Fly with Me: Algorithms and Methods for Influencing a Flock

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Bird Strikes in Aviation

$3 billion per year (PreciseFlight)

Common Bird Strike Reduction Methods

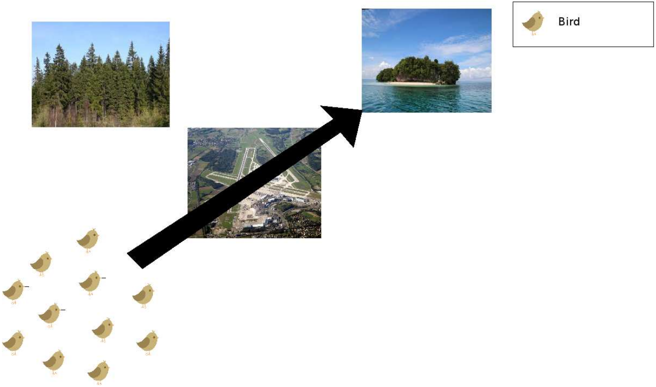
Common Bird Strike Reduction Methods

Common Bird Strike Reduction Methods

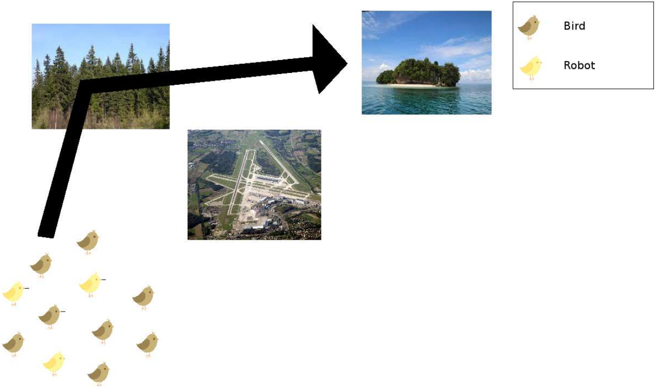
Clear Flight Solutions Robird

- Modeled after a peregrine falcon
- Will be first bird drone to operate on a daily basis for commercial operations at an airport
- 13 week trial at Edmonton begins July 1
- Remote controlled by a trained pilot

Motivating Example



Motivating Example



Thesis Question

Thesis Question:

How can influencing agents be utilized in various types of flocks in order to influence these flocks towards a particular behavior?

Background

- Artificial intelligence
  - Multi-agent systems
    - Teamwork
      - Ad hoc teamwork
    - Swarm behavior
      - Flocking

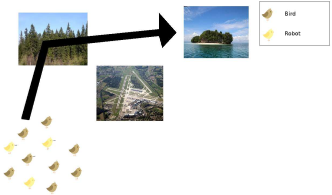
Multi-agent Teamwork

- All agents have the same goal
- Usually considers how to design teams of agents

Ad Hoc Teamwork

- Only in control of a single agent or subset of agents
- Shared goals
- No pre-coordination
- Limited or no communication

Scientific question: How to design an agent to productively join a pre-existing team while requiring no pre-coordination?



Flocking

- Emergent swarm behavior
- Simple local behaviors & interactions
- Group behavior appears well organized and stable

Thesis Question

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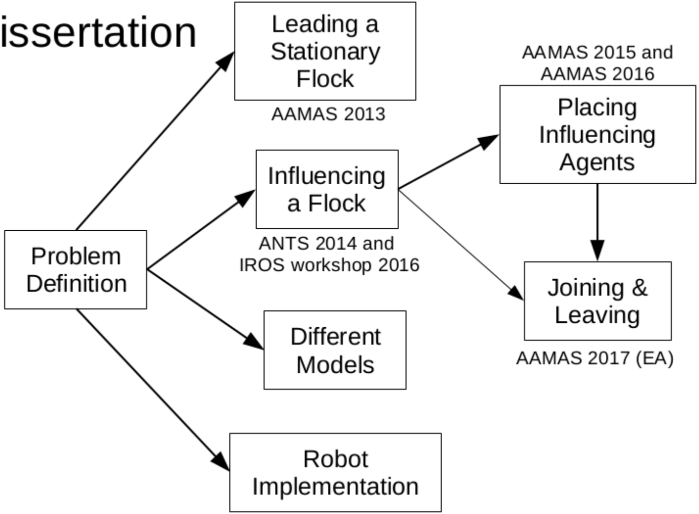
How can influencing agents be utilized in various types of flocks in order to influence these flocks towards a particular behavior?

