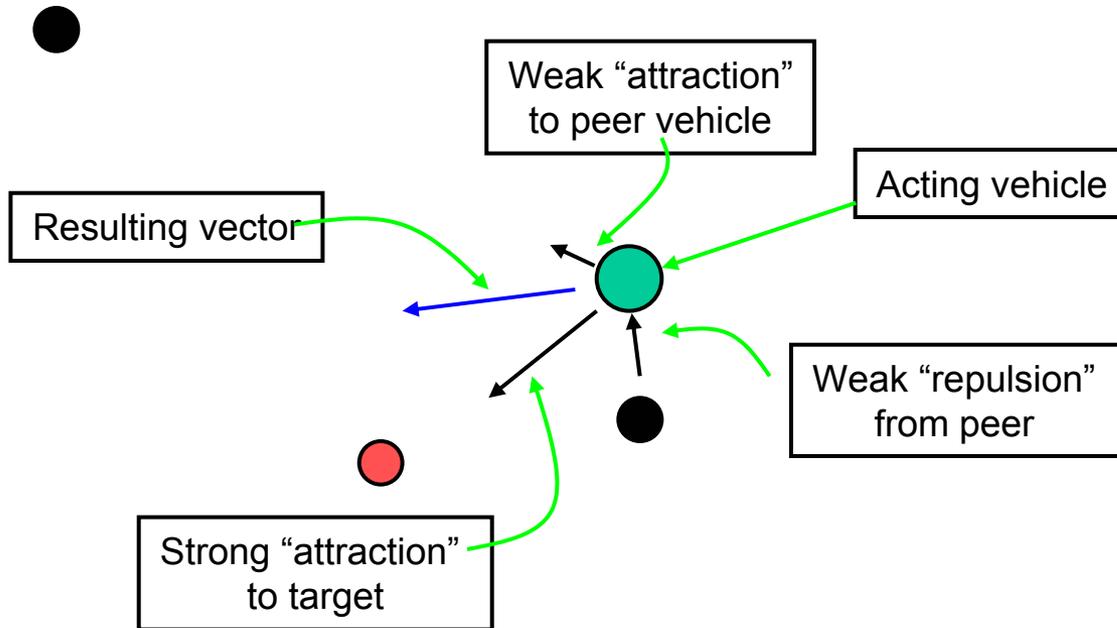
Many Exist, mostly patterned off of natural systems, major themes are:

- ▶ Physicomimetic – Pattered after sub-atomic particle interactions
- ▶ Biomimetic – patterned after social animals
 - » Flocking Behavior
 - » Ant Colony Behavior
 - » Termite/Wasp Nest Building
 - » Wolf-Pack Hunting
 - » Mold Growth



CO-FIELDS BEHAVIORS

Generating Behavior by associating fields with a movement vector.





JHUAPL Innovation: Dynamic Co-Fields

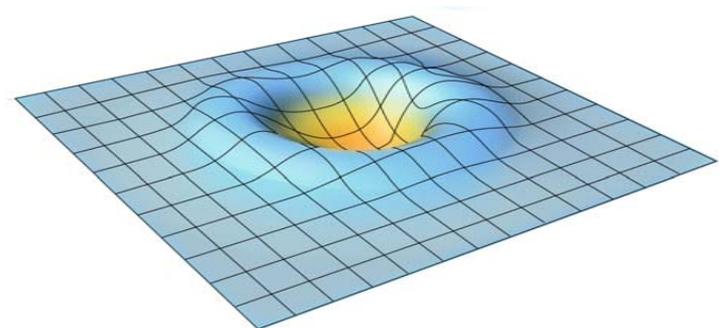
Dynamic Co-Fields Extends Co-Fields by Allowing Individual Fields to Change as a Function of Time

Dynamic Influences May be Generated by:

- ▶ Historical Observations
- ▶ Introducing Temporal Decay To Knowledge
- ▶ Using Observations as an Impetus for Formula Modifications
- ▶ Using Field Strengths as an Impetus for Formula Modifications
- ▶ **Generating One's Own Field**

This Allows Vehicles to:

- ▶ Patrol
- ▶ **Avoid Local Minima**
- ▶ Limit Oscillatory Behavior
- ▶ Adapt by Learning
- ▶ Manage Uncertainty (Intermittent Contacts or Communications)

