Whirligig Beetles vs. Swarm Models: Perturb and Measure the Emergent Properties

Dr. W.L. Romey

State University of New York at Potsdam

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    - 2014: Alicia Lamb, Amy Smith, Jenna Blujus
- Model Makers:
    - Marc Canava
    - Lesley Morrell, University of Leeds, UK.
    - Jose Vidal, University of South Carolina
- Robots: Vijay Kumar and Quentin Lindsey
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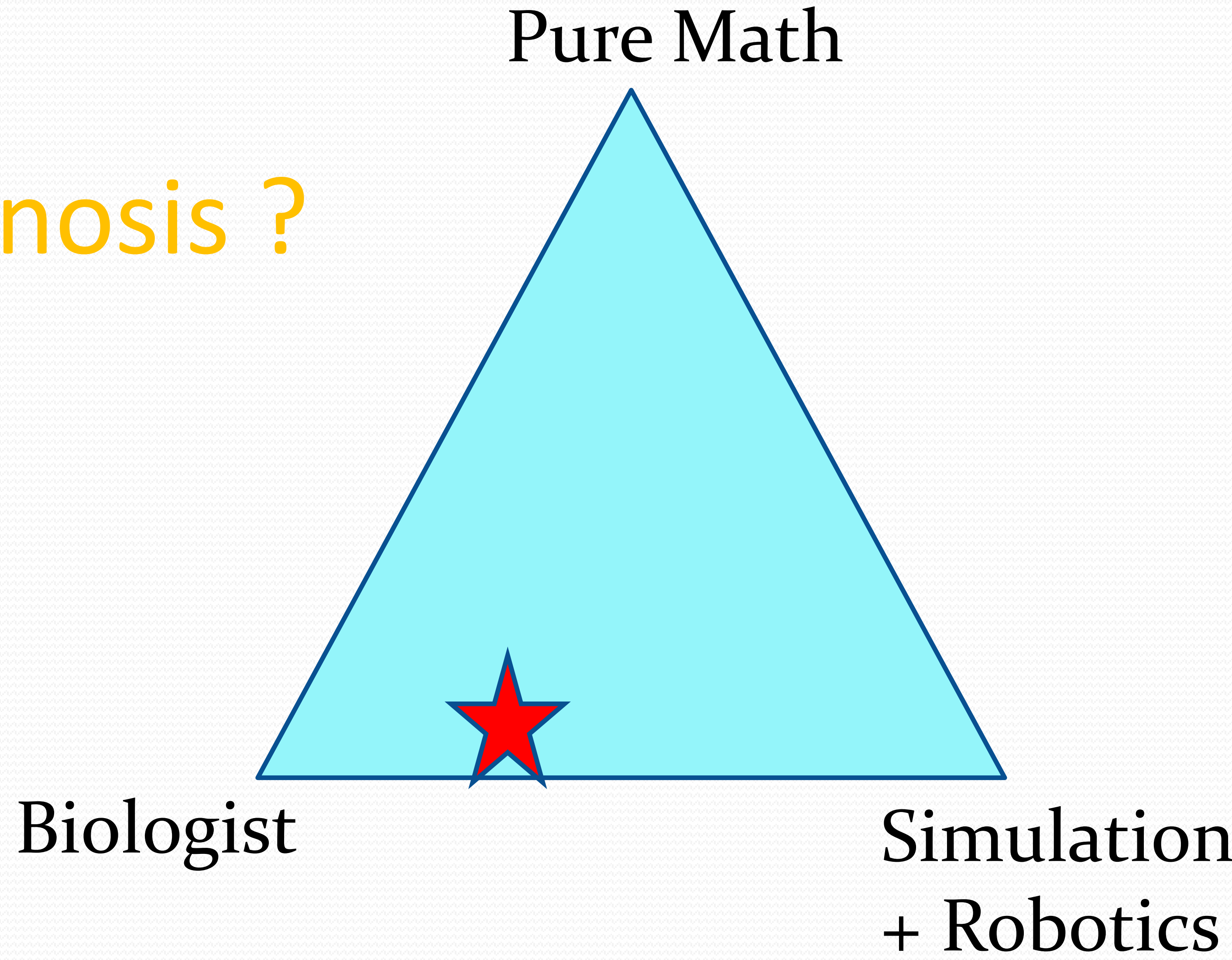
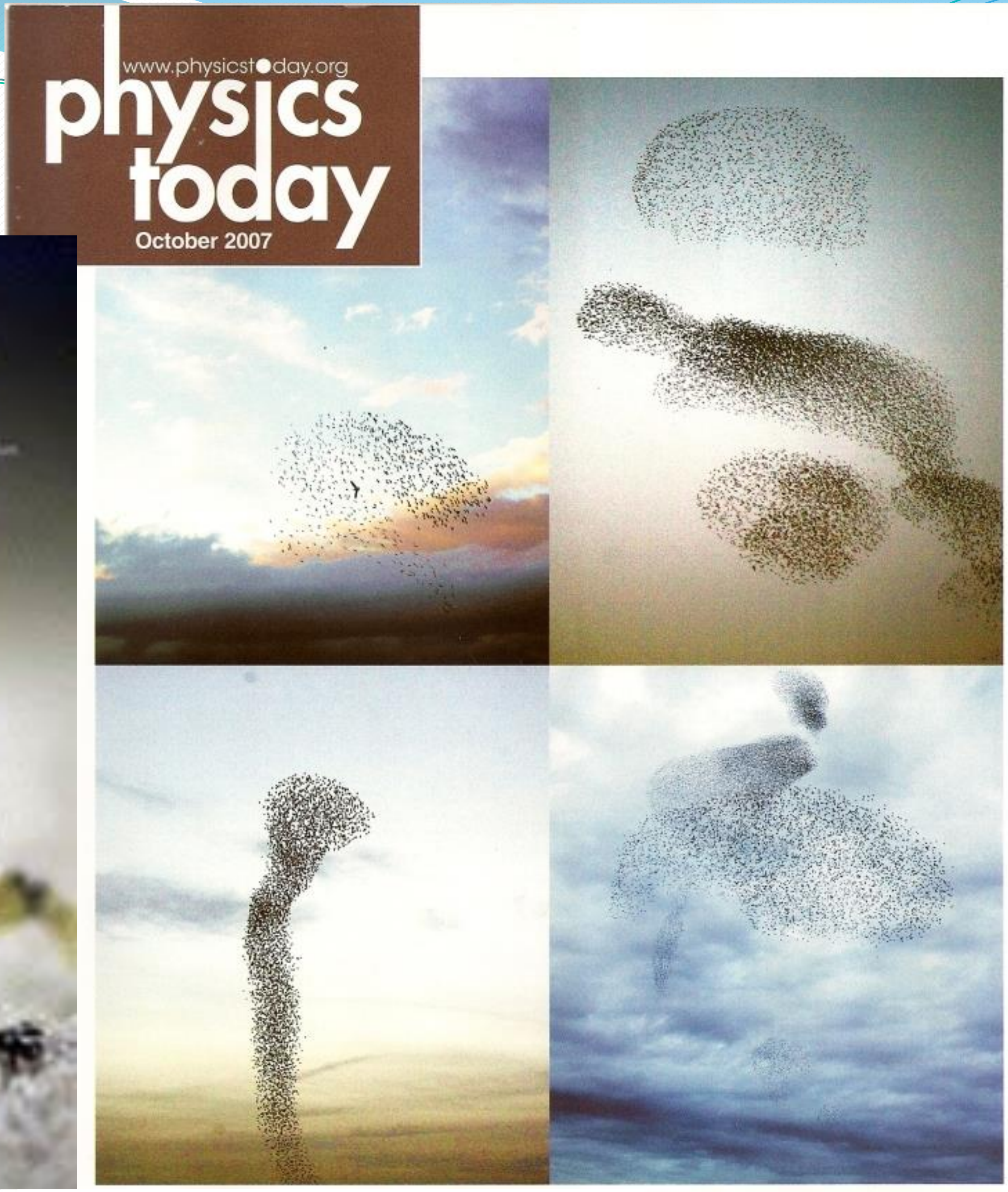
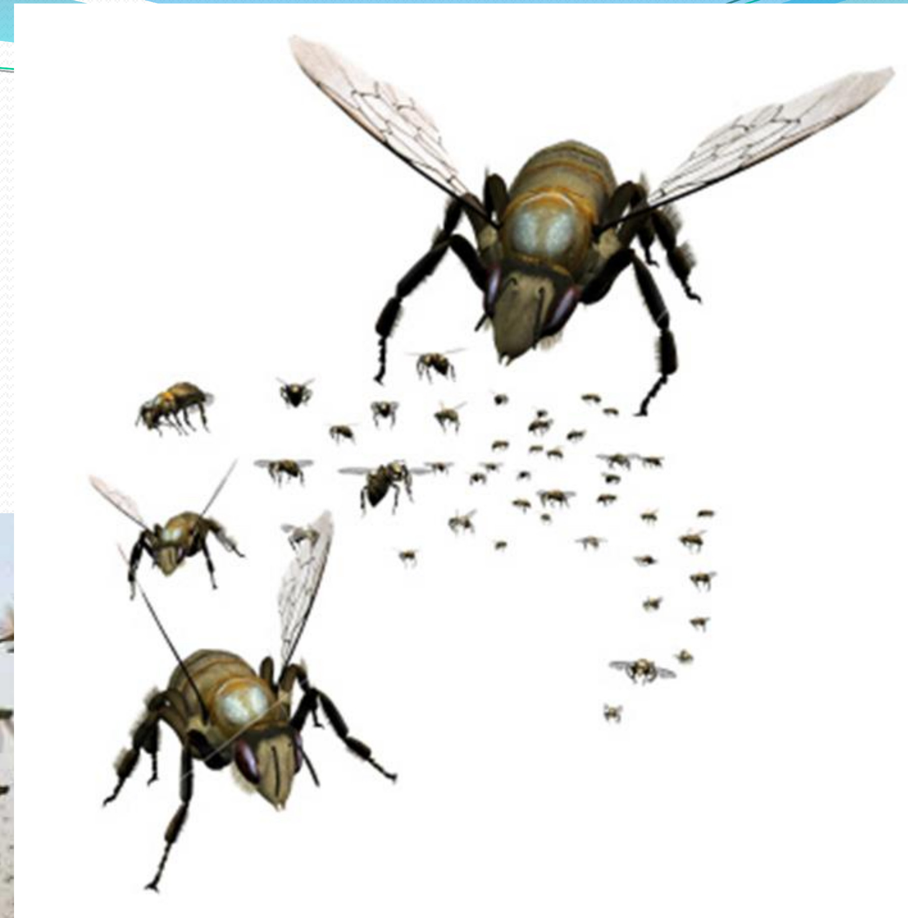
Self Diagnosis ?