Relation to Existing Approaches

- Simulating flock behavior Reynolds 1987 and Vicsek et al. 1995
  - My work: Influence the flock using influencing agents
- Influence the flock to converge eventually Jadbabaie et al. 2003, Su et al. 2009, and Celikkanat and Sahin 2010
  - My work: Influence the flock to converge quickly
- Influencing agent moves much quicker than the flock Han et al. 2006
  - My work: Influencing agents move no quicker than the flock
- Influence a flock via heterogenous herders Lien et al. 2004, Lien et al. 2005, Pierson and Schwager 2015
  - My work: Influence the flock from within

My dissertation



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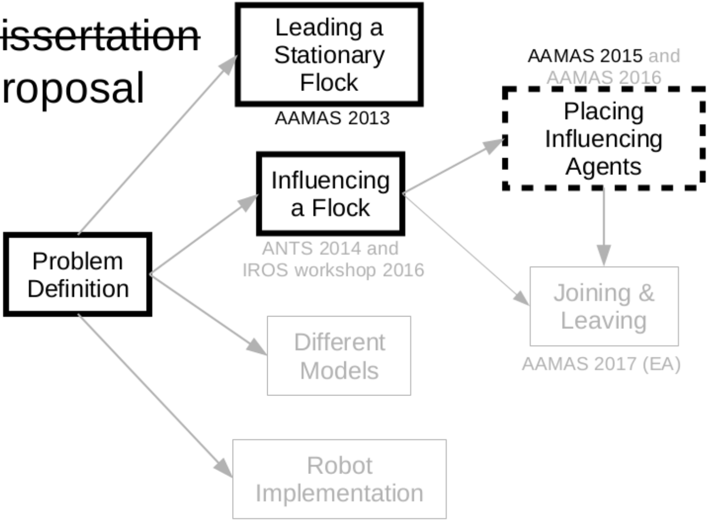
My proposal



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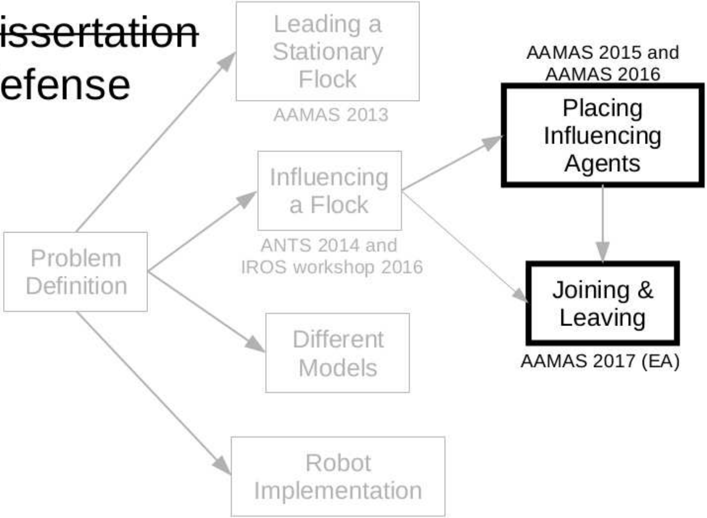

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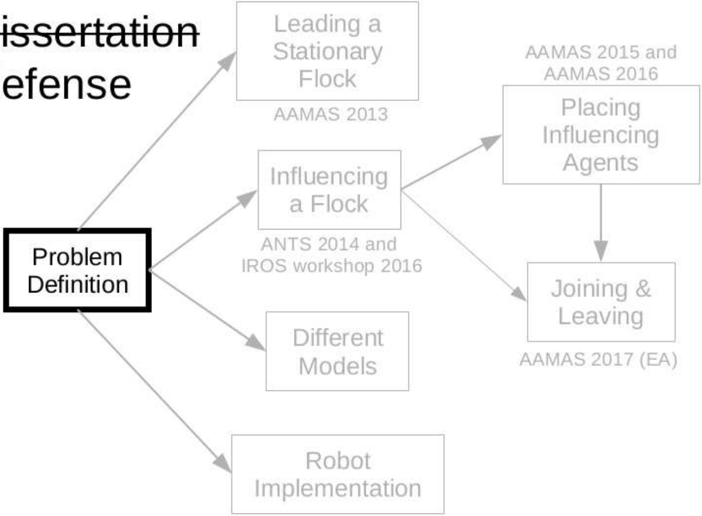


Problem Definition

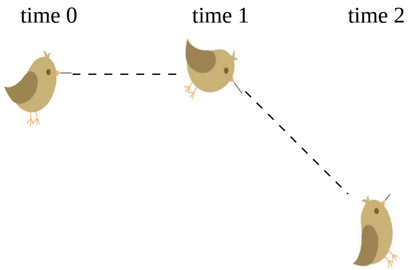
- Define the problem of adding influencing agents to a flock as new scenario for studying ad hoc teamwork