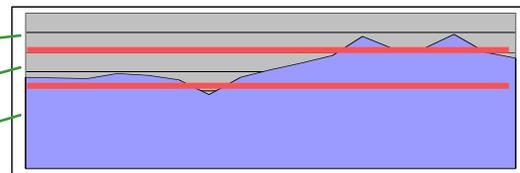
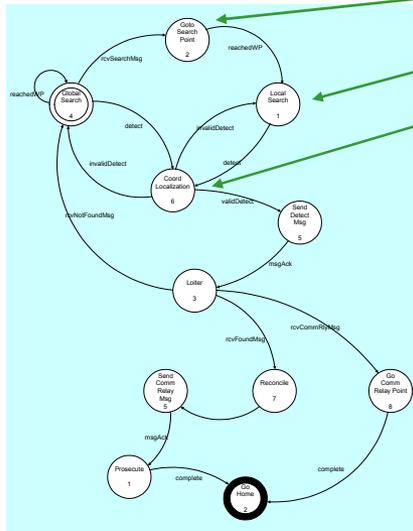




Vehicle Actions and Modal Behavior

Movement is Not Enough...

Vehicles need to be able to take actions and change from one behavior to another. For example, shifting from patrolling to tracking when a target is detected.



Above this Threshold
"flee" the Area

Below this Threshold
Take Action

Field Thresholds may be Used
to Adjust Behavior in Response
to Phenomena

Mode Transitions and Transitory acts
may be Precipitated by Applying
Thresholds to Co-field Magnitudes



Simulator for Autonomous Agents

Agent Swarm Sim

File Help

MILITARY RESERVATION

FORT GEORGE G MEADE

SWITCHBO M

Observation Tower

Sand and Gravel Pit

ROAD

BRUSH

TRAIL

POND

DRAINAGE

UGV01

UGV02

UGV03

UGV04

UGV05

UGV06

Mouse Action

SIM TIME STEP - 1 + seconds

DISPLAY:

COMMS DESTINATION

DETECTS ATTRACTION

SELECTION

UGV02 TOP SPEED: 10.0

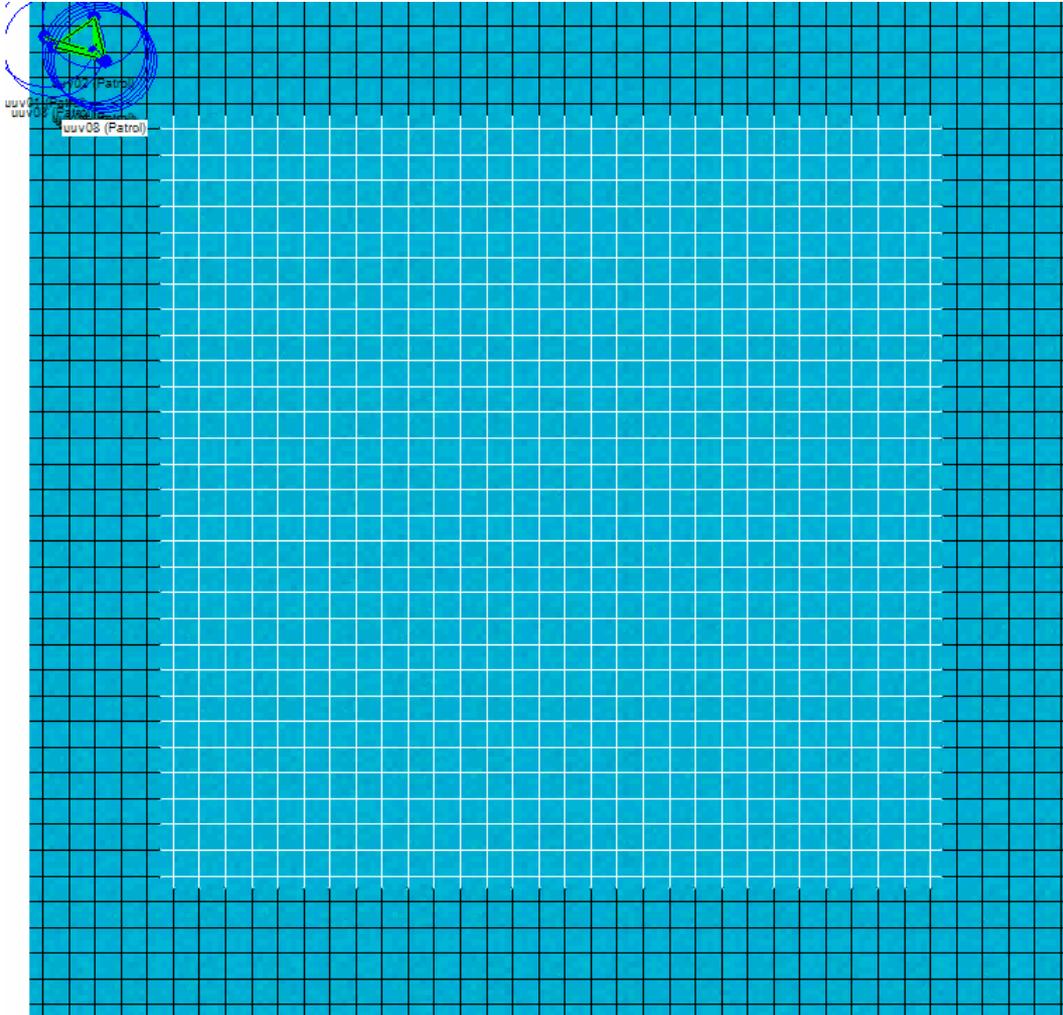
MOBILITY

OPTICAL

03/04/03 15:16:02 X:30.6750313676286 Y:55.43



Cooperative Search (weak comms)



Mouse Action

RUN STOP

SIM TIME STEP - 0 + seconds

DISPLAY

COMMS OBSTACLE FIELD
 DETECTS ATTRACTION
 AOI/AOA TEXT
 Show the dead DecayBitmap

