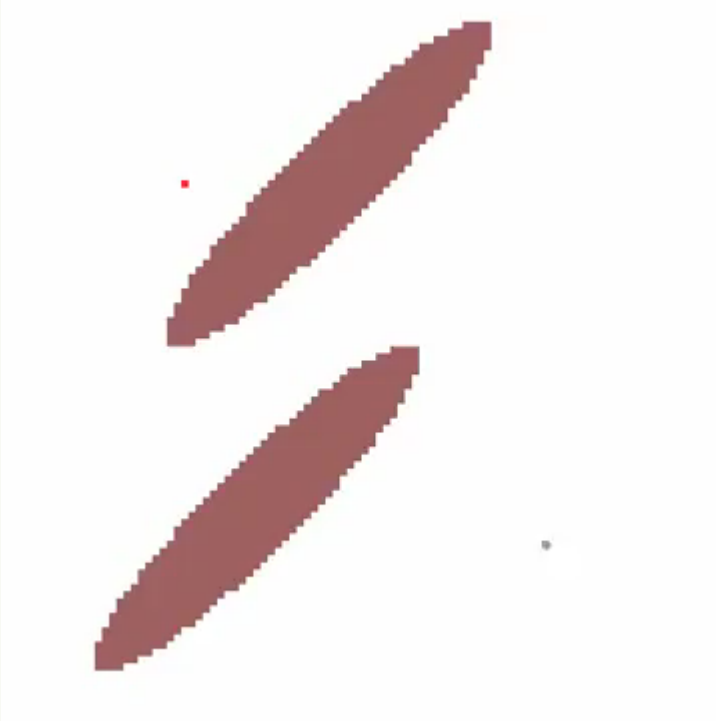
Operator Overload Problem

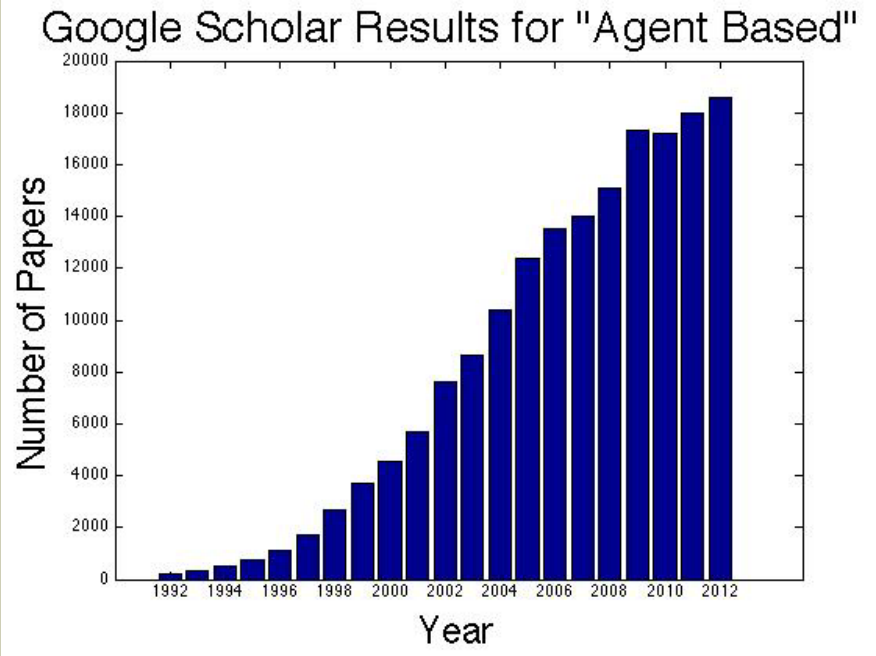
- Unmanned Aerial Vehicles (UAVs)
  - No on-board pilot
  - Varying degree of remote or autonomous control
  - Trending to smaller, cheaper, w/ greater capability
- **One or more** operators required to pilot **1 UAV**
- How can **1** operator control **several** UAVs?

Solution: Swarm Intelligence

- Swarm intelligent systems utilize emergence to solve problems
- **Emergence** – whole greater than sum of parts
- Simple local behaviors across many agents lead to complex phenomena
- Inspired by nature



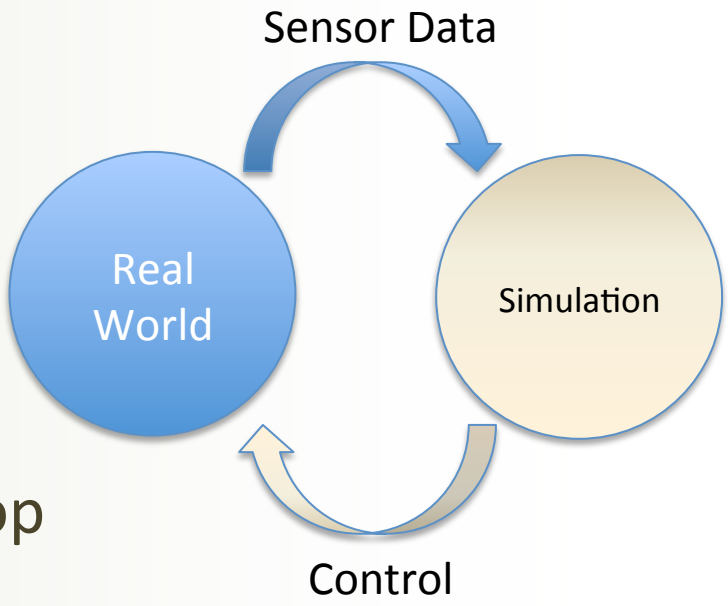
Agent-Based Modeling



- Model system as environment w/ interacting agents
- Bottom-up vs. top-down (equations)
- Captures generative nature of system
- Natural platform for modeling swarms

DDDAS

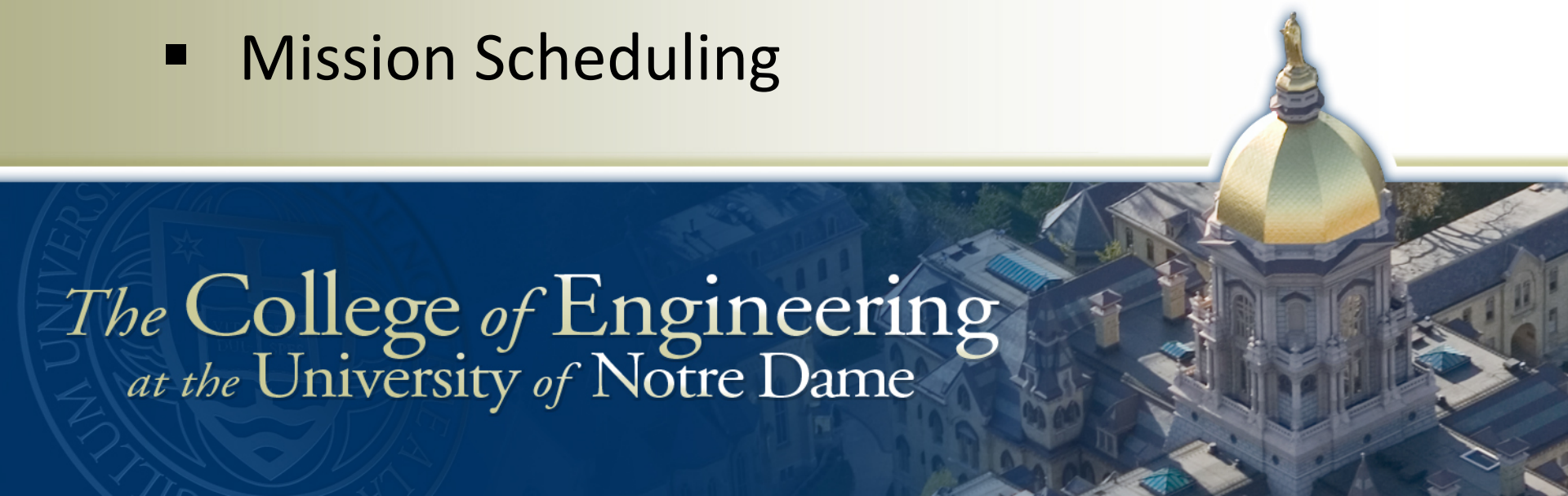
- Dynamic Data-Driven Application System (DDDAS) utilizes two components:
  - Incorporate dynamic data into executing application
  - Application data steers data-gathering process
  - Synergistic feedback control loop
- Excellent for modeling non-linear dynamics



