International Council on Systems Engineering
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Faulted Agent Resilience in Multi-Agent Systems: An Exploration of Two Ant Inspired Strategies

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Guideline for this discussion

- What needs addressed and Why?
  - The Problem
  - Why should systems engineers care?
  - Previous works by the authors
- The Experiment
  - The Strategies
  - The Simulation Environment
  - Our Results
- Conclusion
  - Final Remarks
  - A look at future work
  - Acknowledgments

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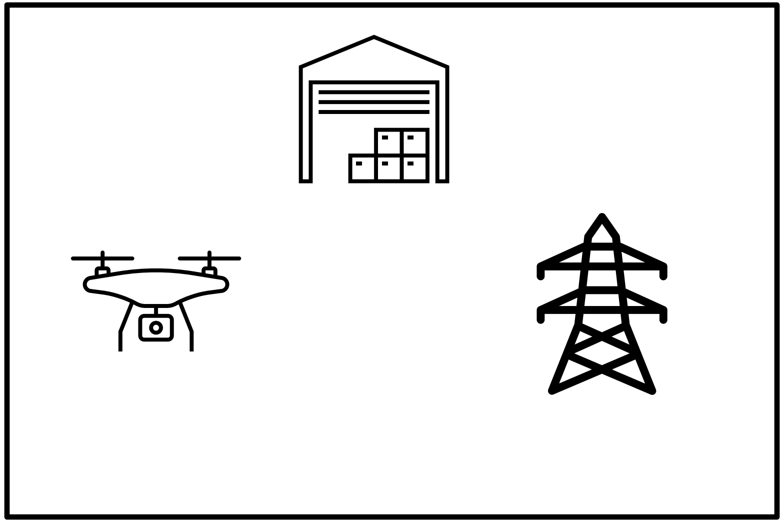
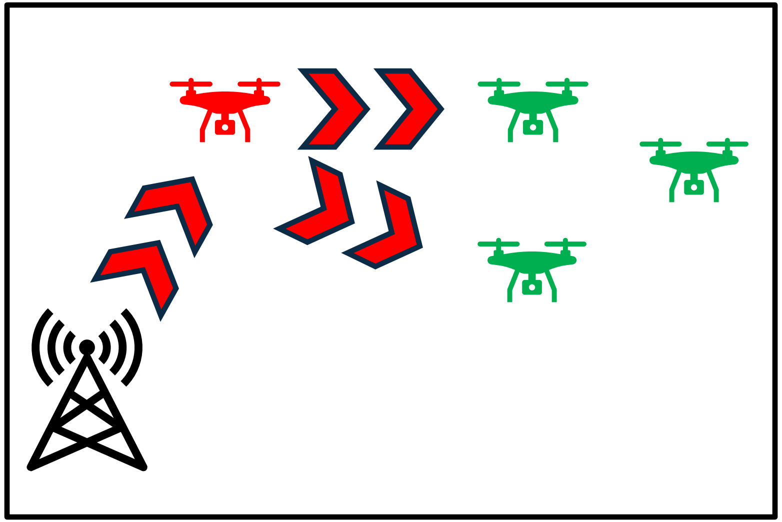
The Problem

Collaborative multi-agent systems are susceptible to faulted agents that can impact system cohesion, task completion, and system health



Multi-agent systems are an integral part of many key industries and services



Spreading faults are of particular interest to collaborative systems

Why should systems engineers care about this work?

This work provides two key contributions to the Systems field:

- A unique look at system resilience to faulted agents
- A study of how these unique biological strategies impact real systems

Highlights a need for system resilience against a wide variety of factors and influences

The war in Ukraine, and recent skirmishes at the Thailand and Cambodia border (Image from Reuters)

Assumptions for ‘Propagating Fault’ Cyber Attacks

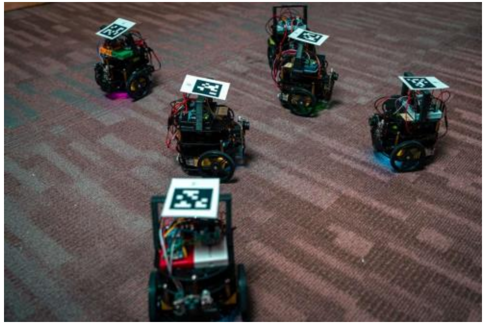
This work assumes the following ‘worst-case’ scenario, based on current literature and emerging trends:

1) Agents do not know who is faulted
2) Faults can spread between agents
3) Those faults make agents maliciously spread the infection

Previous work by the authors

This work is part of a multi-stage project focusing on ways biologically inspired design can improve MAS resilience to faulted agents

Biologically Inspired Strategy Development and Simulation (Image sourced from Unsplash.com)

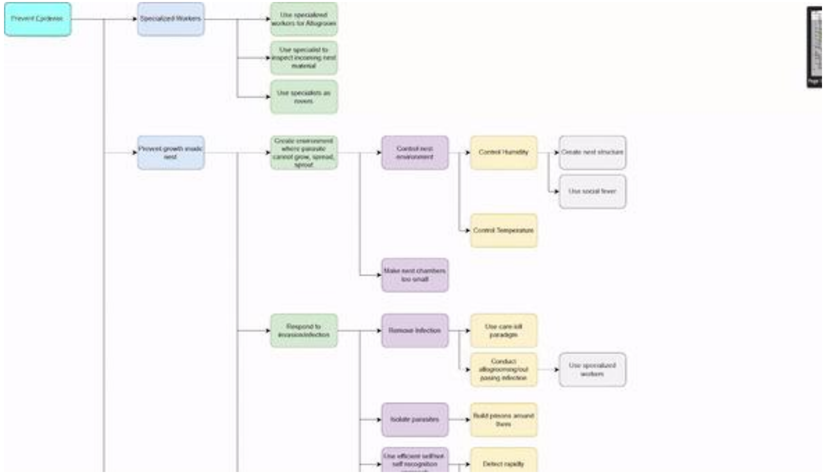


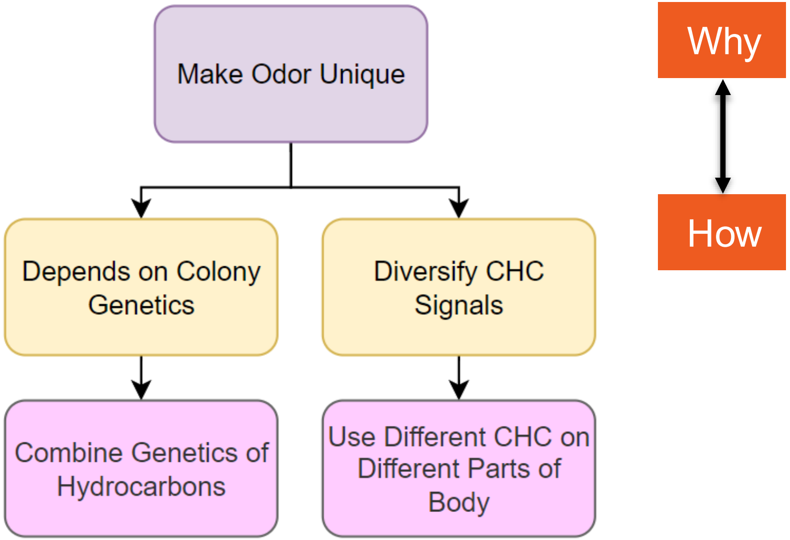
BID4R Lab S.T.A.R.S. Rover Swarm

Widespread Adoption (Image sourced from Unsplash.com)

Previous work by the authors

Previous work identified 148 different ways biological literature says eusocial insects resist epidemics and invasions, passively and actively



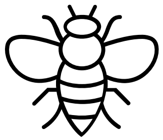


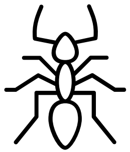
An excerpt of the functional decomposition described in our previous work

(Hand,Watson 2025)

The Research Question

How do biologically inspired individual agent behaviors contribute to MAS resilience to infectious faulted agents?