The physics of flocking

Despite so many *different animal groups*, are there *common rules* of motion leading to convergent *emergent group* behaviors?

- Attraction to
  - avoid predators
  - facilitate foraging
- Repulsion to
  - Avoid collisions
  - Reduce parasite transfer

“Nothing in Biology Makes Sense Except in the Light of Evolution”

- Dobzhansky, 1973

Previous Assumptions about Animal Groups

- Similar Selection Pressures (predation, food)
  - Front, back, middle
- Homogeneous Membership
- Random Positioning of Individuals

Recent Findings

- Different parts of the group have unique "neighborhoods", some with more food, others with more danger
- Individuals "recognize" these areas and gravitate towards them according to their needs (hunger, gender, defense levels)
- These differences lead to differences in emergent group movements: speed, direction, density.

Individual → **Group** → **Emergent Behavior**

At each level of organization the behavior may be evolutionarily:

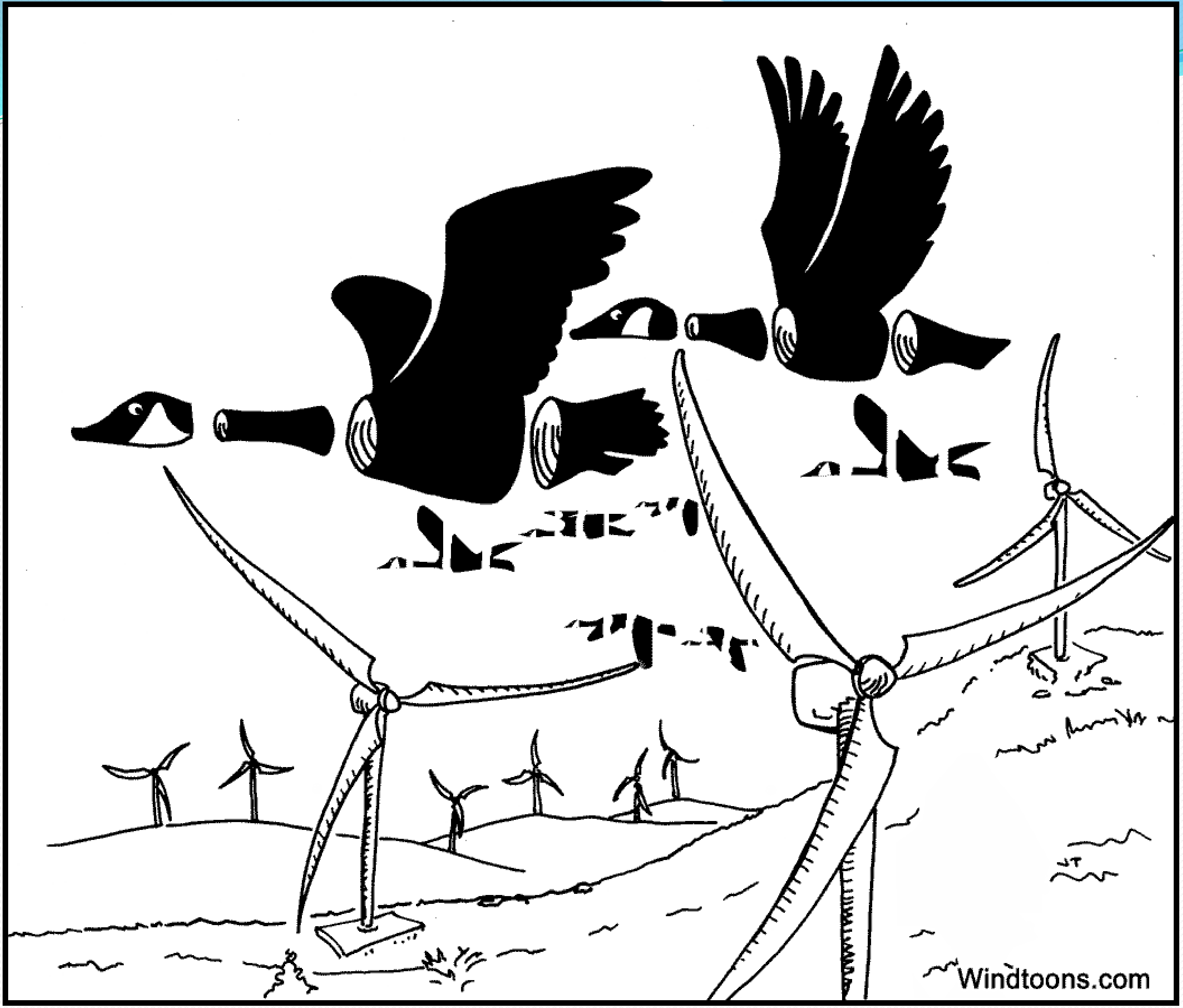
- Adaptive: collective intelligence may solve problems
- Maladaptive: krill and whales
- Neutral: Epiphenomena: interesting but not relevant

Criteria for determining self-organization of emergent behaviors*

1. **Empirical** study of interaction between individuals
2. **Empirical** study of group pattern
3. Design **Model** based on individual rules: bottom up
4. Manipulate **Model** and measure emergent behaviors
5. Manipulate **Empirical** system, measure and compare emergent behaviors to Model

*Camazine et al. (2001) "Self-Organization in Biological Systems" Princeton University Press