- Introduce assumptions and parameters

Problem Definition

All agents have:

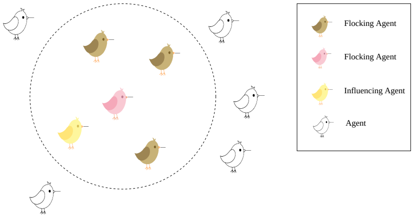
- Constant velocity
- 2D Position
- Global orientation



Problem Definition - Neighborhood Model

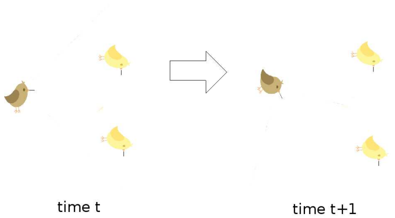
Each agent reacts only to agents within a certain neighborhood around itself.

- Characterized by a visibility radius for most of this dissertation



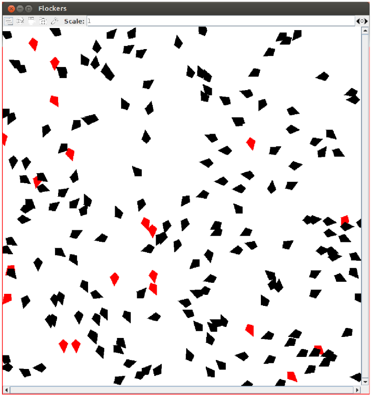
Problem Definition - Influence Model

An agent's orientation at the next time step is set to be the average global orientation of all agents currently within its neighborhood.



MASON Simulator

- Multi-agent simulation library core
- Flockers domain



S. Luke, C. Cioffi-Revilla, L. Panait, K. Sullivan, and G. Balan. MASON: A multi-agent simulation environment. In Simulation: Transactions of the Society for Modeling and Simulation International, 2005.

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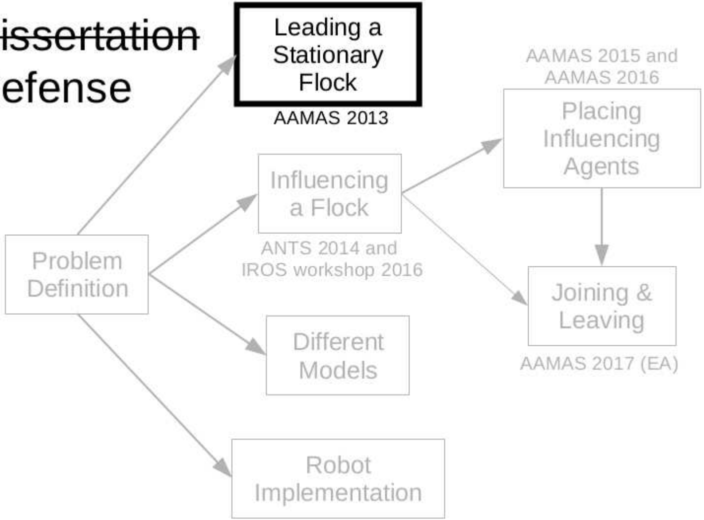

Leading a Stationary Flock

- Set bounds on the extent of influence the influencing agents can have when both the influencing agents and flocking agents are stationary
- Contributed an algorithm for orienting a stationary flock to a desired orientation using stationary or non-stationary influencing agents
- Introduced behaviors for influencing agents that are outside of any flocking agent's neighborhood

K. Genter, N. Agmon, and P. Stone. Ad hoc teamwork for leading a flock. In AAMAS'13, May 2013.

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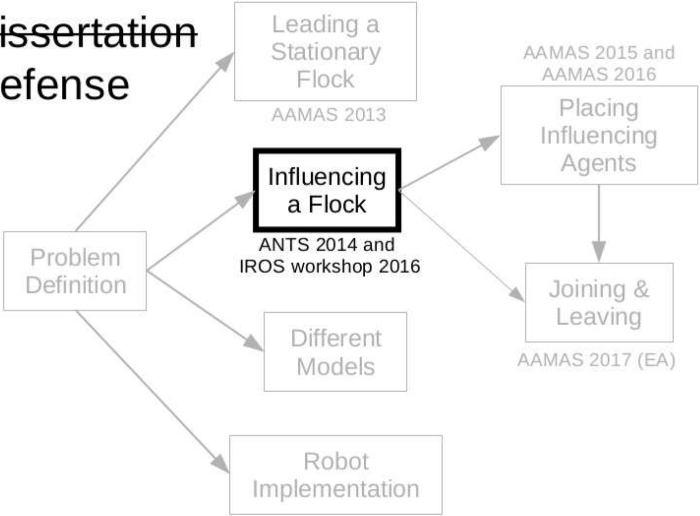

Influencing a Flock

- Contributed algorithms that can be used to influence a flock to orient towards a desired orientation
- Experimentally considered how to maneuver the flock through turns quickly but with minimal agents being separated

K. Genter and P. Stone. Influencing a flock via ad hoc teamwork. In Ninth International Conference on Swarm Intelligence (ANTS'14), September 2014.