SENSOR DISPLAY

All Selected None

OBSTACLES

All Selected None

WAYPOINTS

All Selected None

POSITION HISTORY

All Selected None

SFI FCTION

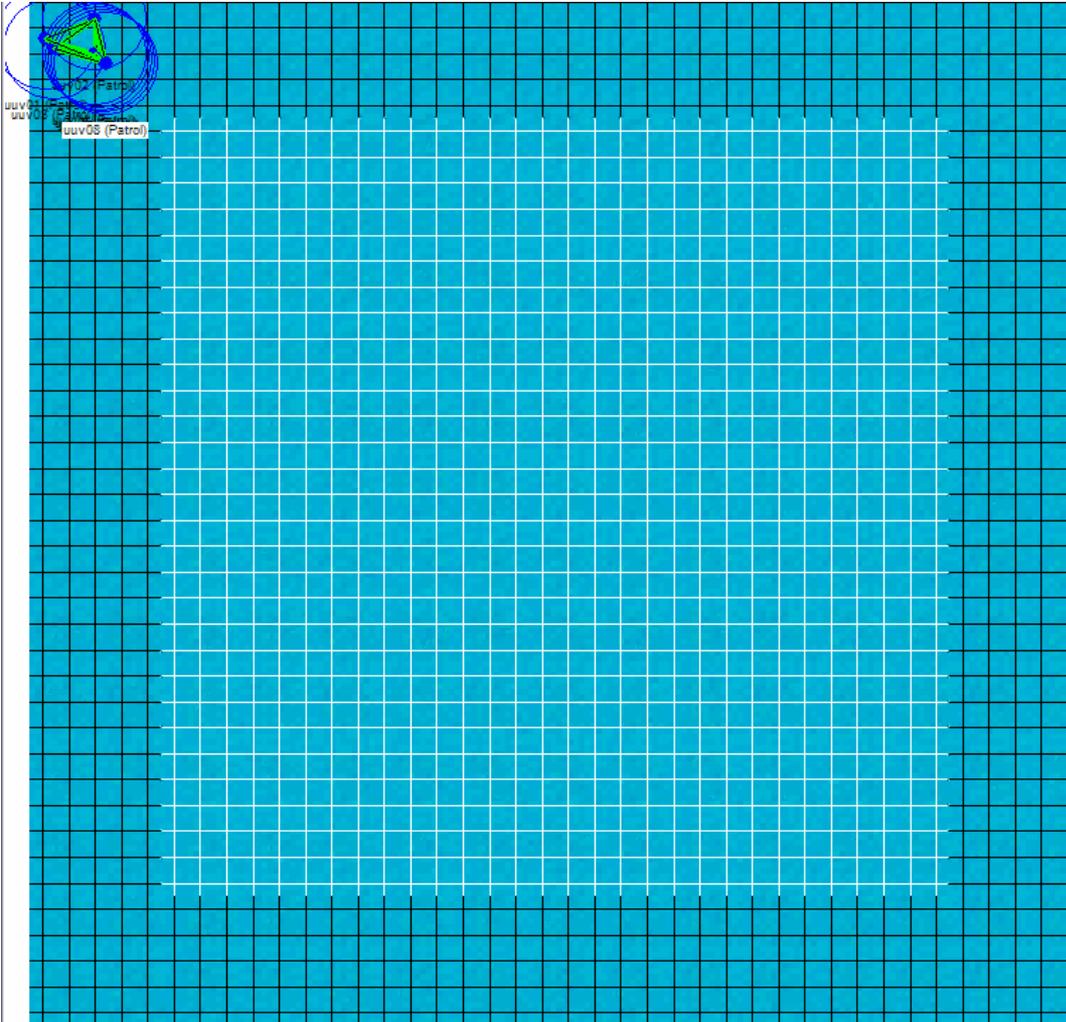
TabSheet2 Contacts

T:0 uuv01 (COMMS) [C: 1.000]
T:0 uuv02 (COMMS) [C: 1.000]
T:0 uuv03 (COMMS) [C: 1.000]
T:0 uuv04 (COMMS) [C: 1.000]
T:0 uuv05 (COMMS) [C: 1.000]
T:0 uuv06 (COMMS) [C: 1.000]
T:0 uuv07 (COMMS) [C: 1.000]
T:0 uuv08 (COMMS) [C: 1.000]

WorkingBehavior = 0.05
AvoidThreatBehavior = 0.6
MaintainCommsBehavior = 0.3
SearchBehavior = 1
NewSearchBehavior = 1e-07
DecaylessSearchBehavior = 0.01
AvoidAreaBehavior = 1
FollowLeaderBehavior = 1
Distance: 1
Heading: 135



Cooperative Search (longer comms range)



Mouse Action

RUN STOP

SIM TIME STEP seconds

DISPLAY
 COMMS OBSTACLE FIELD
 DETECTS ATTRACTION
 AOI/AOA TEXT
 Show the dead DecayBitmap