Importance?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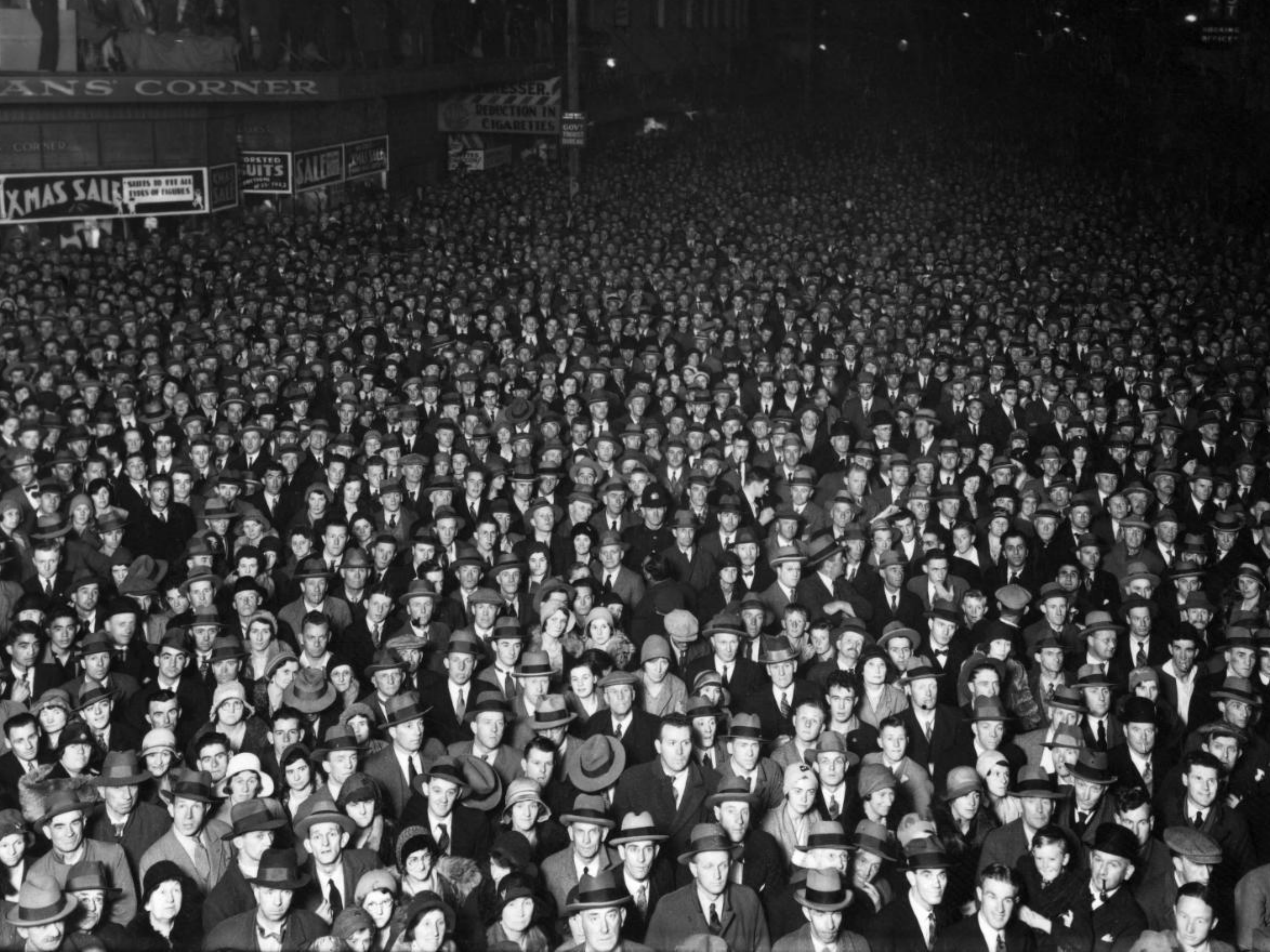

ANS' CORNER
XMAS SALE
REDUCTION IN
CIGARETTES
SUITS
SALE

Outline of This Talk:

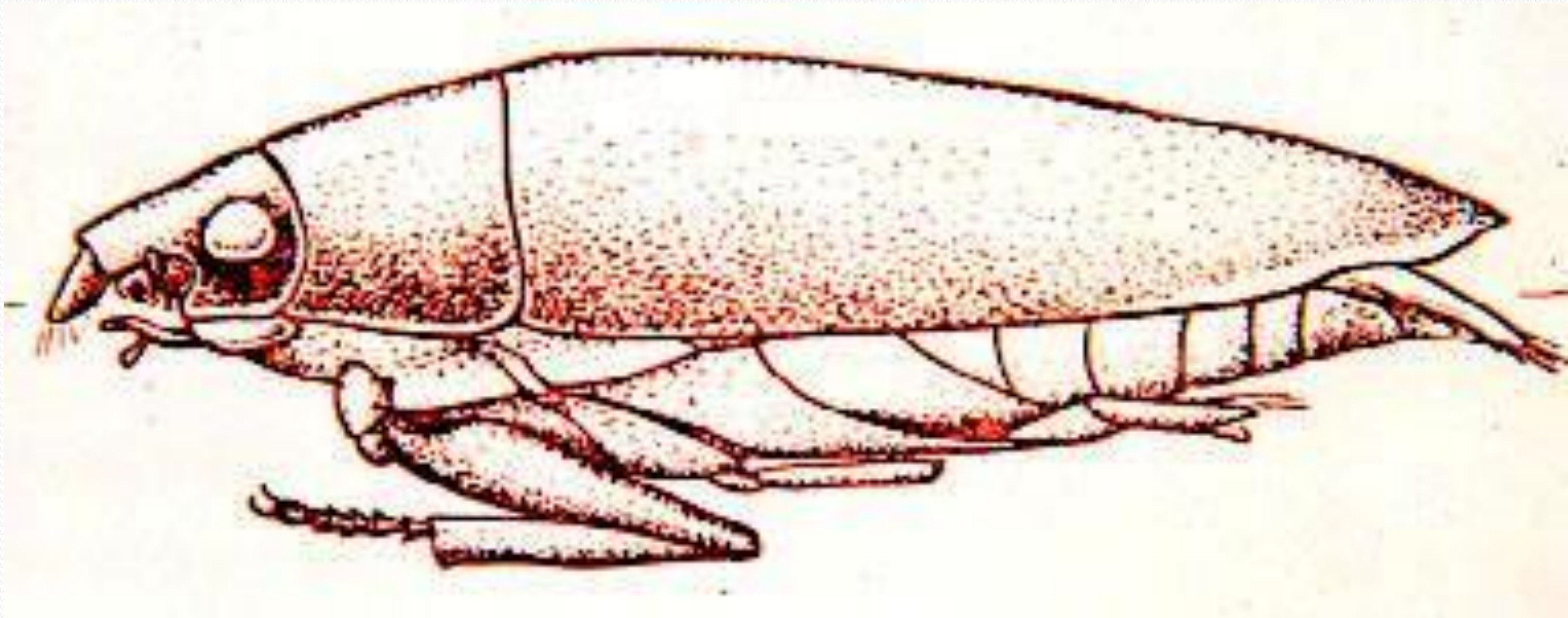
- Introduction and Importance
- Three Methods
- Five Studies

Three Methods

A. Empirical Experiments with Whirligigs

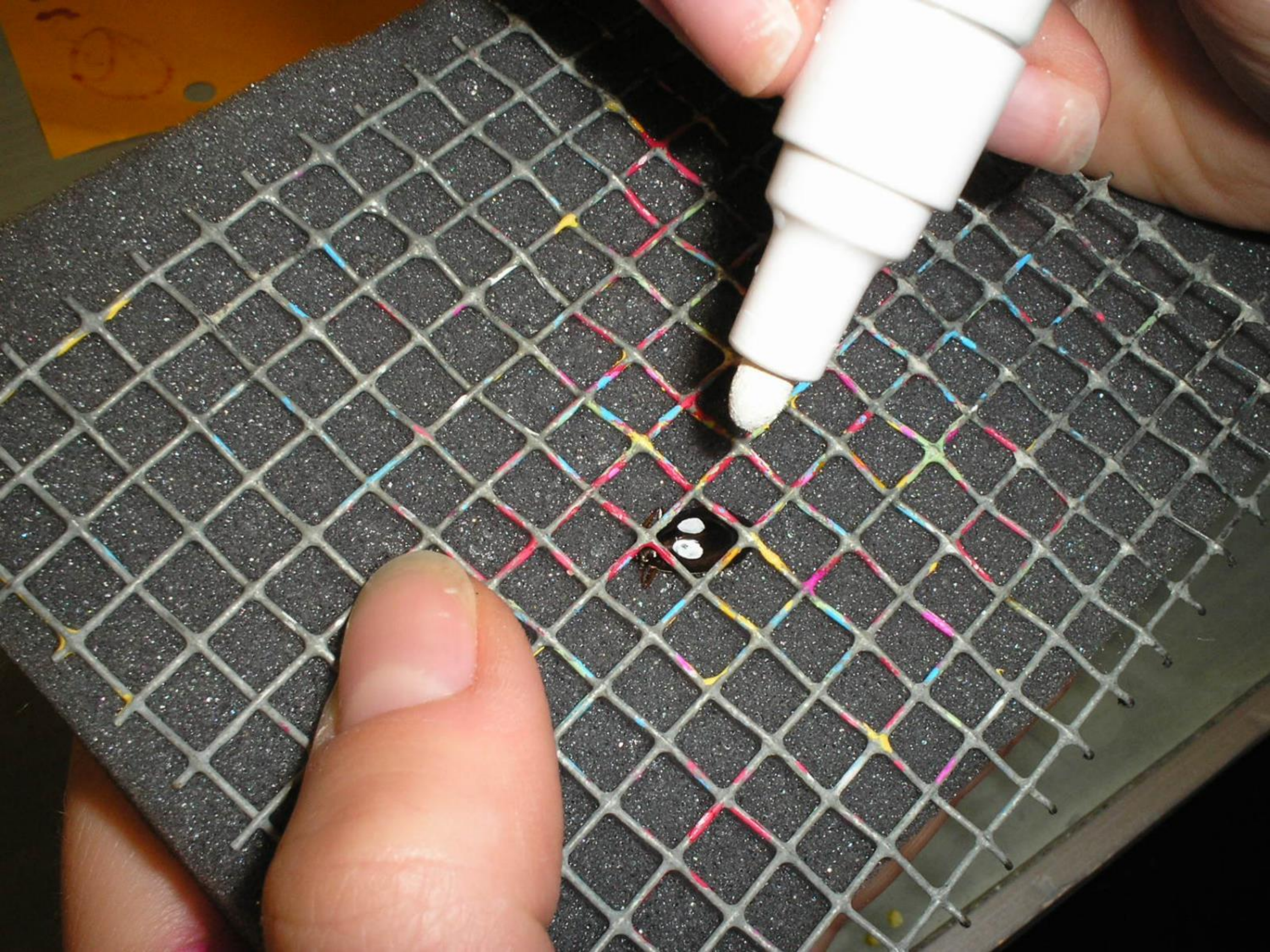
B. Robot with Whirligig

C. Self Propelled Particle (SPP) simulation Modelling



• Whirligig Beetle (Gyrinidae: *Dineutes*)

- Live at surface (2d)
- Non Kin
- Ponds and streams
- Mixed Species Groups
- Foraging at surface
- Predators from above and below



B: Robotic Whirligig

Collaborators: Kumar and Lindsey at Grasp Lab


C: SPP Simulation Methods ("SwarmSim")

- **Romey, 1996**
  - Ecological Modelling
  - "Individual differences make a difference in the trajectories of simulated schools of fish."
- **Romey and Vidal, 2013**
  - Ecological Modelling
  - "Sum of heterogeneous blind zones predict movements of simulated groups."