K. Genter and P. Stone. Ad hoc teamwork behaviors for influencing a flock. Acta Polytechnica, 2016.

1-Step Lookahead Behavior

- For a set number of discrete orientations the influencing agent could adopt, how will each neighbor be influenced?
  - Must estimate how other neighbors of each neighbor will influence the neighbor
- Choose orientation that results in the least average difference between the goal orientation and each neighbor's new orientation after one time step

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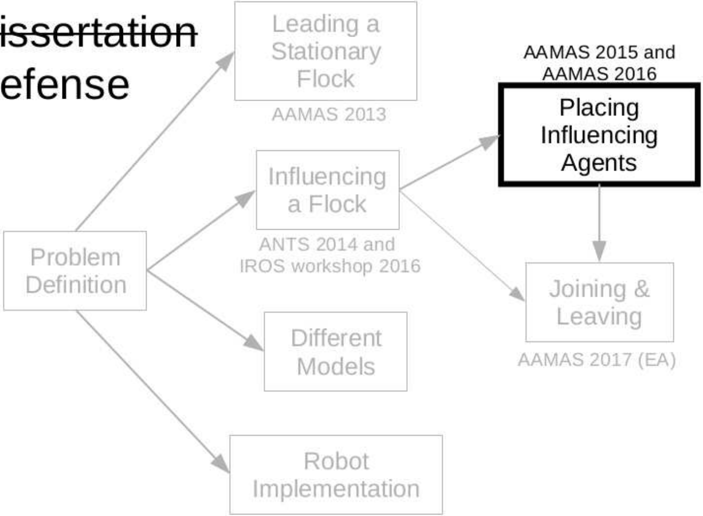


Placing Influencing Agents into a Flock

- The position of influencing agents within the flock affects their influence
- Contribute various approaches for placing influencing agents directly into a flock
- Evaluate on various flock sizes and compositions

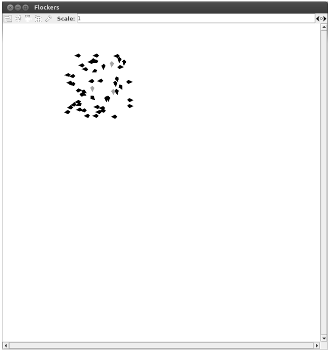
K. Genter, S. Zhang, and P. Stone. Determining placements of robots in a flock. In AAMAS'15, May 2015.

K. Genter and P. Stone. Adding influencing agents to a flock. In AAMAS'16, May 2016.

Placing Influencing Agents into a Flock

Assumptions:

- Flock begins in set area
- Non-toroidal
- Flock may or may not be cohesive
- The flock will interact with each other according to the assumed model



Determining Desired Positions

- Constant-time placement methods
- Graph placement method
- Hybrid placement methods
- Two-Step placement method
- Clustering placement methods

Determining Desired Positions - Constant-time Methods

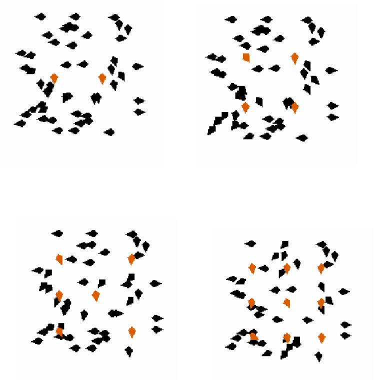
- Constant-time placement methods
  - Random Placement
  - Grid Placement
  - Border Approach
- Graph placement method
- Hybrid placement methods
- Two-Step placement method
- Clustering placement methods

Determining Desired Positions - Constant Time Methods

- Random Placement
  - Randomly place influencing agents within the dimensions of the flock
- Grid Placement
- Border Approach