Controlling UAV Swarms with DDDAS

Four-Project Survey:

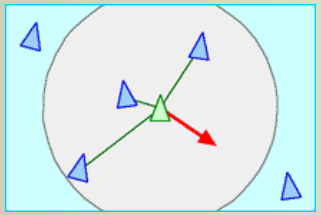
- Flocking Applications
- Communication
- Formation Control
- Mission Scheduling



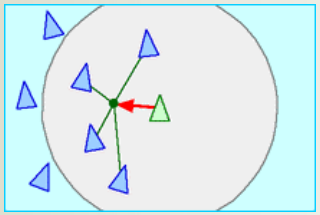
Flocking Applications

What is Flocking

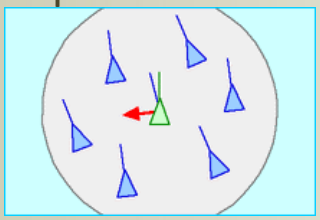
- BOIDS Reynolds (1987)



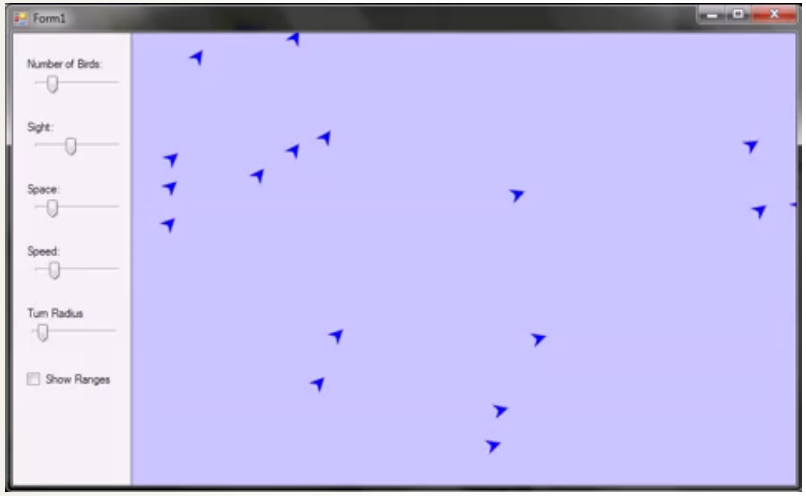
Separation



Cohesion



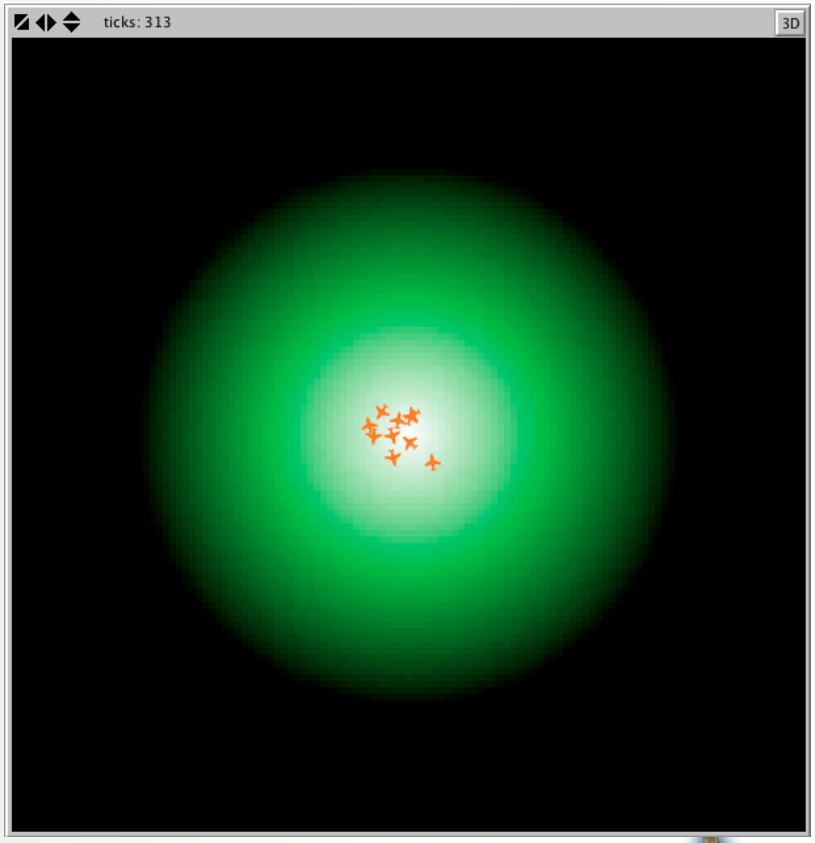
Alignment



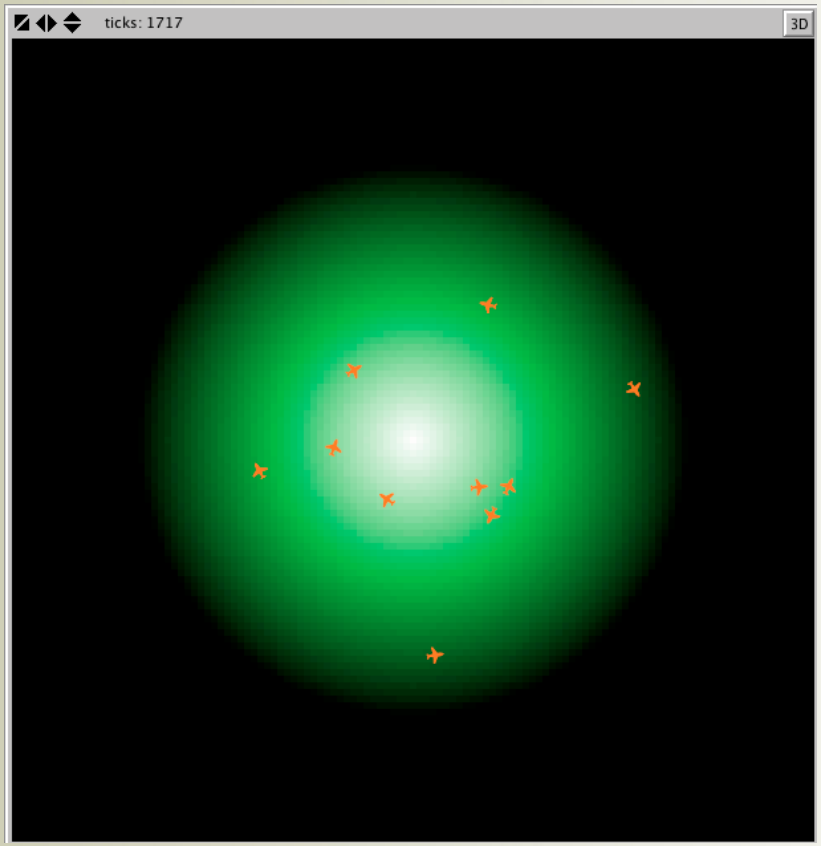
- Coordinated Flocking from Local Behavior
- Applied to Particle Swarm Optimization

