

Synchronization and Swarming: Clocks and Flocks

Andrew J. Bernoff, Harvey Mudd College



Thanks to Chad Topaz, Macalester College

Synchronization *(noun)*

The tendency of periodic systems to align in time.

- Sleep/wake cycles
- Flowering of plants /Estrus in animals
- Clapping (sometimes !!)
- Dancing
- Contraction of muscle in heart cells
- Lasers
- Microwave Ovens

Synchronization of metronomes

Lancaster University, Dept. of Physics

Synchronization of metronomes



Lancaster University, Dept. of Physics

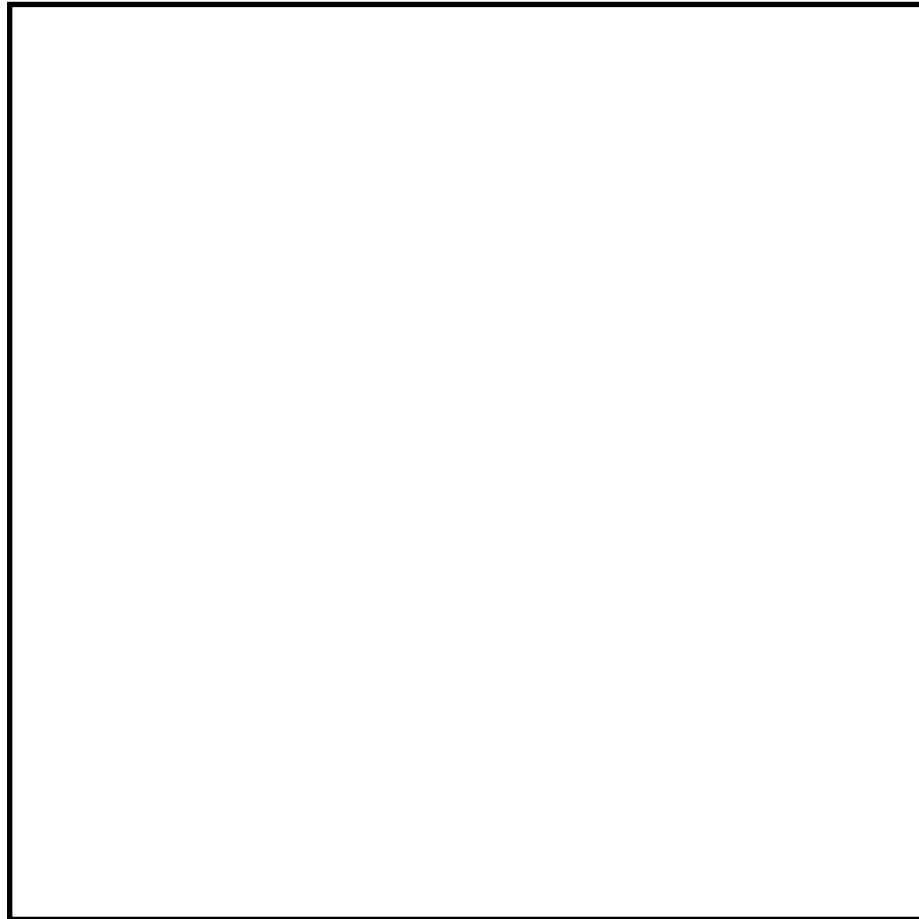
Coupling

(noun)

The influence of one object on another; feedback.