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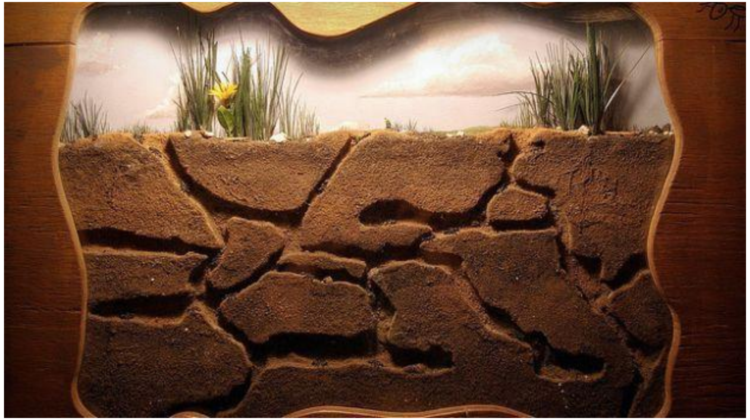
The Experiment: The Strategies

Two strategies were used, derived from a combination of the previously mentioned 148 strategies identified in biological literature

Biological strategies

1. Infected ants cannot be allowed to release spores or complete their life cycle inside of the nest.
2. Ant colonies use specialized workers for specific tasks to expose only a small portion of the swarm to infection vectors.



These two strategies are heavily inspired by ant colony task allocation and nesting habits (Image sourced from Pintrest.com)

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MAS Agent Behaviors

1. *Secure Communications*: Agents within the nesting area communicate less often than other agents but maintain a higher resistance chance to infectious messages.
2. *Spatial Heterogeneity*: Agents are restricted to specific search bands based on age group.

The Experiment: Strategy Specific Agent Rules

Each strategy enforces unique behaviors for individual agents based on rules

MAS Agent Behaviors

1. *Secure Communications*: Agents within the **nesting area** communicate less often than other agents but maintain a higher resistance chance to infectious messages.
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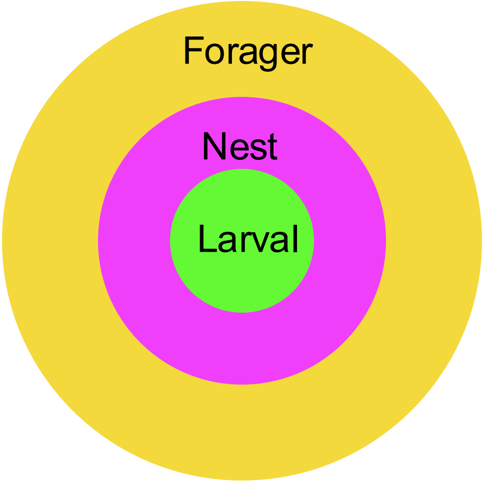


Secure Communications Rules

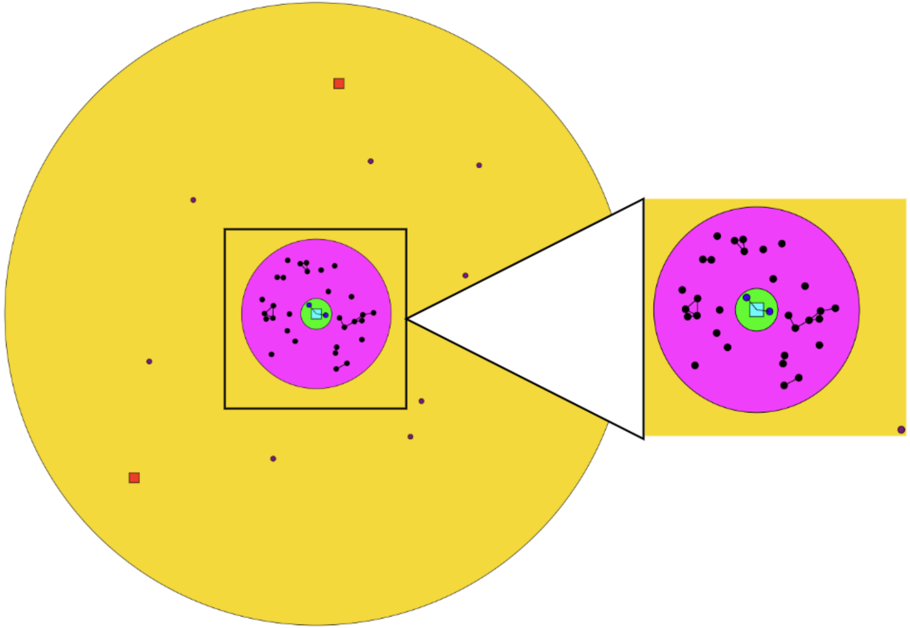
- Agents within Nest and Larval areas communicate once for every 4.5 times other agents do.
- Agents within Nest and Larval Areas have a 90% chance to resist infectious messages when received (4.5 times the resistance chance of other agents).