Plume Scenario

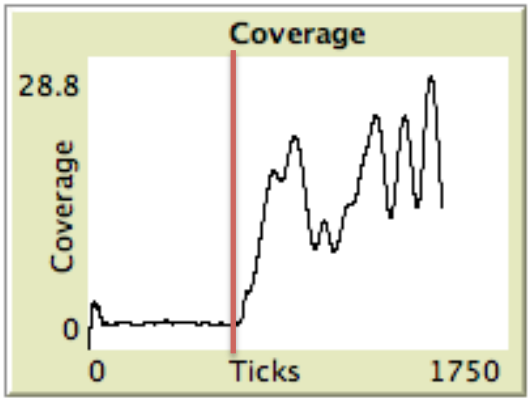
- Contaminant Plume
  - Highest Concentration at center
  - UAVs flock deployed to measure accident
- Want diverse measurements
- Ground operator controls cohesion



Plume Scenario



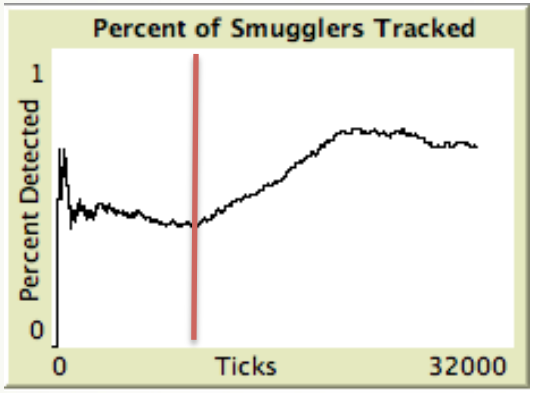
- Ground controller observes standard deviation

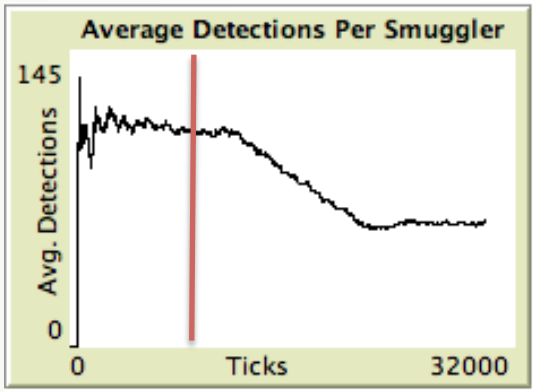


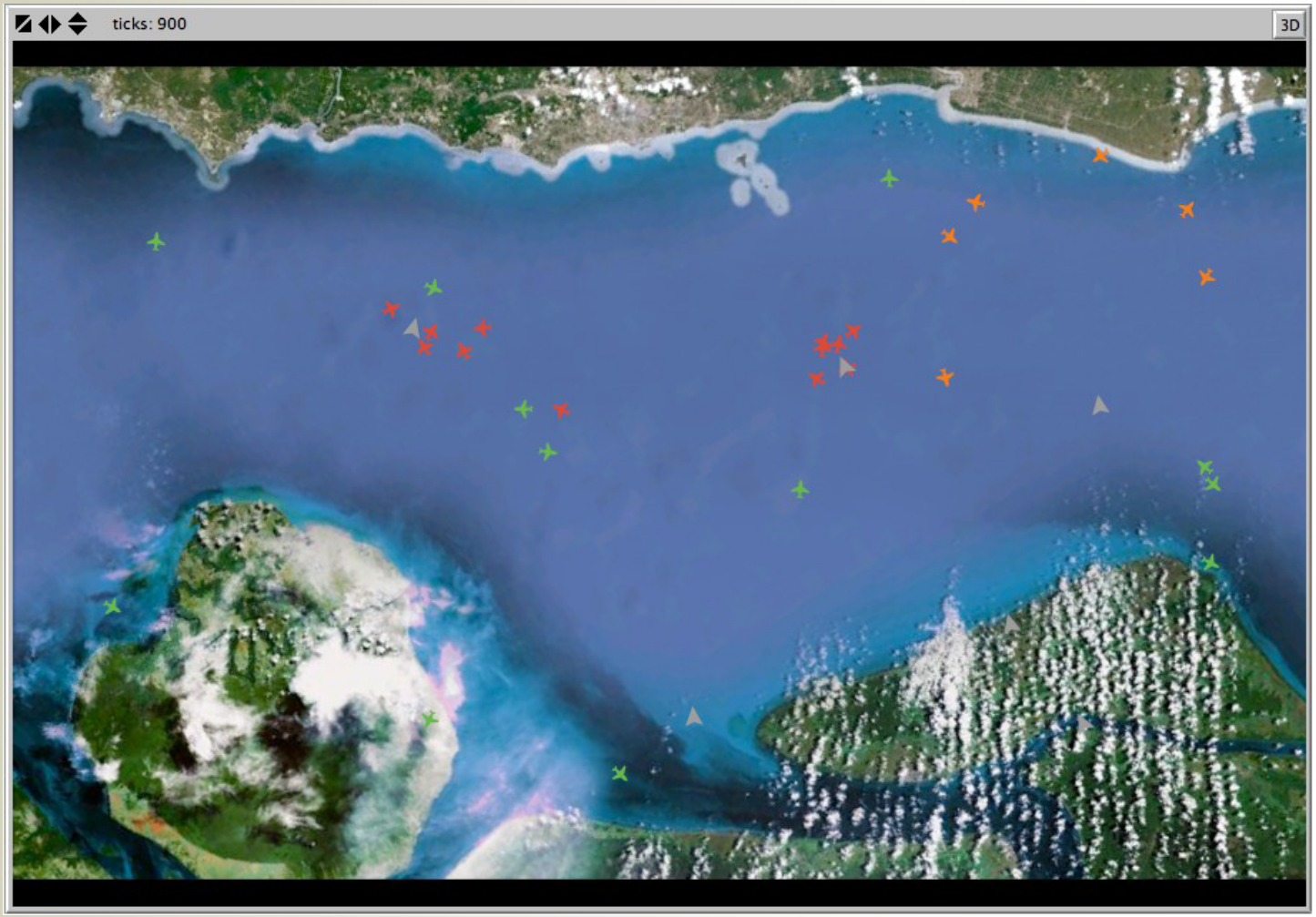
- Adjusts cohesion

Vessel Tracking

- 2 UAV Types
  - Searchers
  - Pursuers
- Operator controls:
  - Pursuer to Searcher ratio
  - # of Pursuers to track each vessel
- 2 Metrics
  - % of vessels detected
  - How well vessels tracked