Problem of different fields not talking to each other in the past

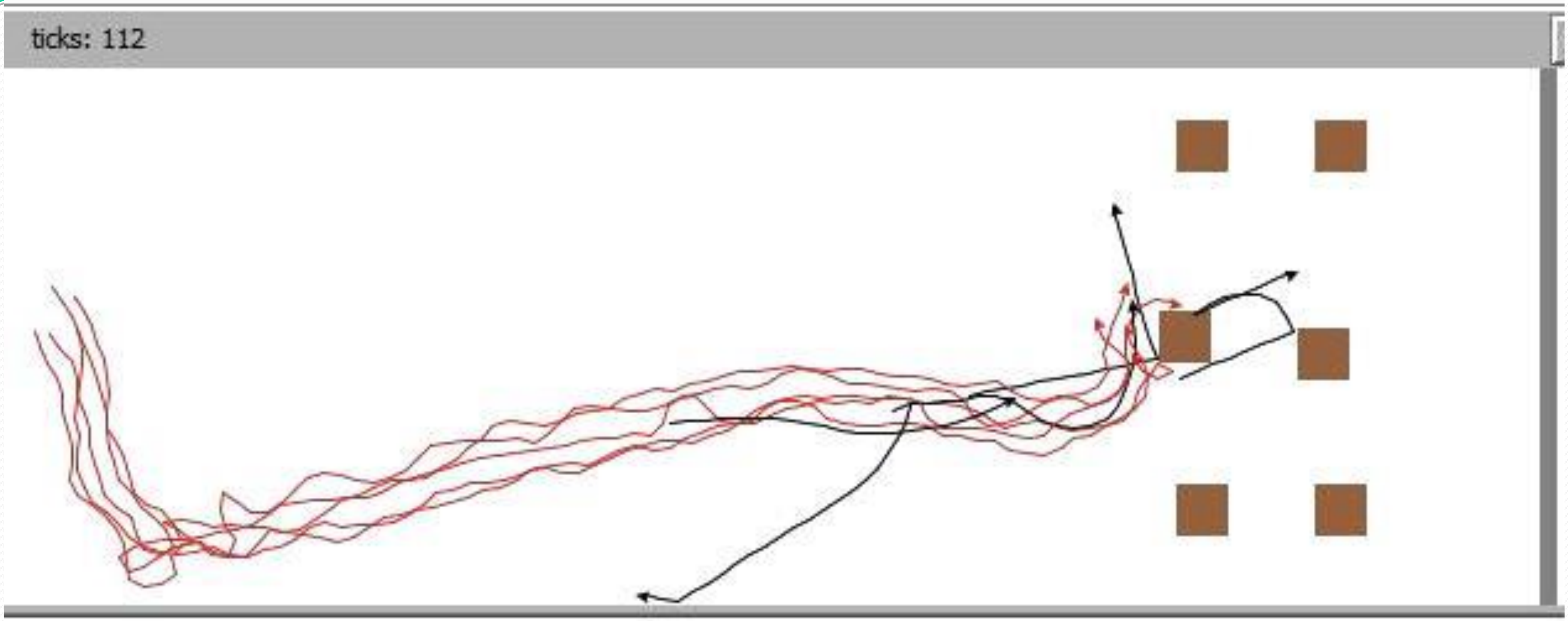
- 1991 Warburton Lazarus Model
- 1992 Huth and Wissel Model
- 1994 Reuter and Breckling Model
- 1995 Vicsek Model
- 1996 Romey Model

What are the rules for *SwarmSim* ?

- *Attraction-Repulsion (AR) Function : (show on board)*
- *No Alignment needed*
- *Momentum (percentage of old vector)*
  - *Tailored to target species: zebrafish, bird. etc.*
- *Viewing angles and distances*
- *Multiple Strategies in Group*
  - *Leadership*
  - *Randomness*
  - *Ratio of different AR rules*

Recent Additions

- Walls and Attractors
- Automated Measurements
  - Group determination: Greedy Hierarchical Method
    - Number in group Area, Diameter, Circumference, Ratio of species,
  - Density, Group vector, polarization



Demonstration

Any Questions about Whirligigs or SwarmSim?

Some Recent Research Studies In My Lab

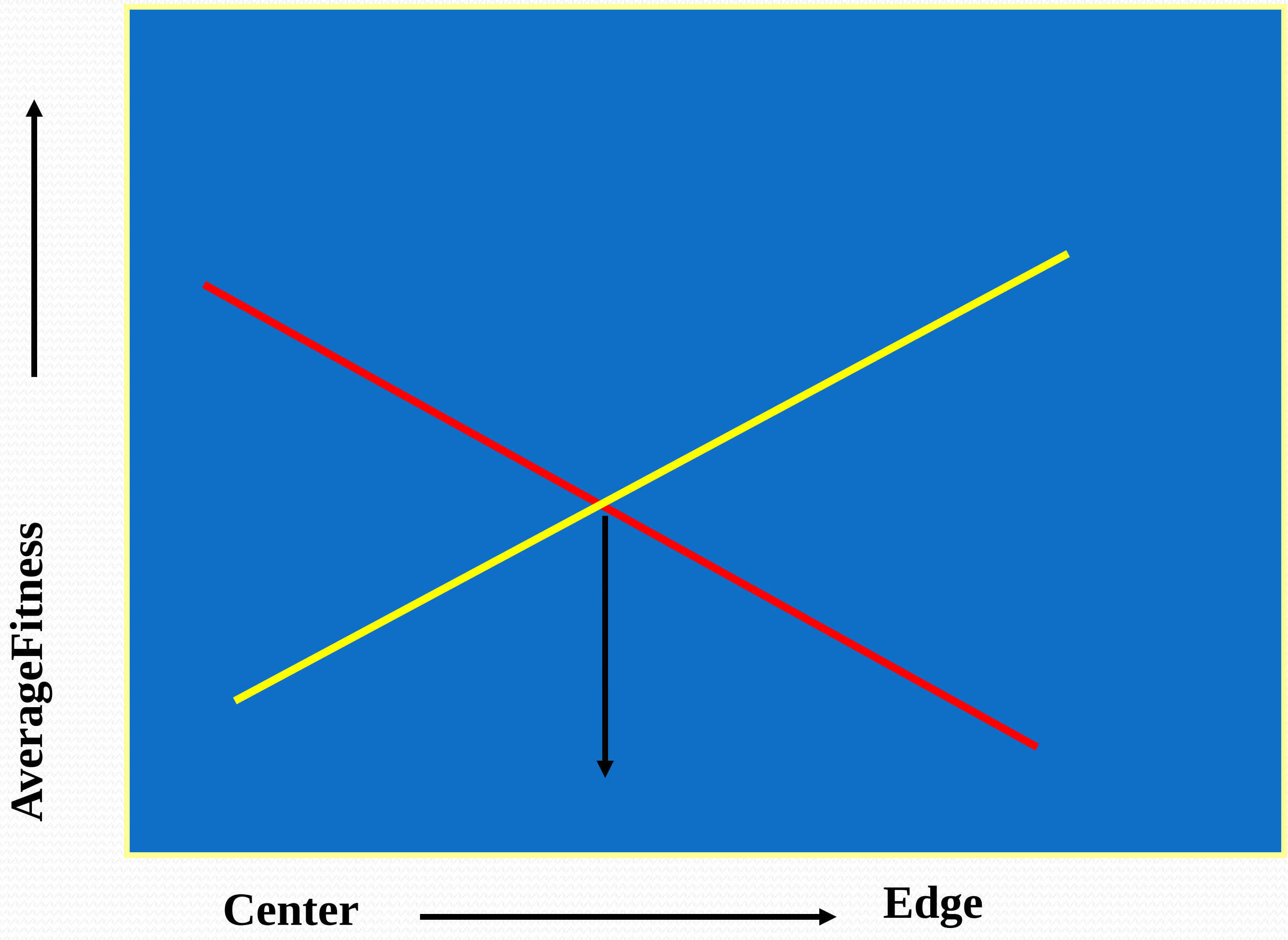
1) How do individual differences (hunger, sex, size) influence position within a group?
2) How do manipulation of long vs. short range sensors influence group escape responses?