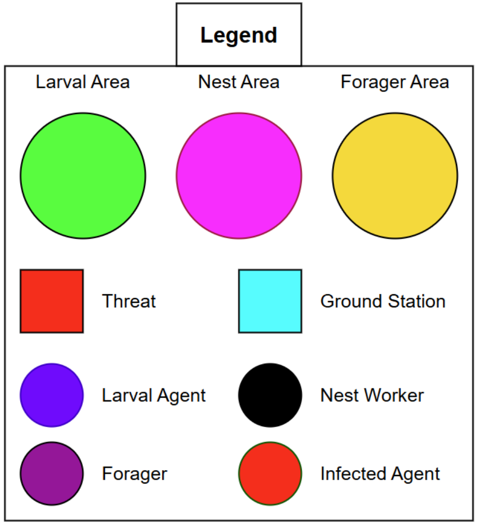
Spatial Heterogeneity Rules

- Agents must stay within the area assigned to them based on their Age.
- Agents within the Forager area will return to the edge of the Nest area to try and transmit information to Nest workers after each search movement.

The Experiment: The Simulation Environment

The AnyLogic simulation environment is meant to mimic a UAV use case scenario with a home ground station and threat actors





Simulation Agent Behaviors

1. *Secure Communications*: Agents within the **nesting** area communicate less often than other agents but maintain a higher resistance chance to infectious messages.
2. *Spatial Heterogeneity*: Agents are restricted to specific search **bands** based on age group.

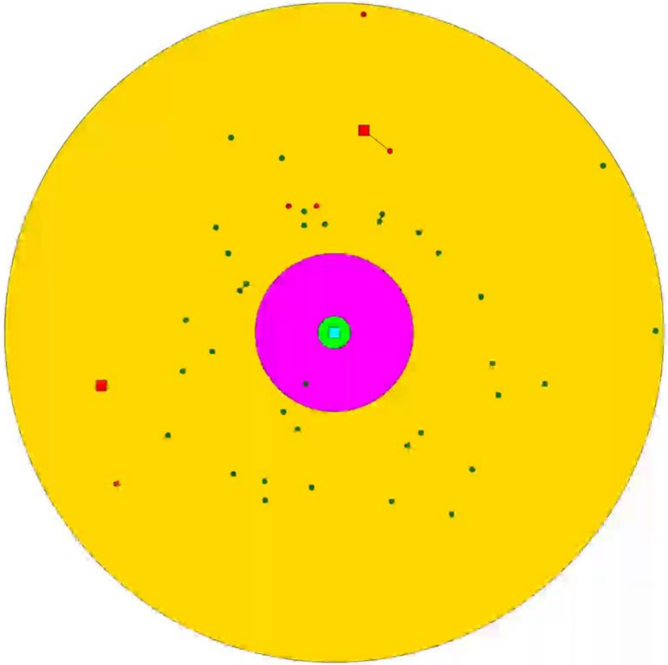
The Experiment: Variables and Initial Conditions

Static Variables	Value
Number of Agents	40
Agent Connection Range	50 meters
Agent Speed	22 m/s
Ground Station Connection Range	250 meters
Larval Radius	62.5 meters
Nest Radius	300 meters
Forager Radius	1250 meters