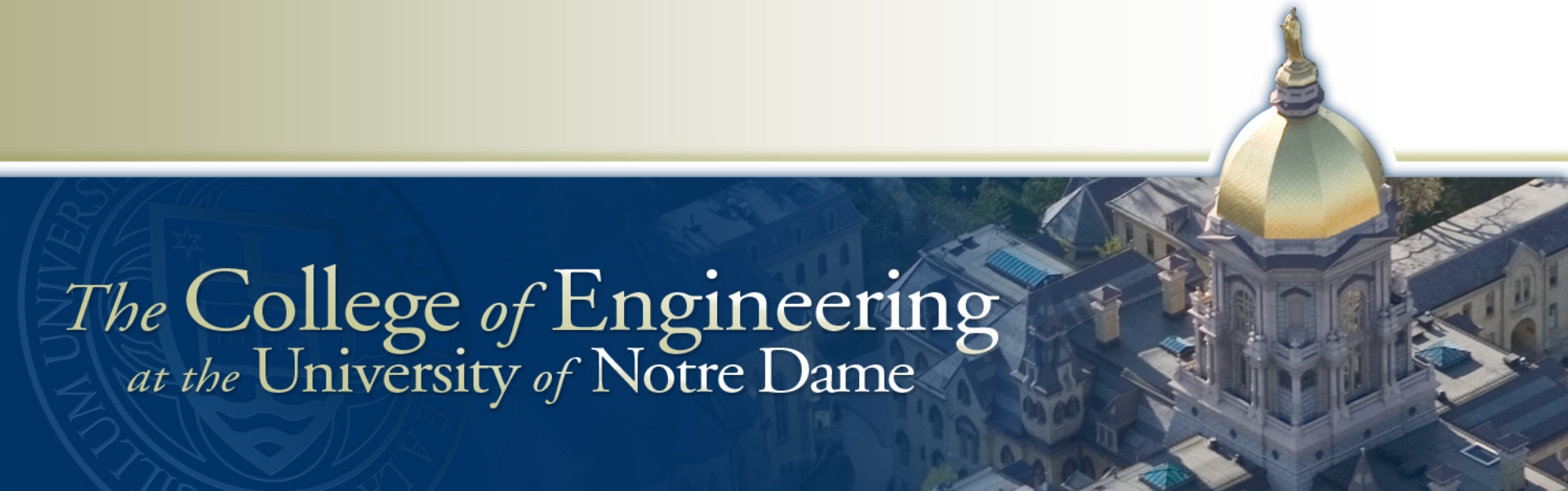



ticks: 900
3D

DDDAS

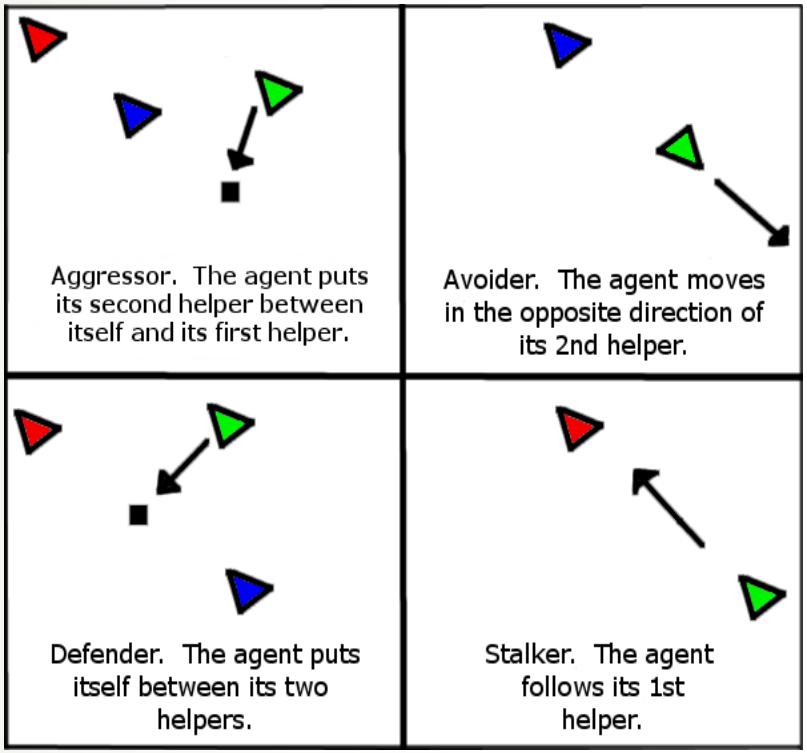
- Optimization via Simulation
  - Identify swarm metric
    - Coverage
    - Pursuers per Target
  - Calibrate simulation with current data
  - Simulate faster-than-real-time
  - Optimize application
    - UAVs are sensors, so
    - Sensor feedback control through simulation

Communication

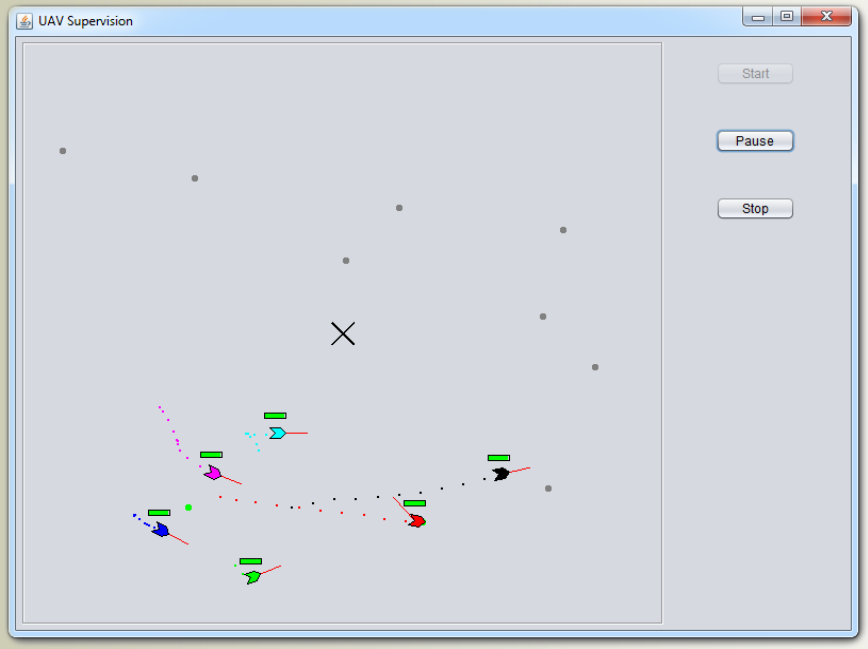


Icosystem Swarm Game

- Illustrates complex behavior from simple rules
- Each agent non-mutually associated with 1 or 2 other agents
- "Sight" parameter impacts global behavior