SENSOR DISPLAY
 All Selected None

OBSTACLES
 All Selected None

WAYPOINTS
 All Selected None

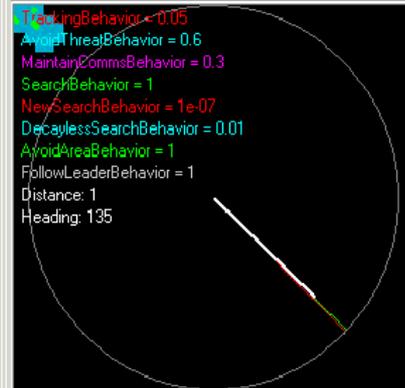
POSITION HISTORY
 All Selected None

SECTION

TabSheet2 Contacts

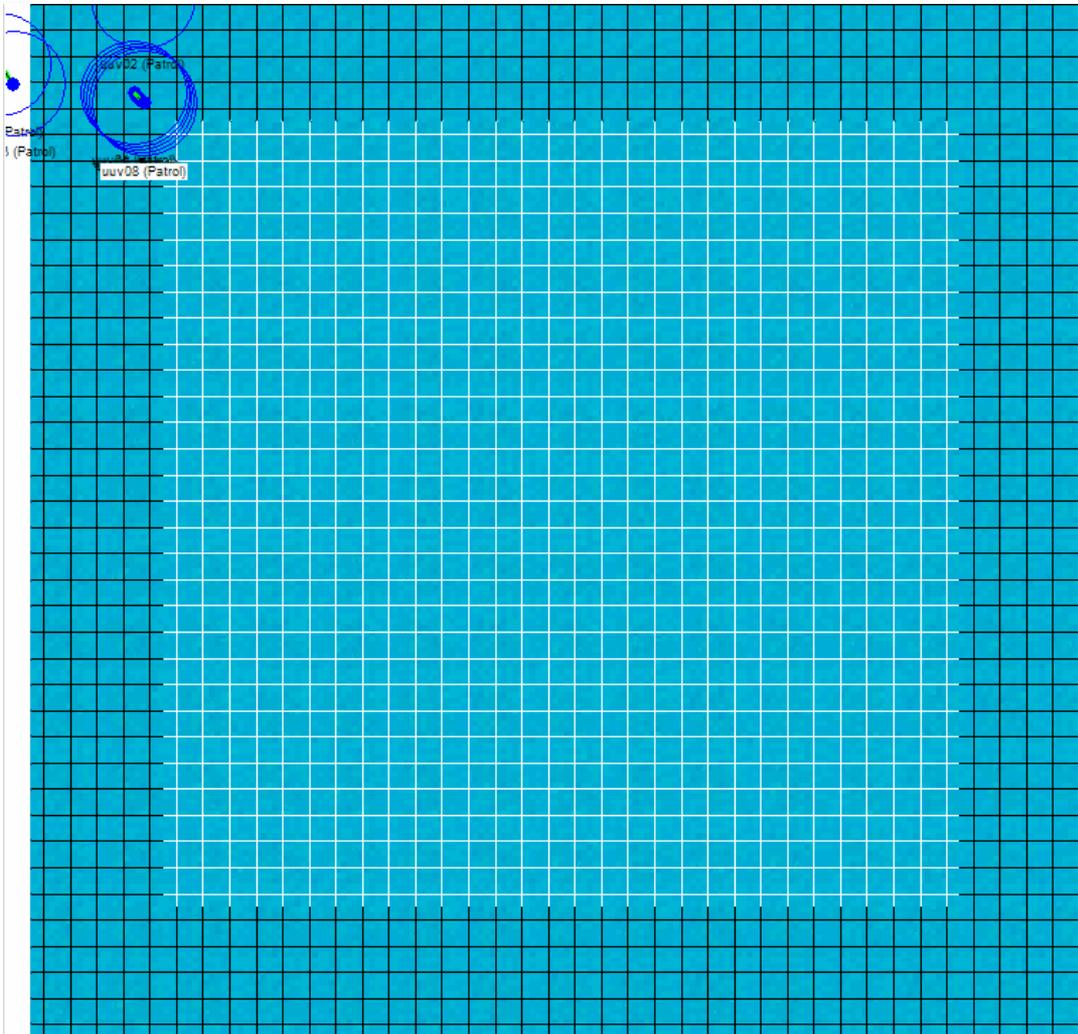
T:0 uuv01 (COMMS) [C: 1.000]
T:0 uuv02 (COMMS) [C: 1.000]
T:0 uuv03 (COMMS) [C: 1.000]
T:0 uuv04 (COMMS) [C: 1.000]
T:0 uuv05 (COMMS) [C: 1.000]
T:0 uuv06 (COMMS) [C: 1.000]
T:0 uuv07 (COMMS) [C: 1.000]
T:0 uuv08 (COMMS) [C: 1.000]

TrackingBehavior = 0.05
AvoidThreatBehavior = 0.6
MaintainCommsBehavior = 0.3
SearchBehavior = 1
NewSearchBehavior = 1e-07
DecaylessSearchBehavior = 0.01
AvoidAreaBehavior = 1
FollowLeaderBehavior = 1
Distance: 1
Heading: 135





Cooperative Search (faster UUV)



Mouse Action

RUN STOP

SIM TIME STEP - 0 + seconds

DISPLAY

COMMS OBSTACLE FIELD
 DETECTS ATTRACTION
 AOI/AOA TEXT
 Show the dead DecayBitmap