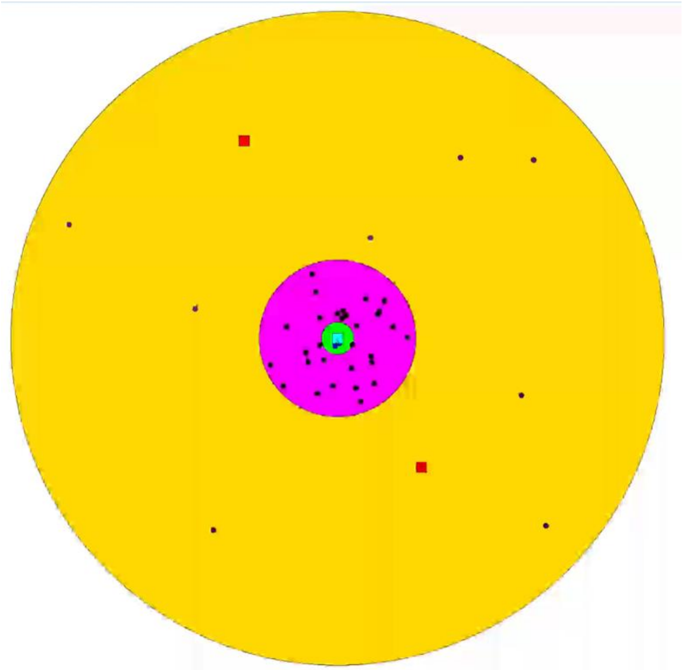
Dynamic Variables	Value
Healthy Agent Communication Timming	1 second
Larval/Nest Agent Communication Timming	4.5 seconds