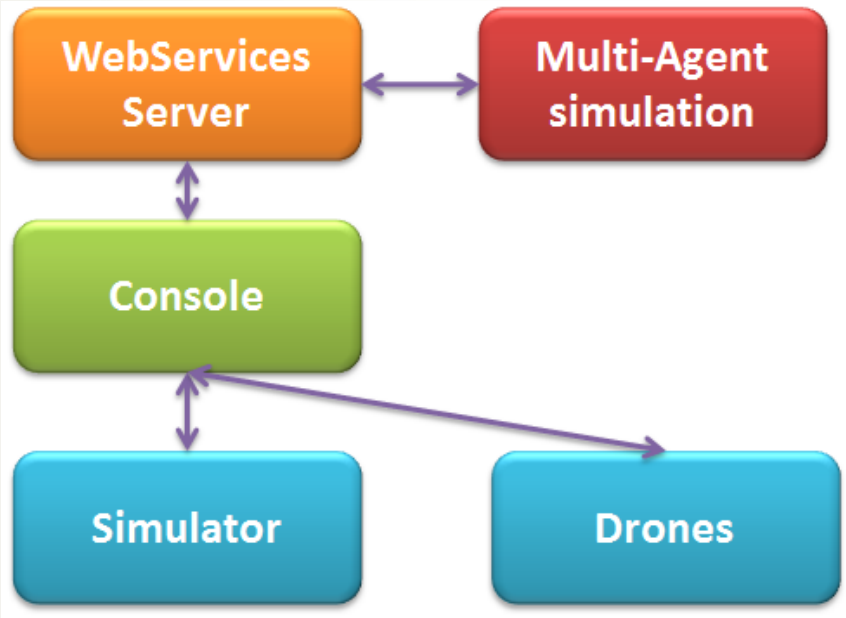
Target Search



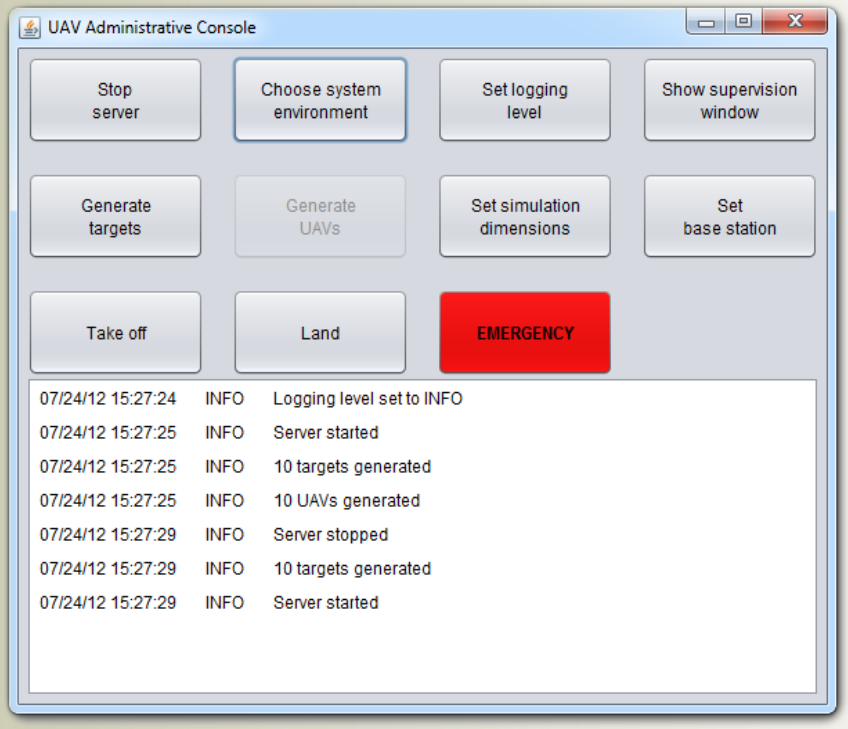
- Aggressor/Defender behavior implemented for target search
- Augmented with "Leader" that follows pre-assigned way-points
- Objective to maximize coverage, identify unknown targets