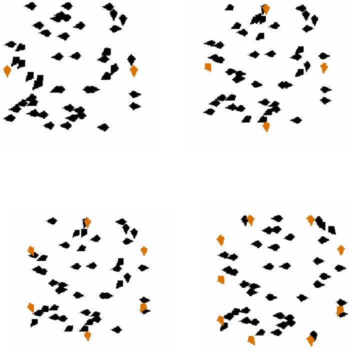
Grid Placement Method

Place influencing agents at predefined gridded positions throughout flock

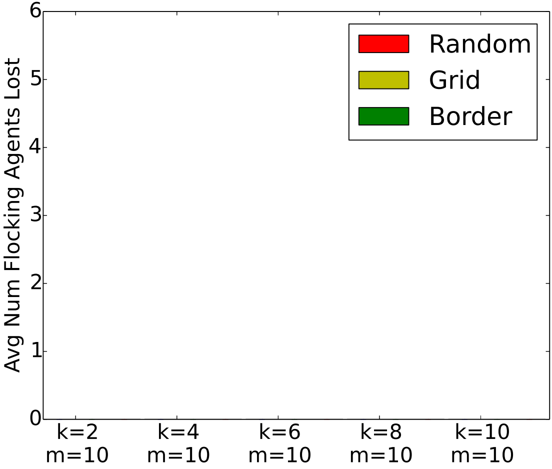


Border Approach Method

Place influencing agents around the space covered by the flocking agents

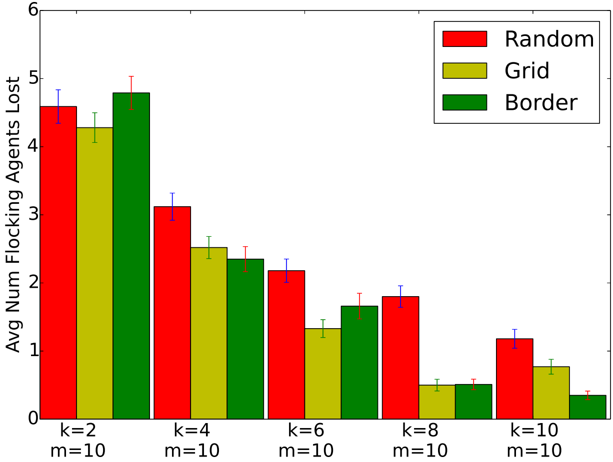


Experimental Results - Constant-time Placement



100 trials, error bars = standard error of the mean.

Experimental Results - Constant-time Placement



100 trials, error bars = standard error of the mean.

Determining Desired Positions - Graph Method

- Constant-time placement methods
- Graph placement method
- Hybrid placement methods
- Two-Step placement method
- Clustering placement methods

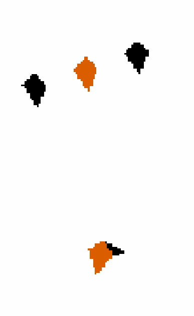
Graph Placement Method

Consider sets of positions in which the influencing agents could be placed.

Evaluate how well these sets connect the flocking agents with the influencing agents.

Graph Placement Method - Steps (1)

- Consider potential influencing agents positions
  - Mid-points between flocking agents
    - Only for flocking agents within 2 neighborhood radii
  - Near flocking agents



Graph Placement Method - Steps (2)

- Evaluate each set of influencing agent positions:
  - minimize flocking agents not *connected* to an influencing agent
  - maximize *connections* between flocking agents and influencing agents

Graph Placement Method - Steps (2)

- Evaluate each set of influencing agent positions
  - minimize flocking agents not *connected* to an influencing agent
  - maximize *connections* between flocking agents and influencing agents

Experimental Results - Graph Placement

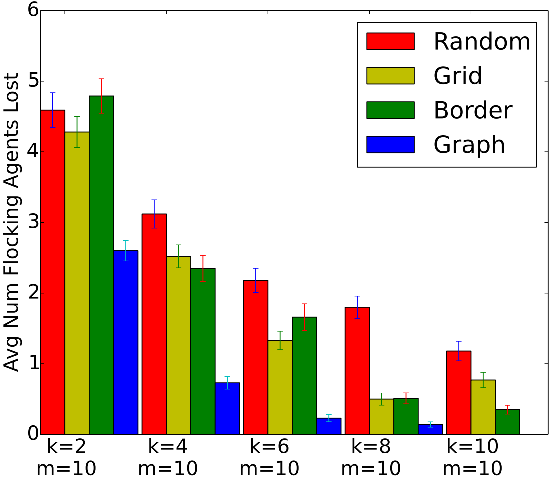


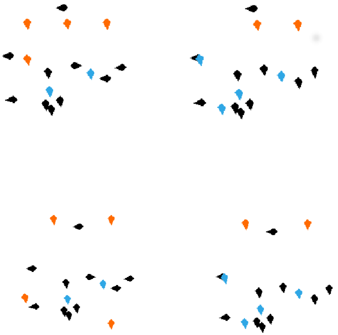
Figure : 100 trials, error bars = standard error of the mean

Determining Desired Positions - Hybrid Methods

- Constant-time placement methods
- Graph placement method
- Hybrid placement methods
- Two-Step placement method
- Clustering placement methods

Hybrid Placement Method

Use the Graph placement method to choose the first k_g influencing agent placements. Then select the remaining $k - k_g$ placements using an constant time placement method.