Question #1

How do individual differences (hunger, sex, size) influence position within a group?

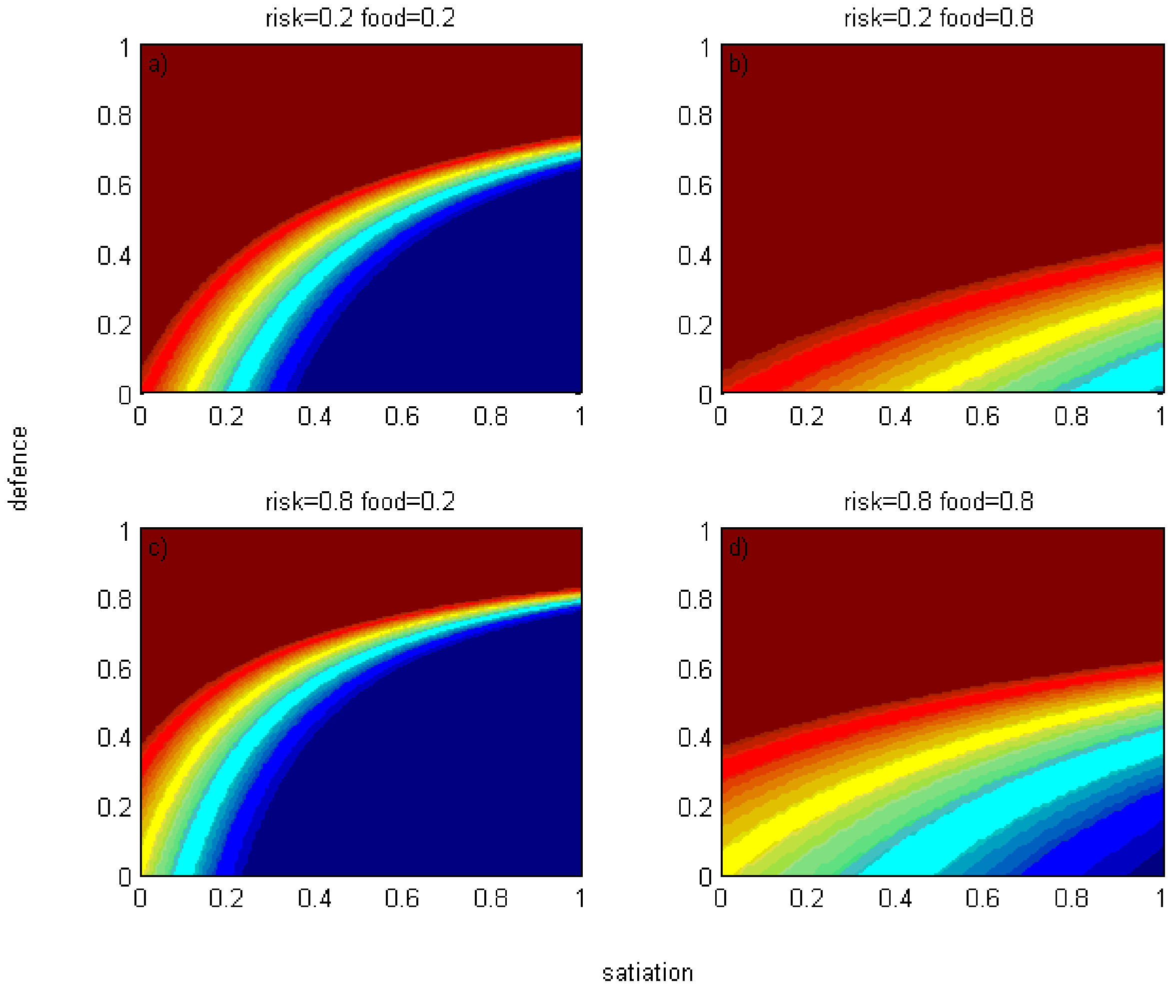
Foraging * *Predation* =

Optimality Modelling



Romey 1995, Behavioural Ecology and Sociobiology
Romey et al. 2008, Behavioral Ecology and Sociobiology

In what part of group should "you" be (color) given individual level of satiation and defense, and overall level of risk and food?

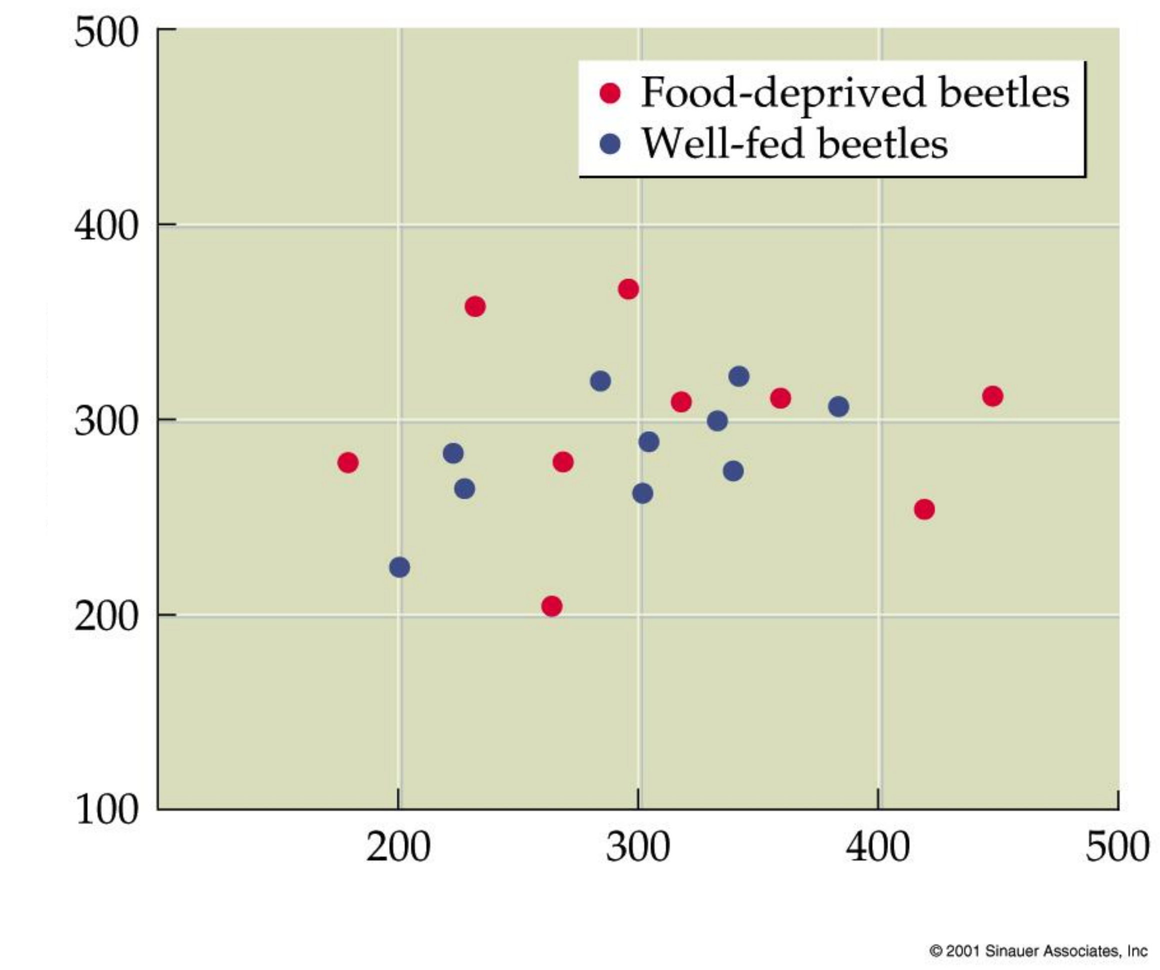


Red = center
Blue = edge

Morrell and Romey, 2008, Behavioral Ecology
"*Optimal individual positions within animal groups*"