SENSOR DISPLAY

All Selected None

OBSTACLES

All Selected None

WAYPOINTS

All Selected None

POSITION HISTORY

All Selected None

SFLECTION

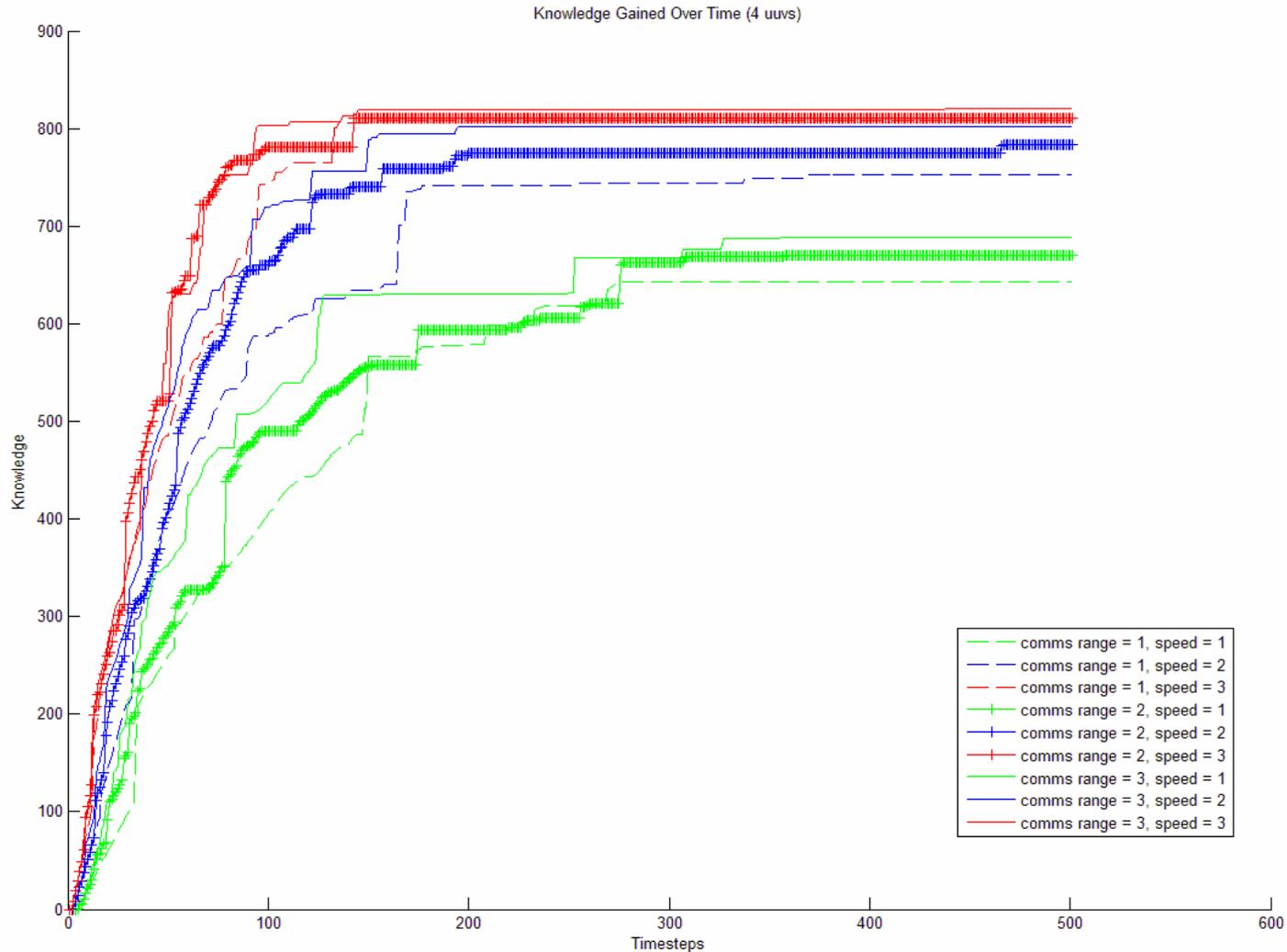
TabSheet2 Contacts

T:1	uuv01 (COMMS)	[C: 0.250]
T:1	uuv02 (COMMS)	[C: 0.250]
T:1	uuv03 (COMMS)	[C: 0.250]
T:0	uuv04 (COMMS)	[C: 1.000]
T:0	uuv05 (COMMS)	[C: 1.000]
T:0	uuv06 (COMMS)	[C: 1.000]
T:0	uuv07 (COMMS)	[C: 1.000]
T:0	uuv08 (COMMS)	[C: 1.000]