Based on ant nest ratio literature

The Experiment: The Simulation In Motion



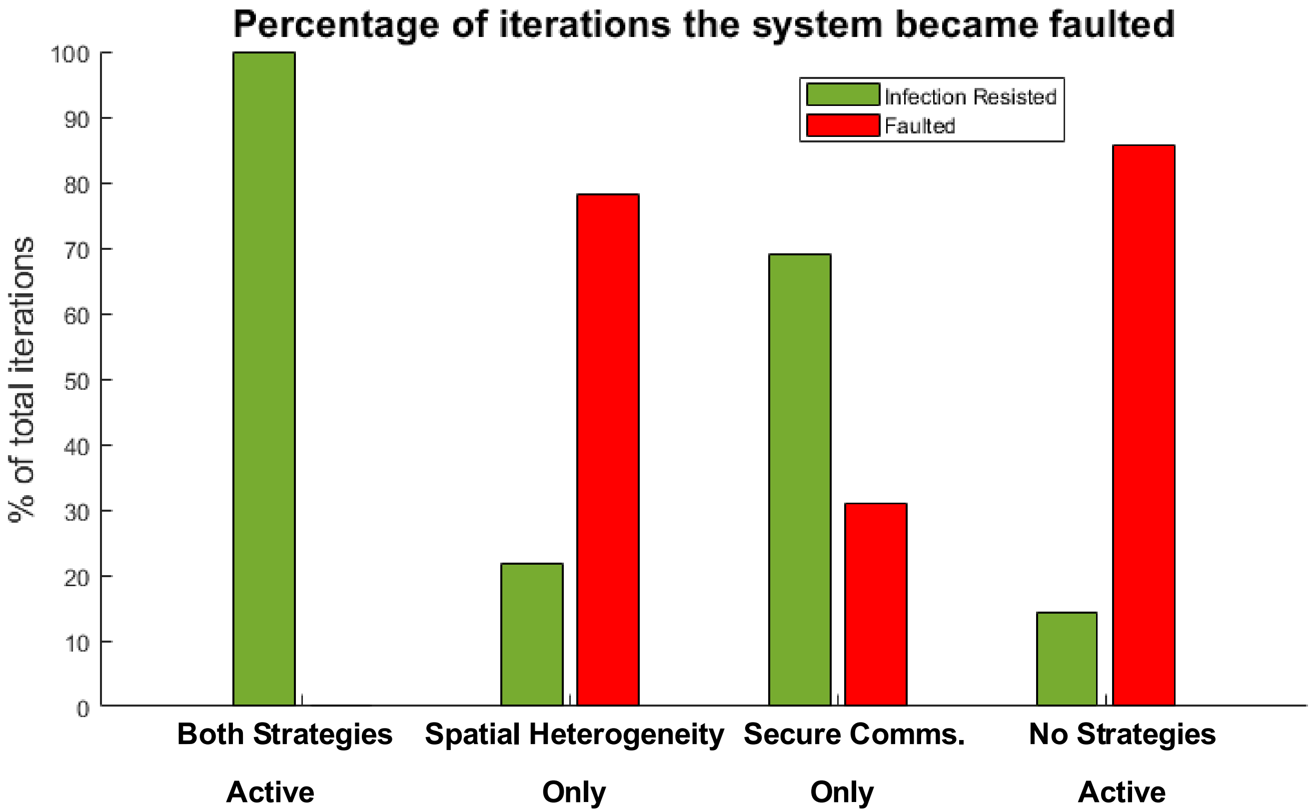
Control Group



BID Behavior Group

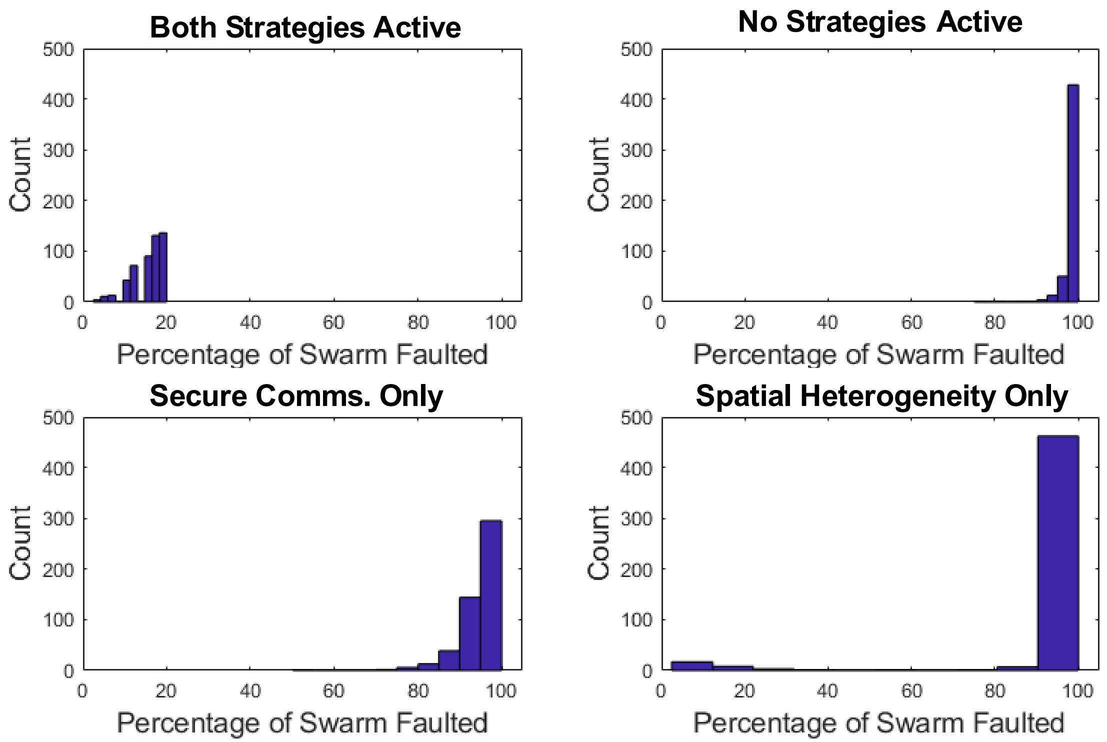
The Results: Fault Propagation

Both strategies greatly reduced the number of iterations with full fault propagation