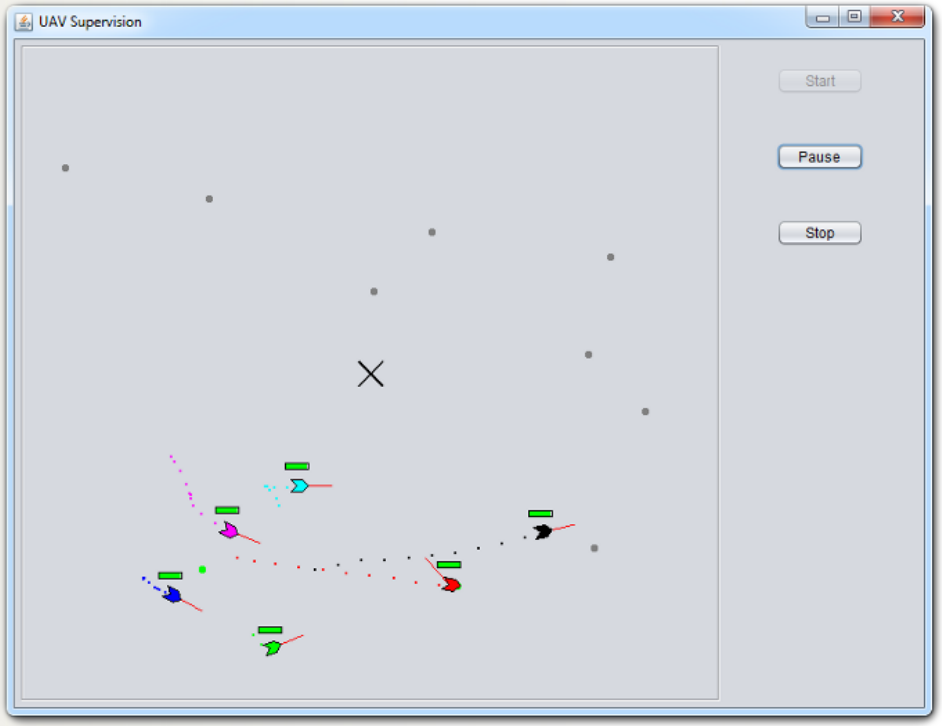
DDDAS Implementation

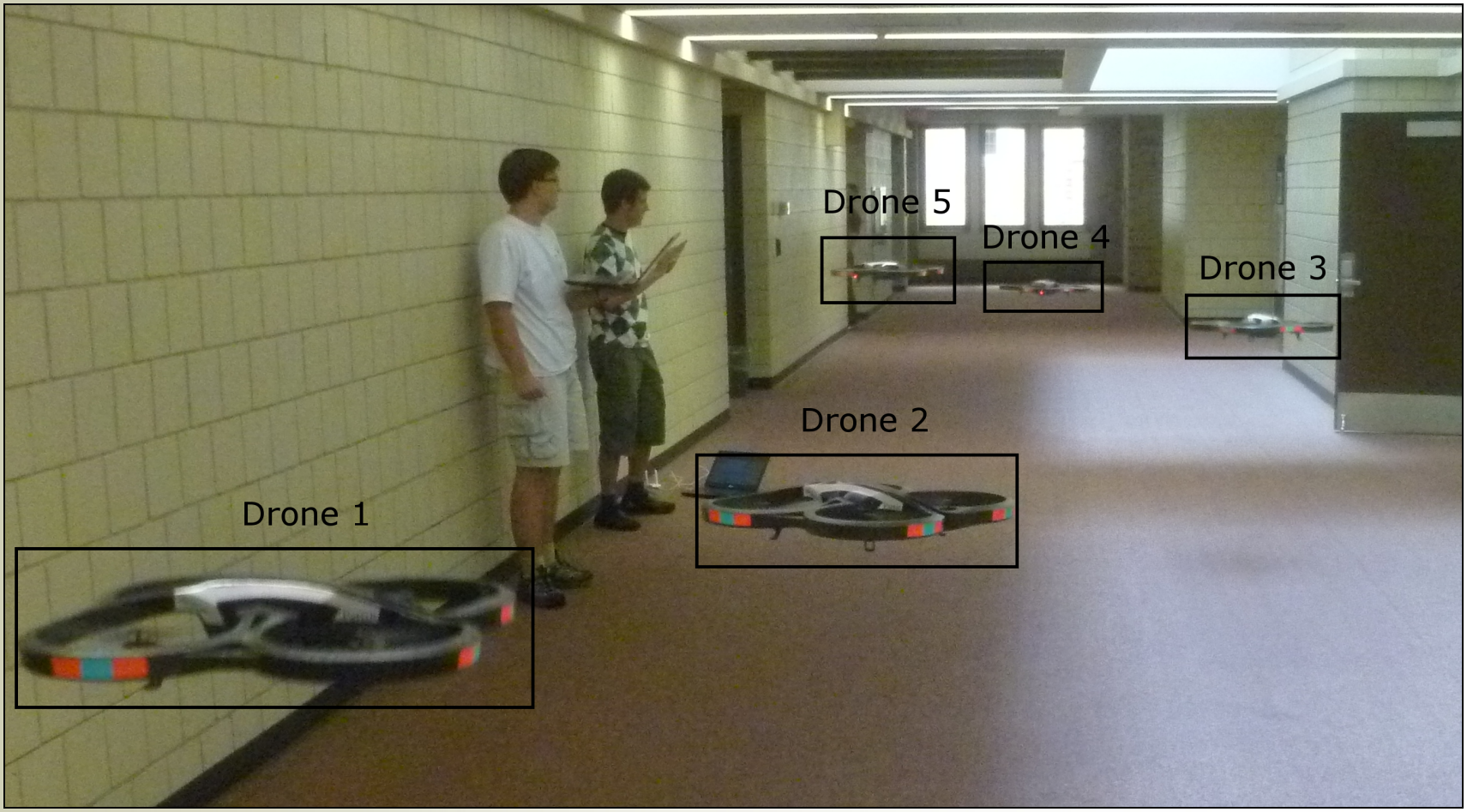
- DDDAS
  - Inputs "real-world" parameters
  - Execute simulation
  - Outputs results
  - Steers "real-world" application
- Communicates via webservices
- Experiments with intra-swarm communication
  - Fixed radius vs multi-hop
  - Energy Considerations



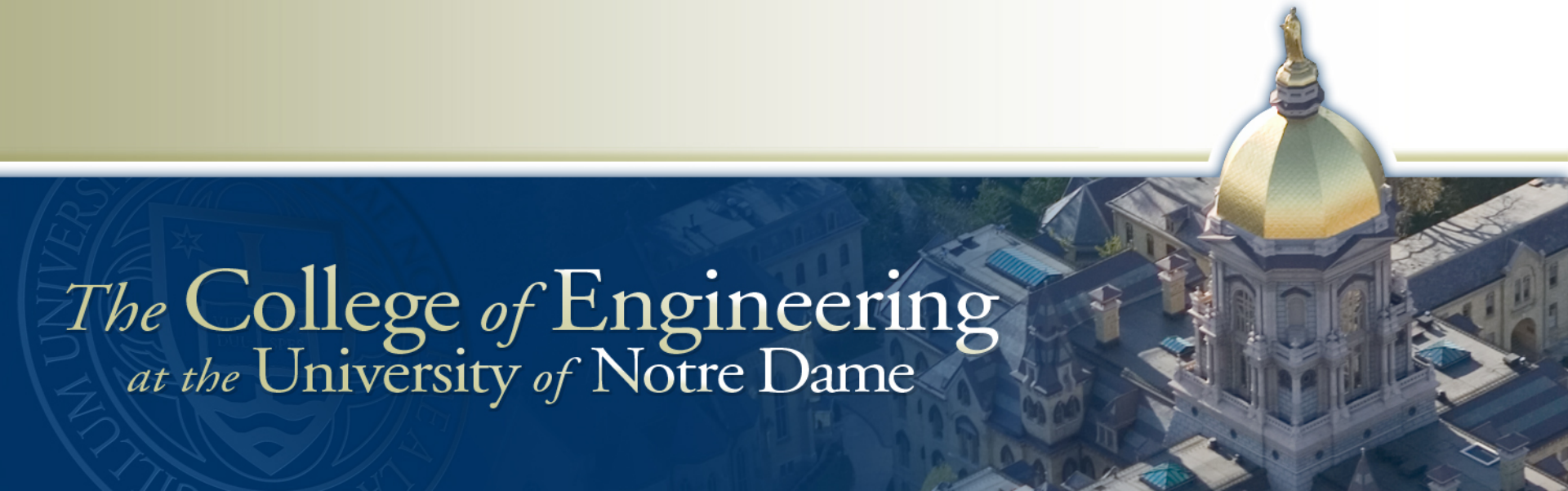
Console Screenshot





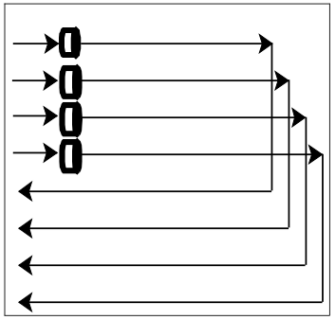

Drone 5
Drone 4
Drone 3
Drone 2
Drone 1

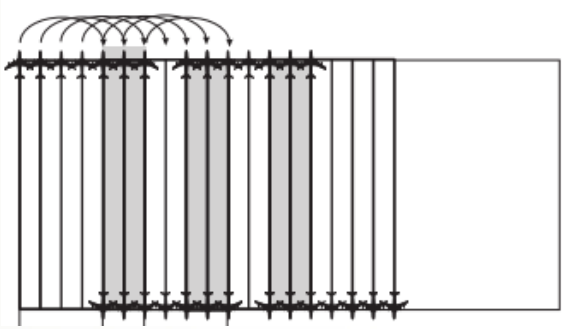
Formation Control



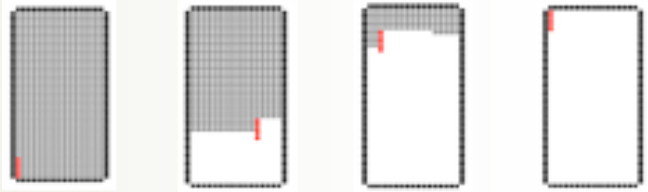
Cooperative Search w/ Swarms

- Developed previous work on cooperative search
- "Dynamic Cleaning" problem
- Two emergent protocols
  - Parallel Paths
  - SWEEP