TrackingBehavior = 0.05
AvoidThreatBehavior = 0.6
MaintainCommsBehavior = 0.3
SearchBehavior = 1
NewSearchBehavior = 1e-07
DecaylessSearchBehavior = 0.01
AvoidAreaBehavior = 1
FollowLeaderBehavior = 1
Distance: 3
Heading: 135

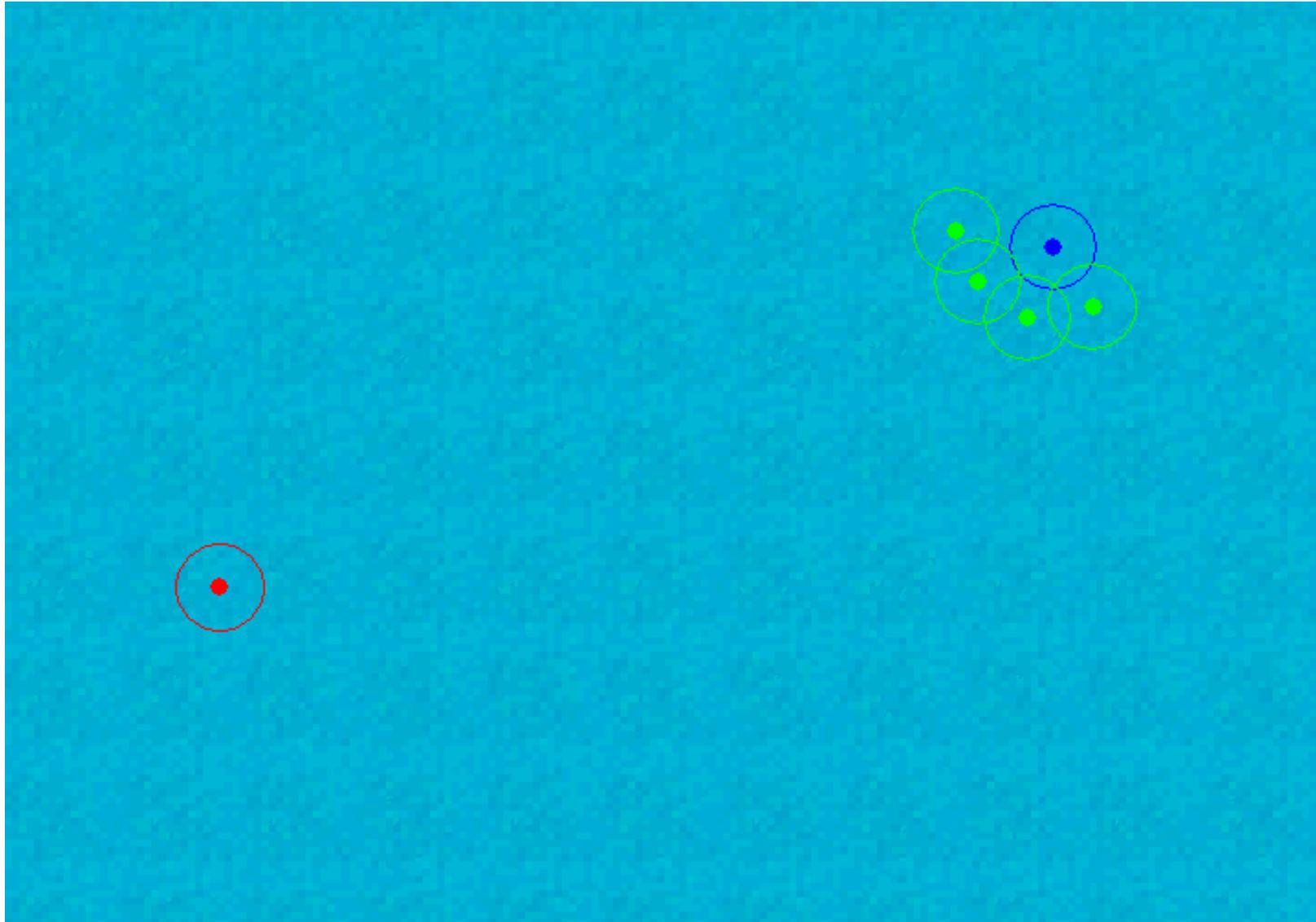


Comms vs. Speed Results





Mode Transition to Comms Chain





Swarming Autonomy Benefits



1,000,000,000,000 Cicadas Can't Be Wrong!