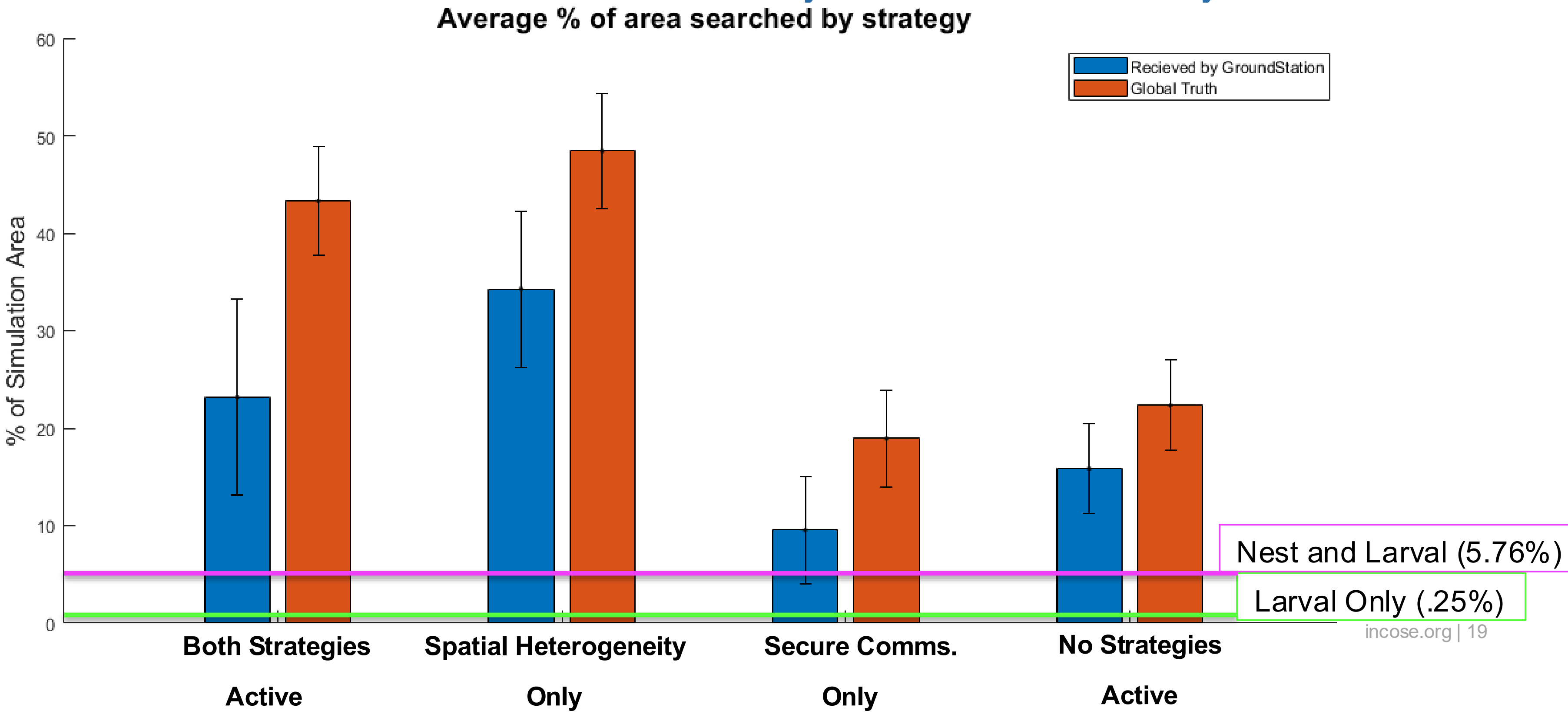
The Results: Fault Propagation – From Another Angle

Each strategy and combination provides a unique dynamic in infection spread



The Results: Search Success

The use of secure comms. reduces the ability of the swarm to relay information



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Conclusions from this work

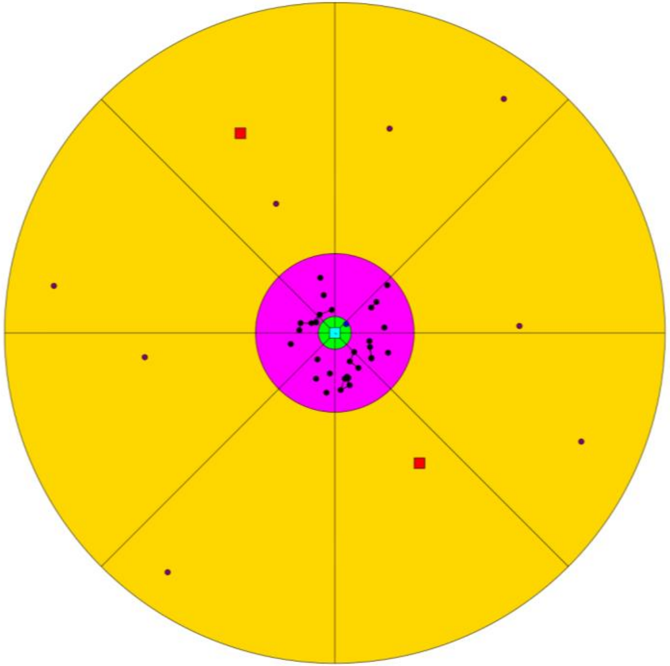
RQ: How do biologically inspired individual agent behaviors contribute to MAS resilience to infectious faulted agents?