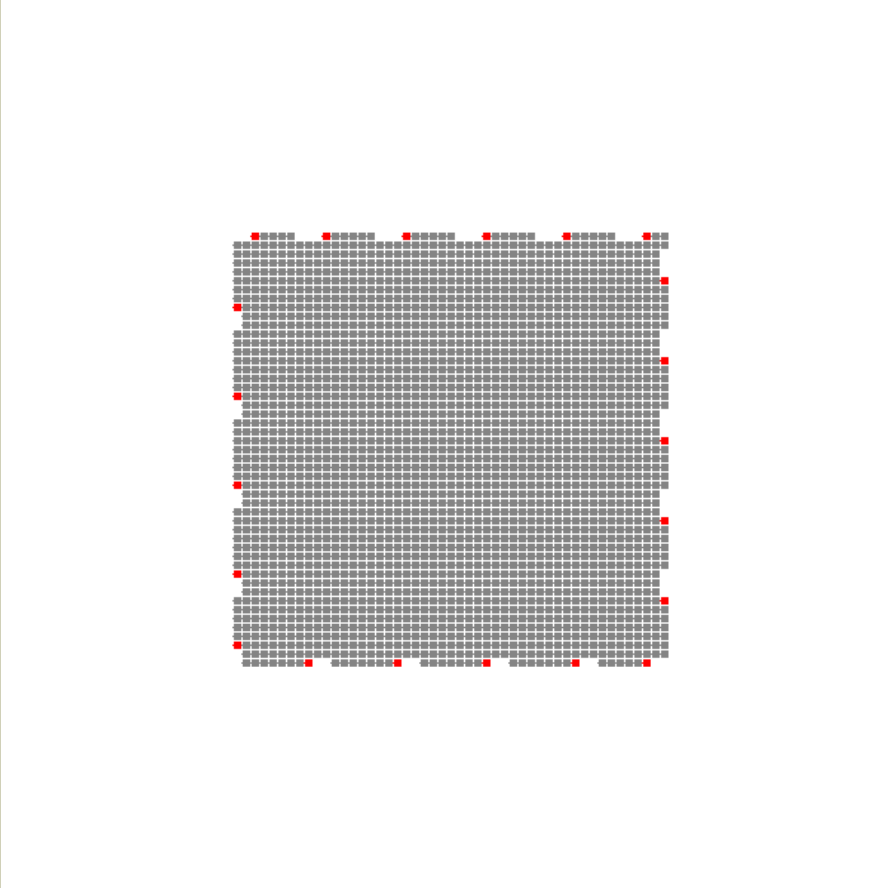




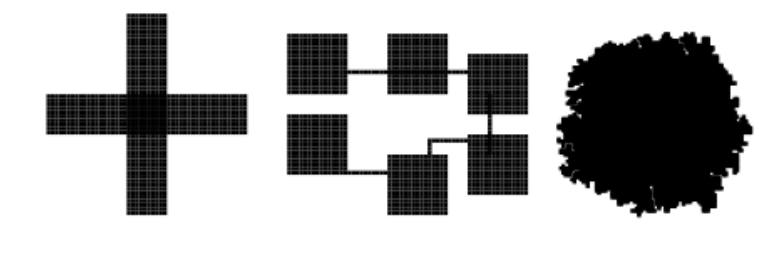
Parallel Path



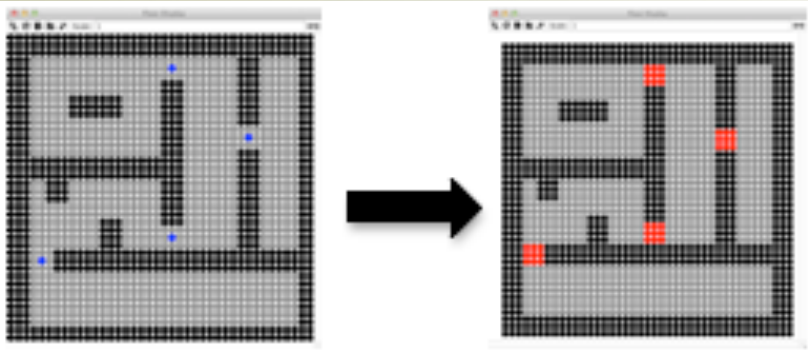
SWEEP Demo

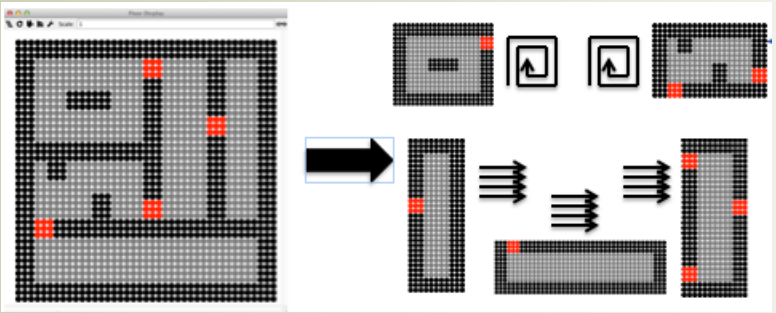


Capable of "cleaning" diverse topologies



Additional "Sentry" Behavior

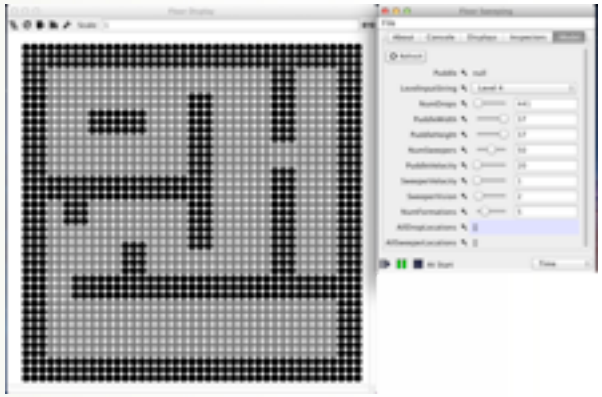




- The 2 cooperative search protocols have trade-offs
  - Parallel paths simple
  - SWEEP higher overhead but more applicable
- Add "sentry" to partition
- More efficiently search environment

DDDAS

- Agent-based simulation for ground control
- Highly dynamic environment
  - Topology change
  - UAV failure/reassignment
- Evaluate on different parameters
  - Time/steps
  - Cost/communication
- Implement within DDDAS framework



Runtime Console

Mission Scheduling

Scheduling Framework

- A **swarm** consists of many agents
- A **mission** consists many tasks
- Tasks are associated with a cost
- Some tasks may depend on other tasks
- The problem is to efficiently assign tasks to agents