Thank you!

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(and David H. Scheidt)

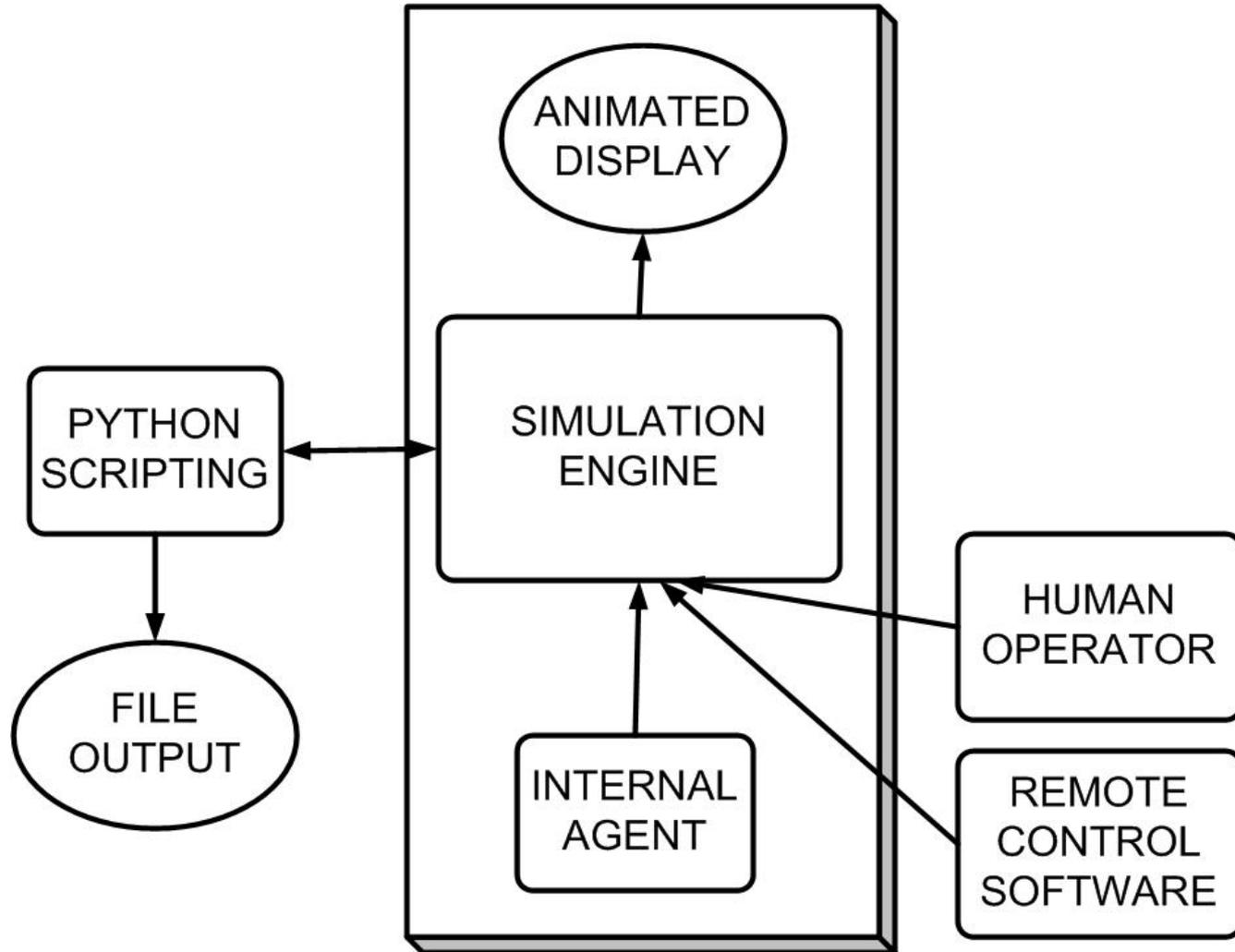




BACKUP SLIDES



Swarming Engagement Simulator Input/Output





Agent Architecture