Experimental Results - Hybrid (Grid/Graph) Placement Method

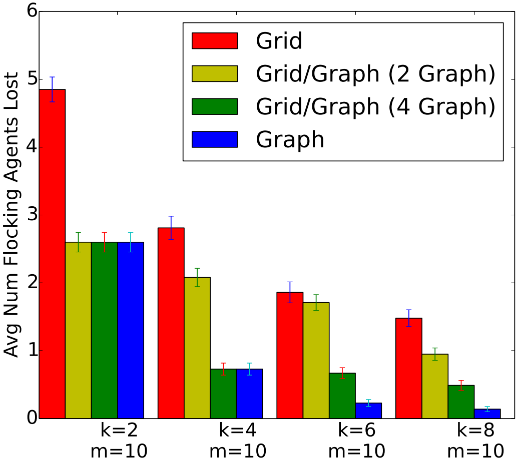


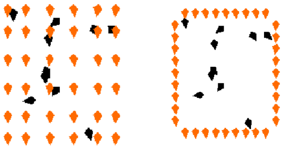
Figure : 100 trials, error bars = standard error of the mean

Determining Desired Positions - Two-Step Method

- Constant-time placement methods
- Graph placement method
- Hybrid placement methods
- Two-Step placement method
- Clustering placement methods

Two-Step Placement Method

- Constant-time methods for defining a set S of possible positions
  - Grid Set
  - Border Set
- Methods for selecting k influencing agent positions from S
  - Random
  - OneNeighbor
  - MaxNeighbors
  - MinUninfluenced



Determining Desired Positions - Clustering Methods

- Constant-time placement methods
- Graph placement method
- Hybrid placement methods
- Two-Step placement method
- Clustering placement methods

Clustering Placement Methods

Well-recognized clustering methods to identify *k* clusters of flocking agent positions

Figure : Farthest First

Figure : K-Means

Clustering Placement: Farthest First

- Randomly choose a flocking agent and place the first influencing agent
- Then, on each subsequent placement, place an influencing agent at the flocking agent farthest from all previously placed influencing agents

Clustering Placement: K-Means

- Choose *k* flocking agents as cluster centers
- Until convergence:
  - Assign all flocking agents to nearest cluster center
  - Calculate centroid for each cluster, centroid becomes a new cluster center

Experimental Results - Clustering Placement

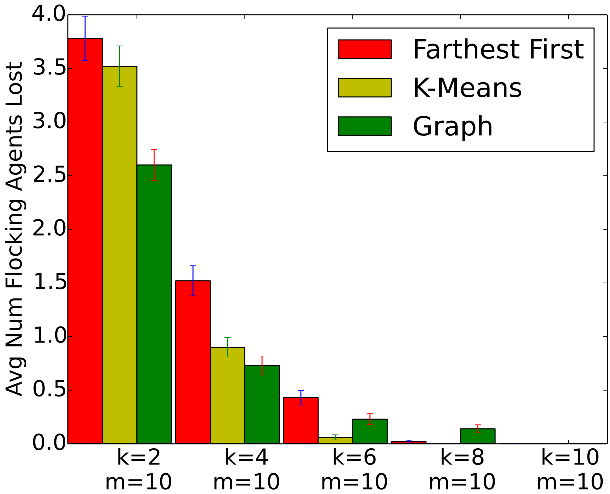


Figure : 100 trials, error bars = standard error of the mean.

Placing Influencing Agents into a Flock - Summary

- The position of influencing agents within the flock affects their influence
- Contributed various approaches for placing influencing agents directly into a flock
- Evaluated on various flock sizes and compositions