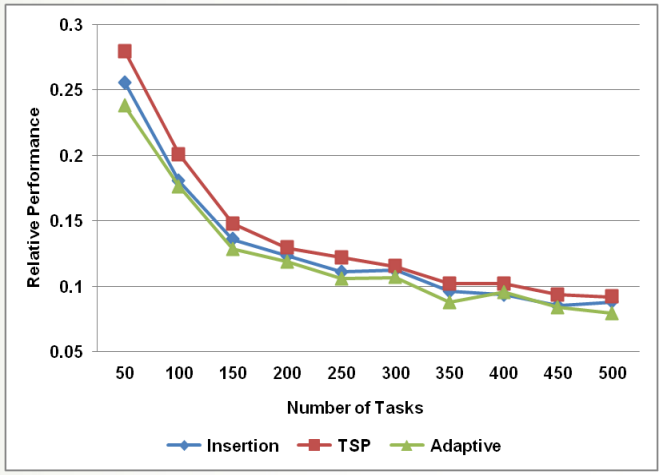
Symbol	Description
S	A UAV swarm.
v_i	The ith UAV in the swarm.
$v_i(t)$	The state of the ith UAV at time t.
n	Total number of UAVs in the swarm.
MS	A mission.
T	The set of tasks in the mission.
t_i	The ith task.
D	The set of task dependencies in the mission.
$\{t_i, t_j\}$	A task dependency pair specifying task t_j has a dependency on task t_i.
MS_t	The state of a mission at time t.
C	The set of completed tasks in the mission state.
P	The set of in-progress tasks in the mission state.
W	The set of not-started tasks in the mission state.
M	Scheduling mapping from the set of tasks to the swarm.

Solution Approach

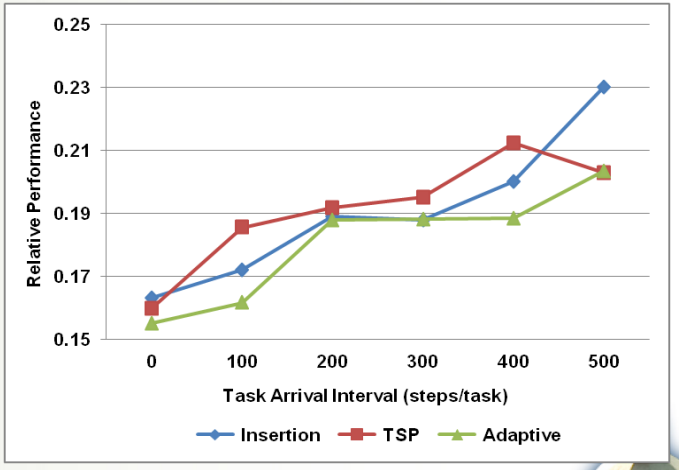
- Global-local hybrid planning and scheduling
  - 1 Swarm Control Agent (SCA)
    - Interface between ground operator and UAVs
    - Assigns new mission tasks to UAVs
  - UAV agent
    - Service running on UAV
    - Communicates with SCA
- SCA attempts to minimize cumulative cost
  - Maintain task queue
  - Assign tasks as they become available
- UAV agent decides order of execution

DDDAS

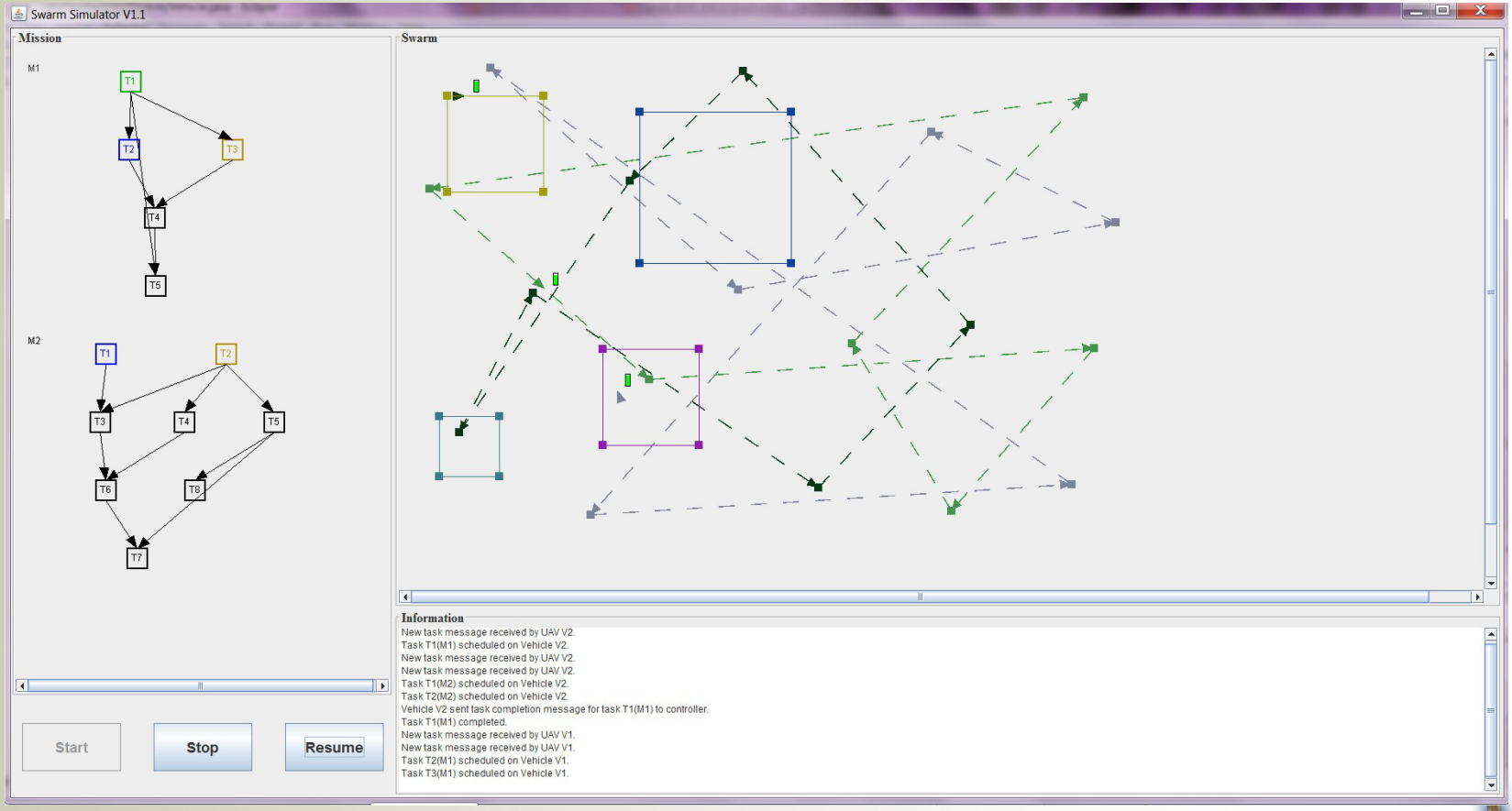
- Agent-based simulation developed in Java
- Several local assignment algorithms implemented
  - First-come first-serve
  - Travelling Salesman
  - Insertion-based
  - Adaptive
- Simulation executed by ground control upon arrival of new missions



Relative Performance to First-come First-serve



Scheduling GUI



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Thank you! Questions?