- Multi-agent systems face a growing threat of faulted agents and malicious infiltration.
- Ant inspired behaviors greatly increase system resilience and search completeness.

Image from Erich G. Vallery, USDA Forest Service – SRS-4552, Bugwood.org

A glimpse at the future work of this project

Data has already been gathered on 2 additional strategies from the 148 previously mentioned, and a special control group, with an analysis of the various combinations of all 4 strategies working in concert currently being conducted



The two additional biologically inspired strategies

Gene/Cone Spatial Heterogeneity: Agents within the nest are restricted to specific search bands based on genes.
Age Reset: Agents age outwards from the larval chamber, with the chance to reset their age which increases over time.

<u>Most Resilient and Search Complete Combination</u>:

- Secure Comms., Circular and Cone Heterogeneity

<u>Least Resilient and Search Complete Combination</u>:

- All Strategies Off (Control Group)

Acknowledgements

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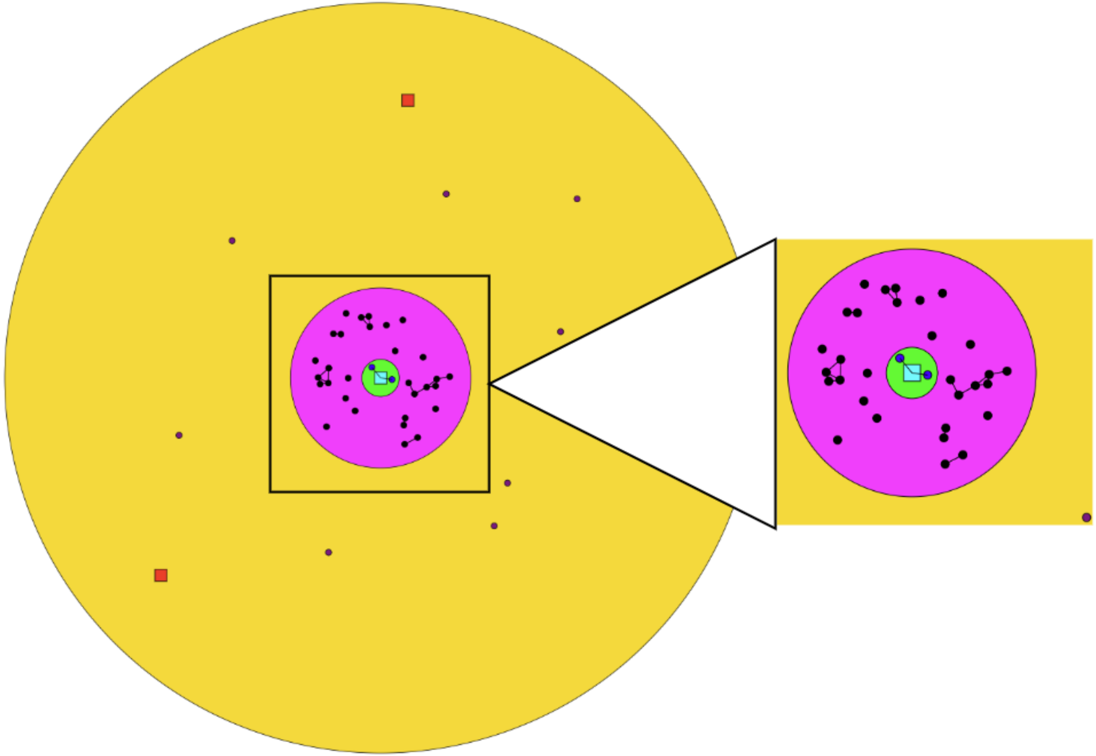
- Embry-Riddle Aeronautical University FIRST Grant
- Department of Defense SMART Fellowship

Questions?



Supporting Slides

The Experiment: Base Agent Actions

All agents have a set of actions they must perform, though the specifics of that action are altered based on the strategies active

- **Communicate**
  - Connect to nearby agents, send a copy of search data, and receive search data
- **Search**
  - Based on a search radius check grid positions nearby as searched in internal search grid
- **Check Position**
  - Based on agent position, does its behavior need to change?
- **Move**
  - Move based on active strategy

Weighted Scores for All Strategies