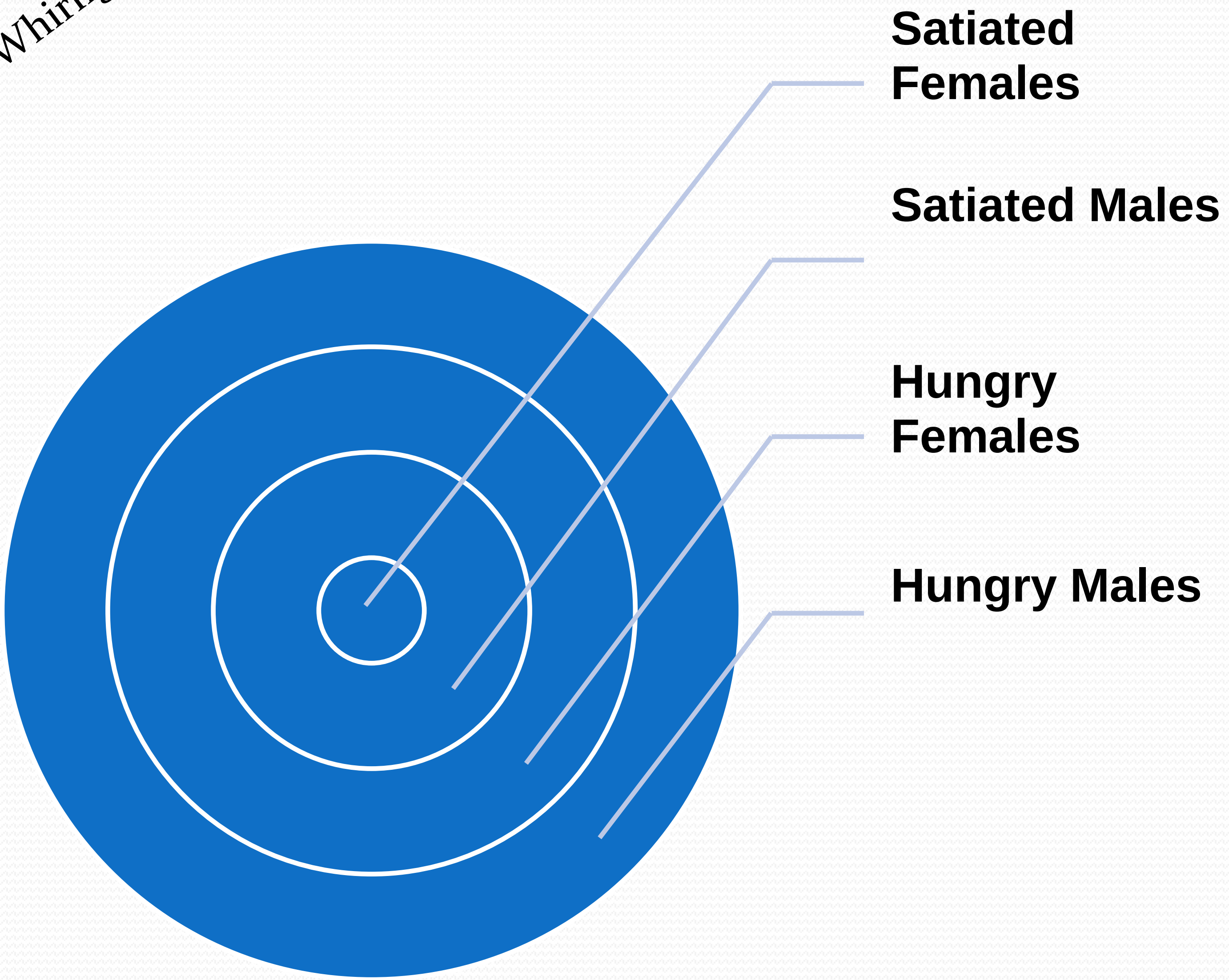
Whirligig Experiment

Aerial View of Group of Whirligig Beetles



Romey, 1995, Behavioral Ecology and Sociobiology

Whirligig Experiment



(Romey and Wallace, 2007)

SPP models

- Are positions adaptive or byproduct of other rules?
  - Which is cause, which is effect?

    (NND vs. Position Preference)
- Vary the Nearest Neighbor Distances in movement rules and individuals move to outside/inside.
- Alternative rules that might lead to differences in position?
  - Speed
  - Random movement

Question #2

How does manipulation of long vs. short range sensors influence group escape responses?

(Are sensors for attraction and repulsion rules separated?)


Velodyne laser scanner
GPS
3 cameras
odometer
radar
lux laser scanner
AUTONOMOS

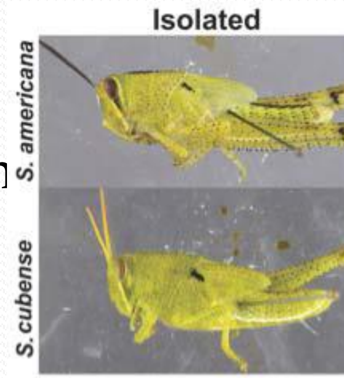
Previous Studies of Which Senses Control Attraction or Repulsion

Fish schools

- Partridge and Pitcher 1980; Faucher et al. 2010
- Methods: block eyes or cut lateral line nerve
- Results:
  - blinding does not effect Nearest Neighbor Distance (NND)
  - Lateral Line blockage leads to smaller NND and more collisions

Locust swarms

- Bazazi et al. 2008
- Methods: block eyes or sever abdominal sensory neuron
- Results: more collisions and cannibalism

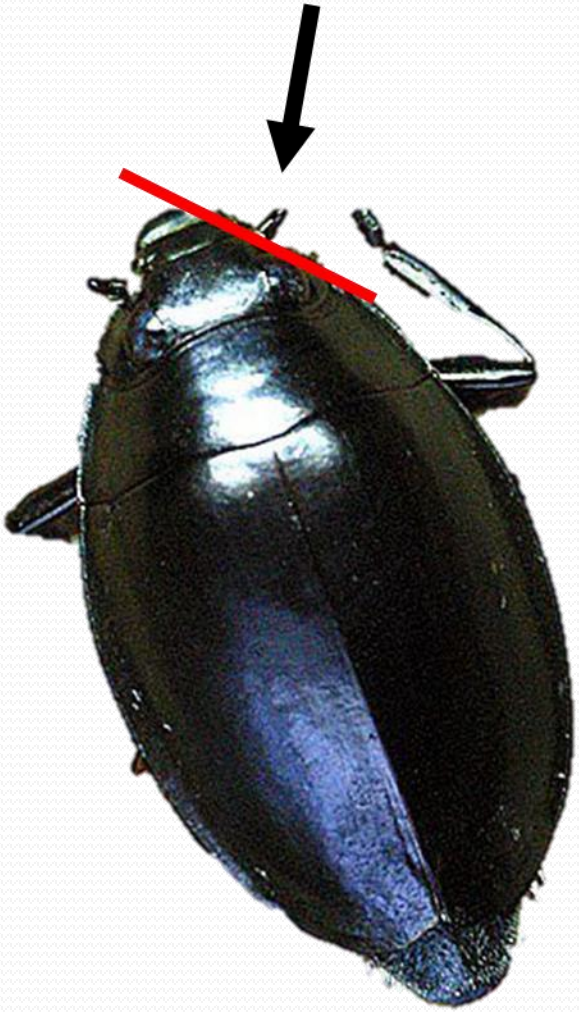


Methods (empirical experiment):

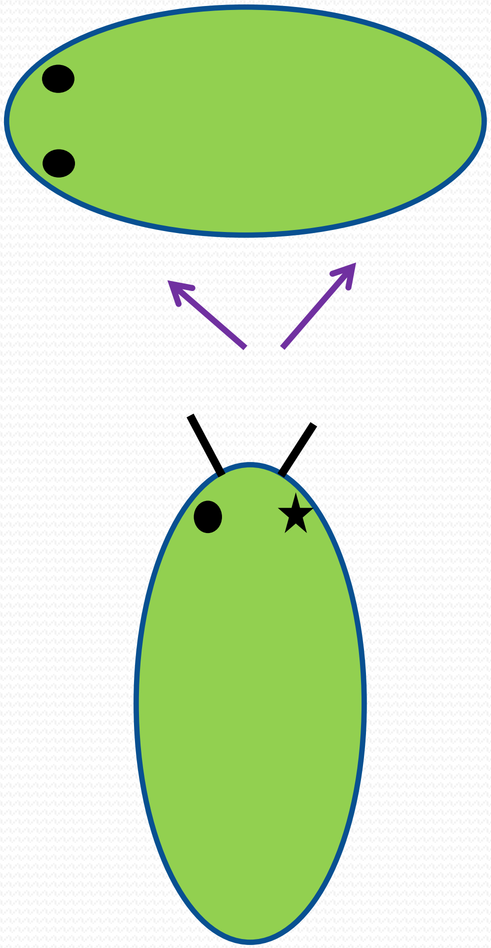
1) Paint one set of eyes or remove one antenna on some beetles
2) Construct 3 types of group of size 24 each
   1) Control
   2) ½ eyeless (attraction?)
   3) ½ antenna-less (repulsion?)
3) Film the Flash Expansion of 24 groups of each
4) Video analysis to determine
   1) Individual: turn direction, bump rate, speed
   2) Emergent Group: diameter, FE development time
5) (Simulation methods to follow)