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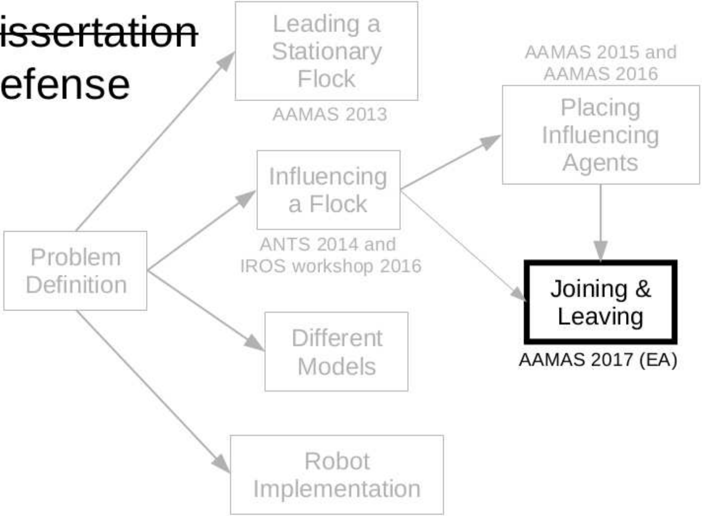


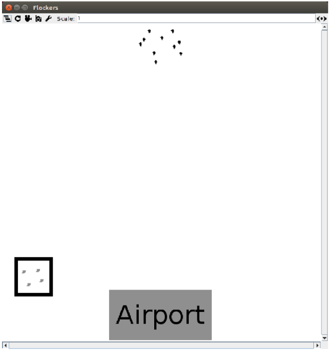
Joining and Leaving a Flock

- Consider how influencing agents should join a flock in motion with the goal of altering its orientation
    - Why don't placement methods work?
- Consider how influencing agents can leave a flock

K. Genter and P. Stone. Agent behaviors for joining and leaving a flock (Extended Abstract). In AAMAS'17, May 2017.

Joining and Leaving a Flock

- Leave a station positioned ahead of the flock
- Assumptions:
  - Influencing agents can not travel faster than the flocking agents
  - Flock is cohesive and flocking in a particular direction



Approaches for Joining and Leaving a Flock

Two different scenarios:

- Hover: the influencing agents are able to hover with a particular orientation at a set position
- Intersect: the influencing agents maintain the same velocity as the flocking agents

Approaches for Joining a Flock

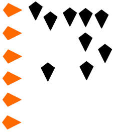
Two different scenarios:

- Hover: the influencing agents are able to hover with a particular orientation at a set position
- Intersect: the influencing agents maintain the same velocity as the flocking agents

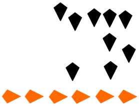
Intersect Approach

- Target formation
- Calculate the desired time to join the flock and begin influencing
  - All influencing agents join together
  - Constant velocity

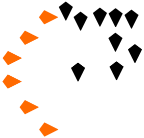
Intersect: Target Formations



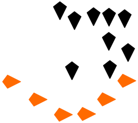
(a) Push to Goal Line



(b) Forward Line



(c) Push to Goal Funnel



(d) Forward Funnel

(e) L Corral

Approaches for Leaving a Flock

Three different scenarios:

- Hover: all of the influencing agents hover in place facing the desired orientation of the flock
- Nearest Edge: leave the flock at the nearest edge
- Influence while Leaving: trade-off between influencing and leaving

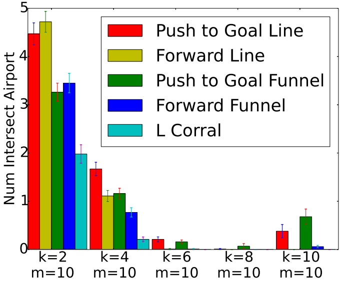
Nearest Edge Approach for Leaving

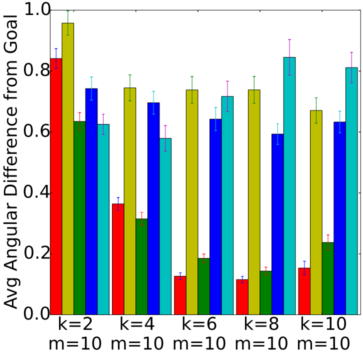
- Influencing agents know approximate position in flock
- When time to leave, orient towards the nearest edge
  - Nearest 3-edge: don't leave towards the flock's desired orientation
  - Nearest 2-edge: don't leave towards the airport or the flock's desired orientation

Influence while Leaving Approach for Leaving

- Alternate between influencing and leaving
- If no neighbors, leave
- Else if the neighbors aren't aligned to the goal or the influencing agent has left the flock for too long, influence
- Else, leave

Sample Results





Intersect for joining and *influence while leaving* for leaving. 100 trials, error bars = standard error of the mean.