Ventral set of eyes

Antennae

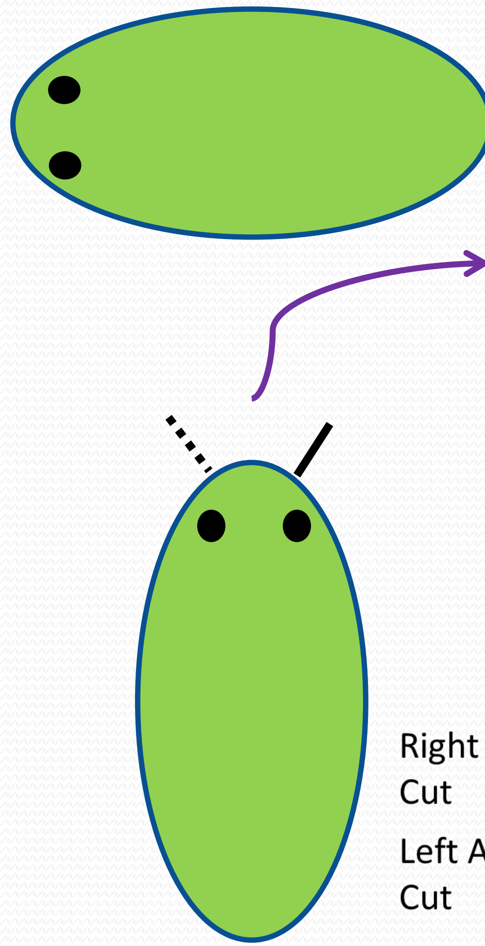


Unilateral Eye Block



Less collisions and turn equally L+R

Unilateral Antenna removal

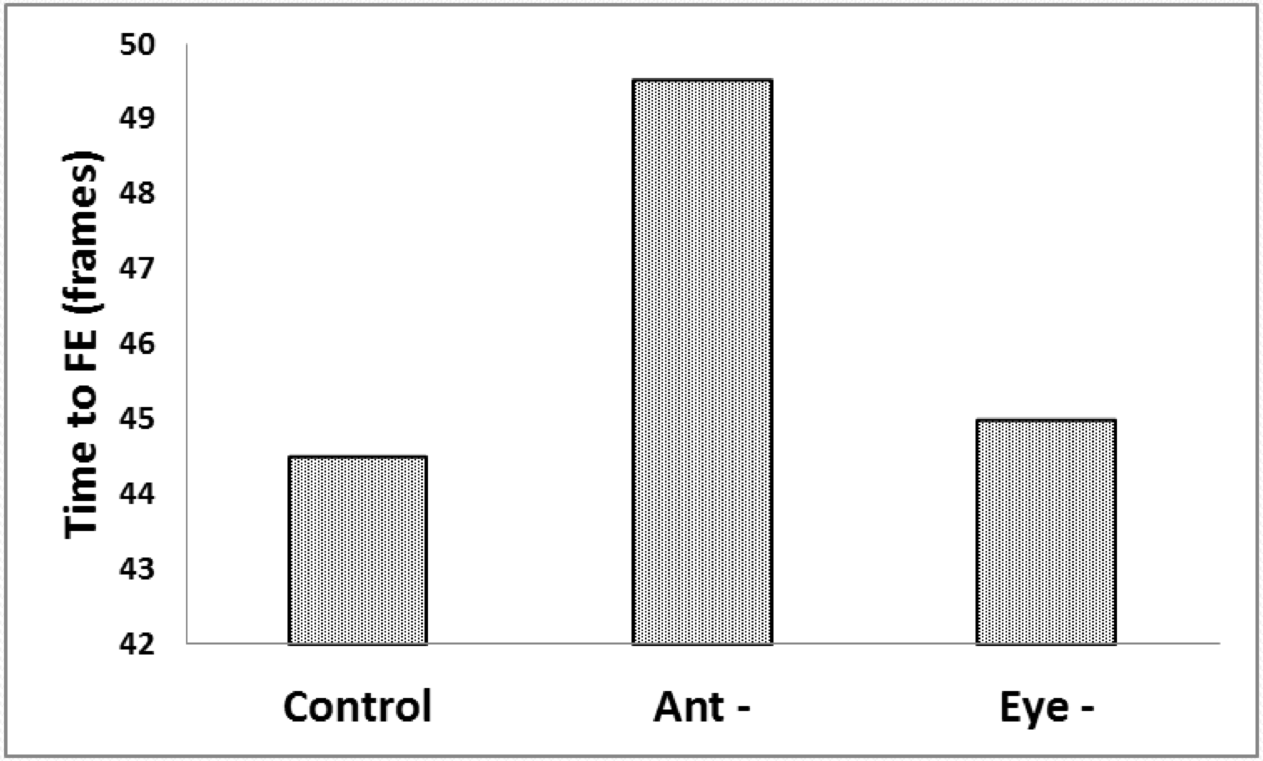


Turned Towards

	Left	Right
Right Ant. Cut	33	8
Left Ant. Cut	8	25

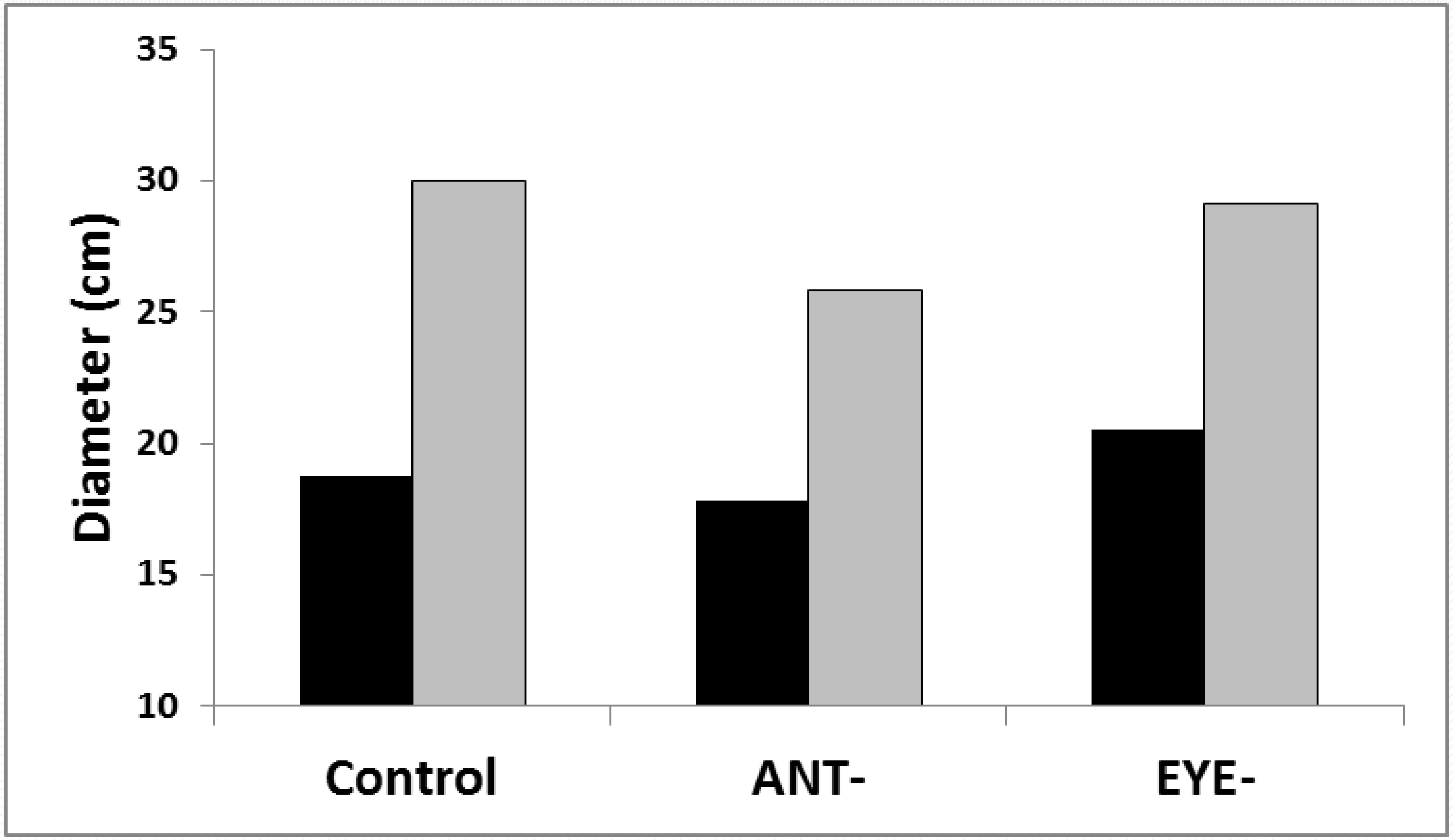
More collisions

Emergent Behaviors of Group



Mean time in which groups of beetles took to achieve a full flash expansion (FE). (30 frames per second)

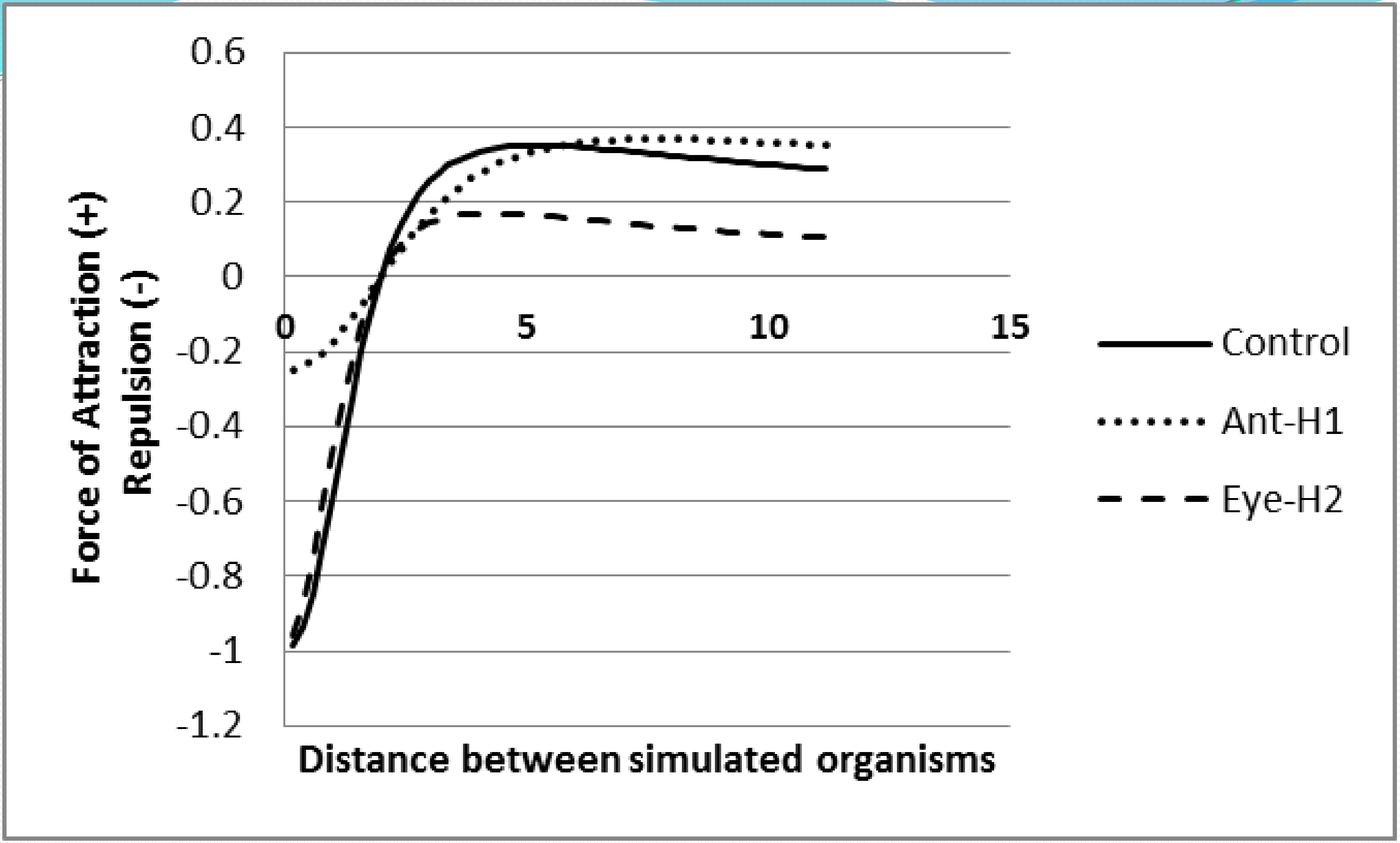
Romey, W.L., Miller, M.M., and J.M. Vidal. 2014. Collision avoidance during evasive manoeuvres: a comparison of real versus simulated swarms with manipulated vision and surface wave detectors. *Proceedings of the Royal Society- B*.



Mean Diameter of group **before** (black) and **after** (gray) Flash Expansion

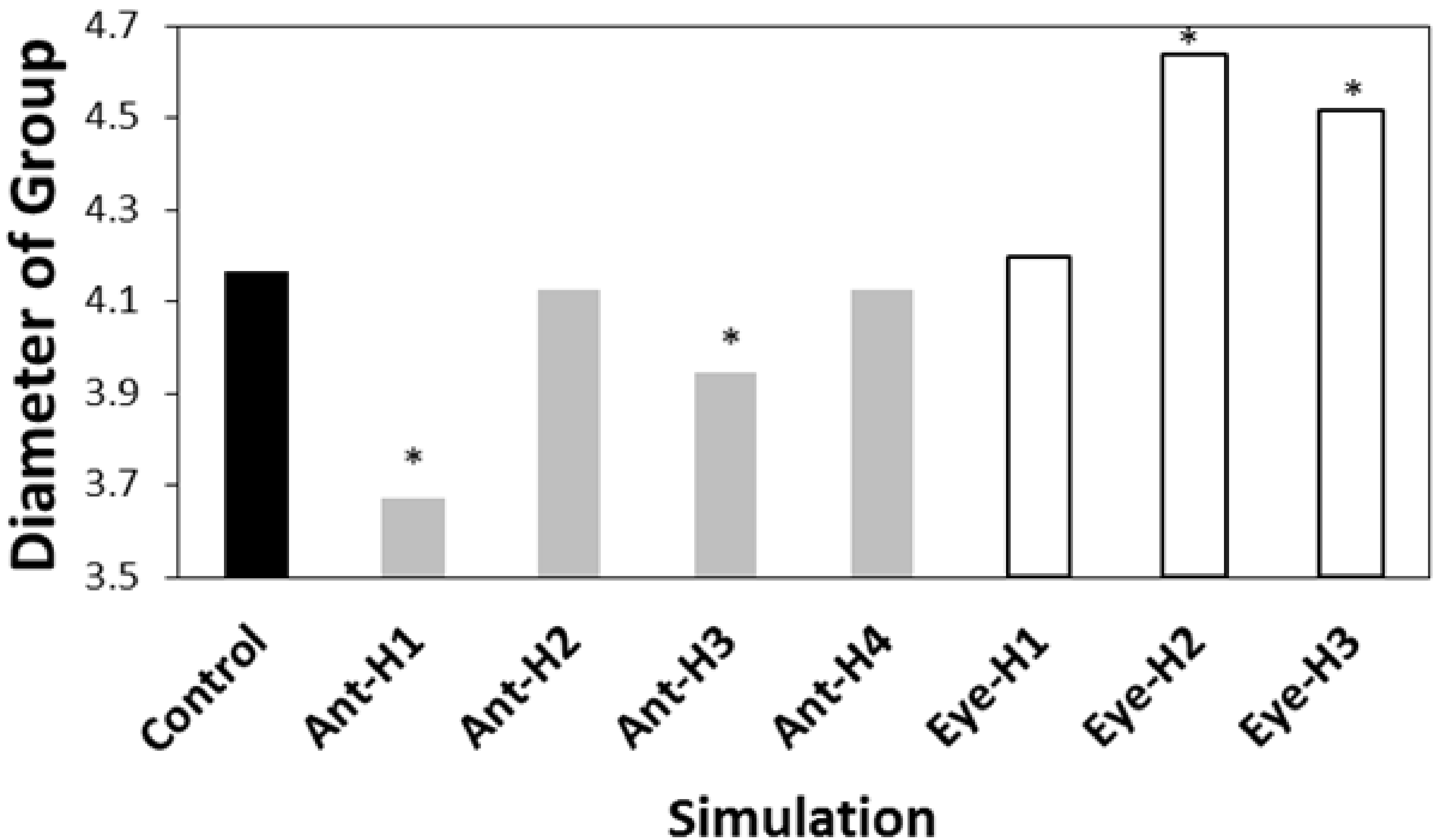
Simulation Methods

- Make simulation program: Swarm-Sim
- Control rules based on average whirligigs
- Design 8 alternative hypotheses (rule sets) for reduced attraction and repulsion
- Measure group diameter and NND after 500 time intervals of 100 simulations
- Qualitatively compare with control and whirligig results



Also changes in: viewing distance, unilateral/bilateral, ratio of deprived vs. control individuals

	Reduced A or R ?	Uni/Bilateral?	Pure/Mixed
Control	none	None	Pure
Ant-H1	R	Bi	Pure
Ant-H2	R	Bi	Mix
Ant-H3	R	Uni	Pure
Ant-H4	R	Uni	Mix
Eye-H1	Truncated	Bi	Mix
Eye-H2	A	Uni	Pure
Eye-H3	A	Uni	Mix



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Comparing Real and Simulated Groups

Whirligig

- ANT- leads to decrease in Group Diameter
- EYE- leads to increase in Group Diameter

Swarm-Sim

- 2/4 repulsion decreasing rule sets led to decrease in Group Diameter
- 2/3 attraction decreasing rule sets led to an increase in Group Diameter

Overall Talk Summary

- Individuals balance competing selection pressures by occupying specific positions in groups.
- Diversity within group influences emergent group structure and movement.
- Combination of empirical studies, robotics, and simulations can help understand collective motion.
- Camazine: Pair perturbations of matching empirical and simulation system and measure similarity in emergent behavior.

Questions ?

Email: romeywl@potsdam.edu
Website: google: “romey, potsdam”