Joining and Leaving a Flock - Summary

- Considered how influencing agents should join a flock in motion with the goal of altering its orientation
- Considered how influencing agents can leave a flock

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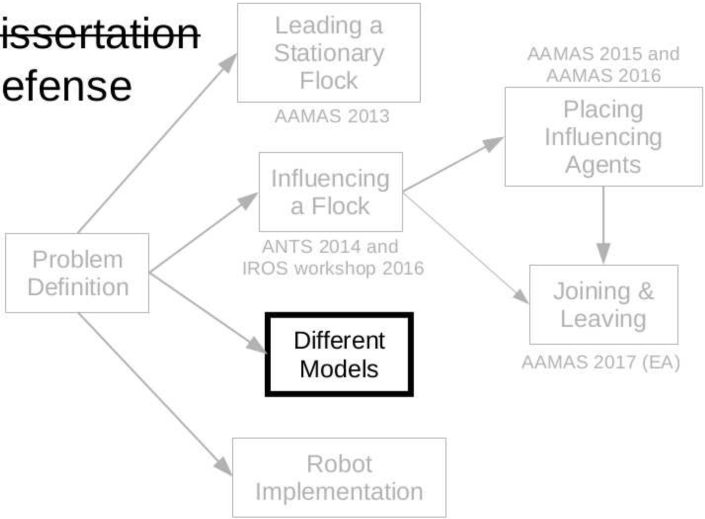

Evaluation on Different Flocking Models

- How well do the methods generalize to other flocking models?
  - Alternate neighborhood models
  - Full Reynolds flocking algorithm
- Do the influencing agents need to know the true model?

Different Neighborhood Models

- Considered alternate neighborhood models:
  - Visibility Sector
  - N-Nearest Neighbors
  - Weighted Influence
- The 1-Step lookahead algorithm generalized to different neighborhood models
- It is not critical that the influencing agents know the true neighborhood model

Different Influence Models

- Considered three aspects of Reynolds flocking algorithm:
  - Alignment: towards average heading of neighbors
  - Separation: away from neighbors to avoid collisions
  - Cohesion: towards the average position of neighbors
- Best for influencing agents to believe the flocking agents are behaving according to the Alignment influence model

Evaluation on Different Flocking Models - Summary

- The methods generalize well to other (similar) flocking models
  - Alternate neighborhood models
  - Full Reynolds flocking algorithm
- Knowing the true model utilized by the flocking agents is not critical

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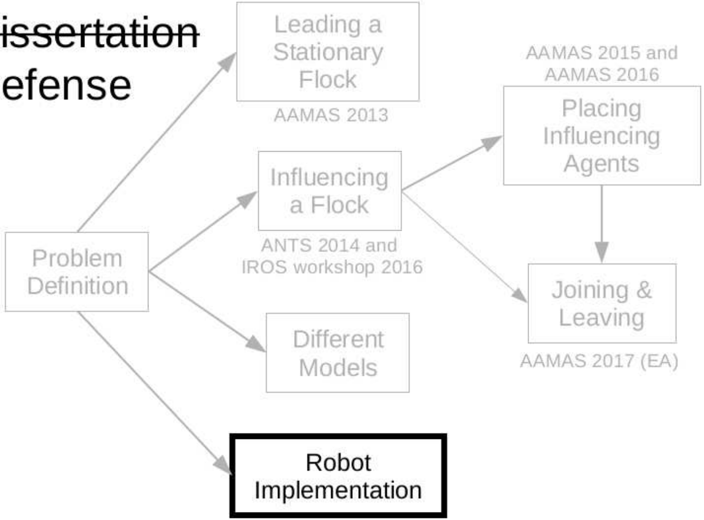
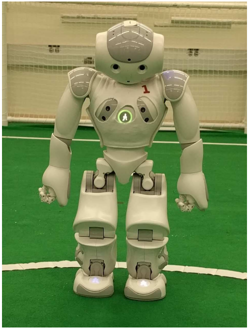


Robot Implementation

How can influencing agents influence a flock of bipedal robots to avoid a particular area?



Robot Implementation - Summary

- The 1-Step lookahead algorithm can be utilized to influence a flock of bipedal robots with small alterations
  - Only consider influencing agent orientations that can be reached in one time step

Thesis Question

Thesis Question:

How can influencing agents be utilized in various types of flocks in order to influence these flocks towards a particular behavior?

Future Work

- Additional coordinated influencing agent behaviors
- Placement based on agent heading
- How to enter a flock
- Learning flocking models and how to influence
- Extending robot implementation to robot birds
- Extensions to other domains: endangered species, validating theories of biologists

Conclusion

Thesis Question:

How can influencing agents be utilized in various types of flocks in order to influence these flocks towards a particular behavior?

- How should the influencing agents behave?
- Where should the influencing agents be placed?
- How should the influencing agents join and leave the flock?
- How well do the methods generalize?
- How well do the methods transfer from simulation to a robot platform?