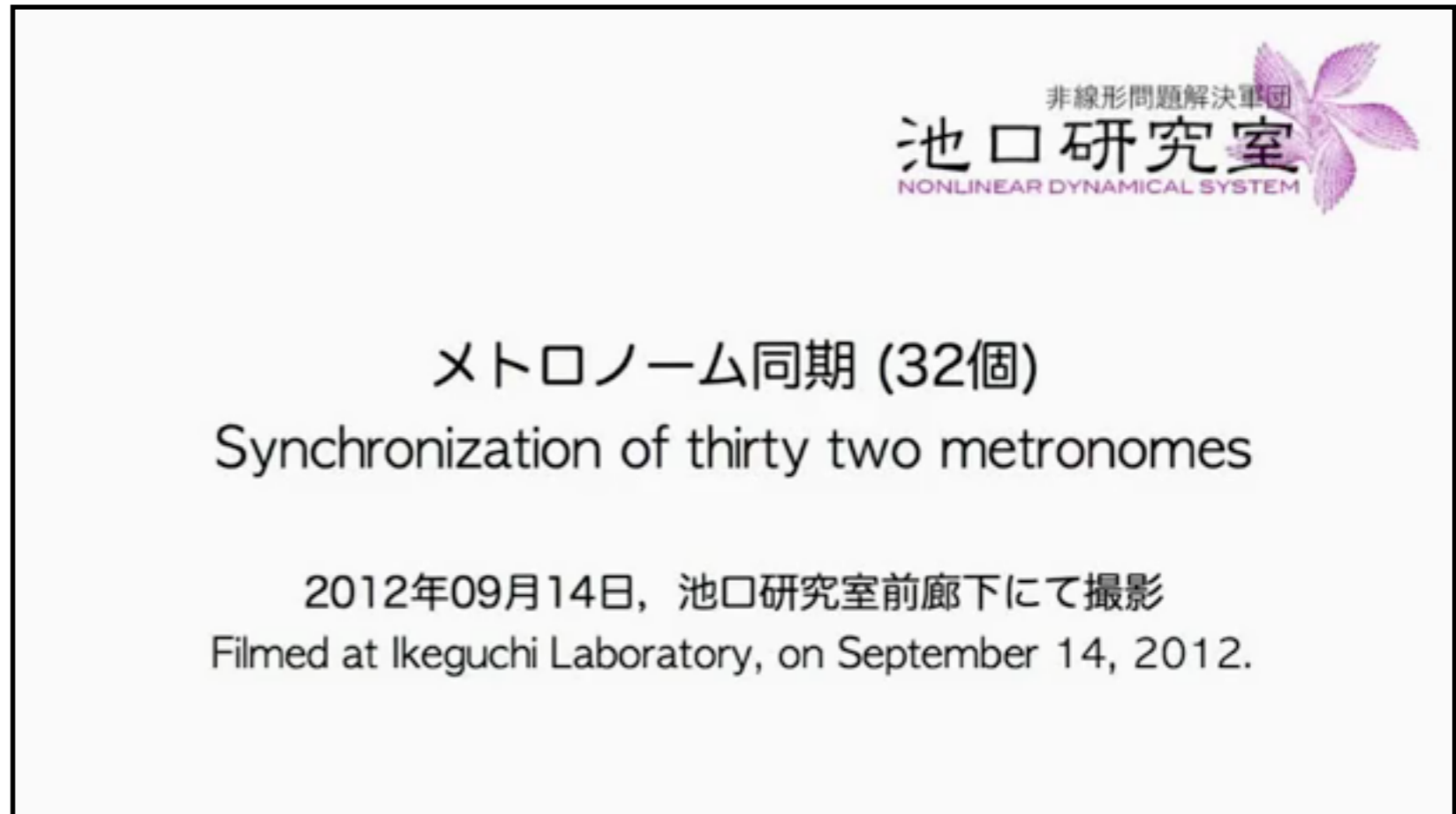
- Sight, sound, smell, vibrations
- Pheromones
- The internet
- Vibrations
- Crickets chirping, fireflies flashing

Coupled oscillators



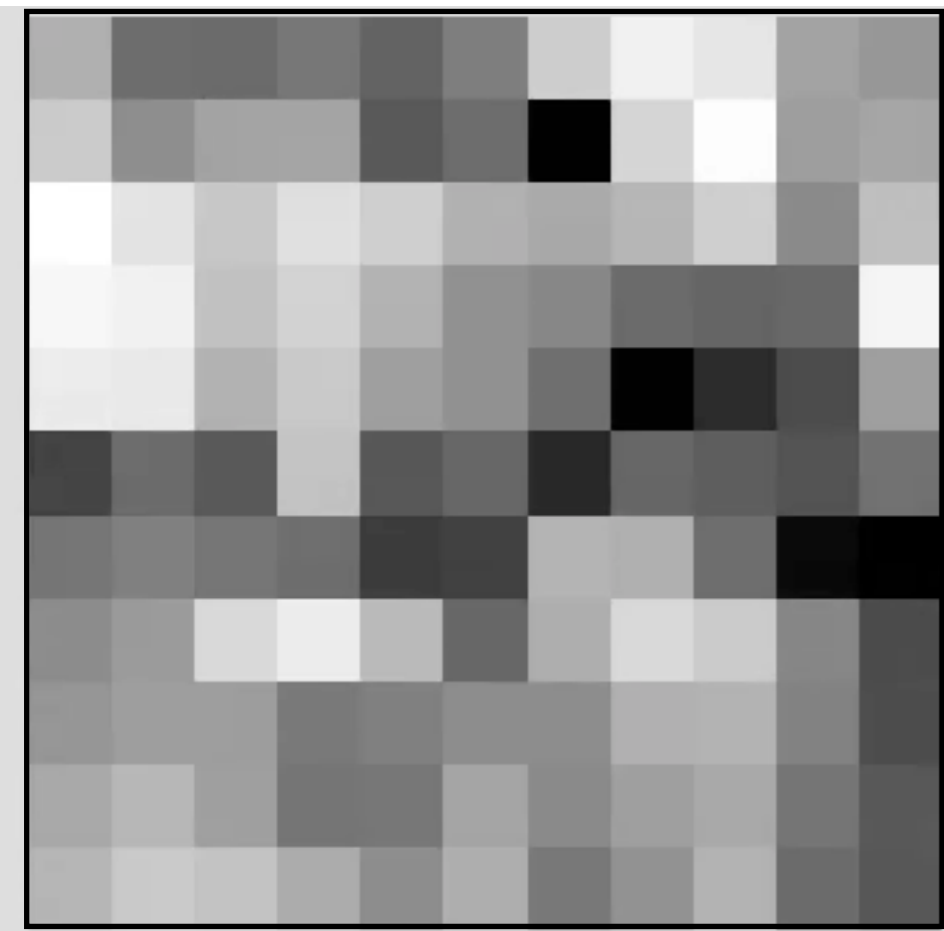
11 x 11 Grid of Oscillators

Strong local coupling
Weak global coupling



32 Metronomes

Coupled oscillators



11 x 11 Grid of Oscillators

Strong local coupling
Weak global coupling



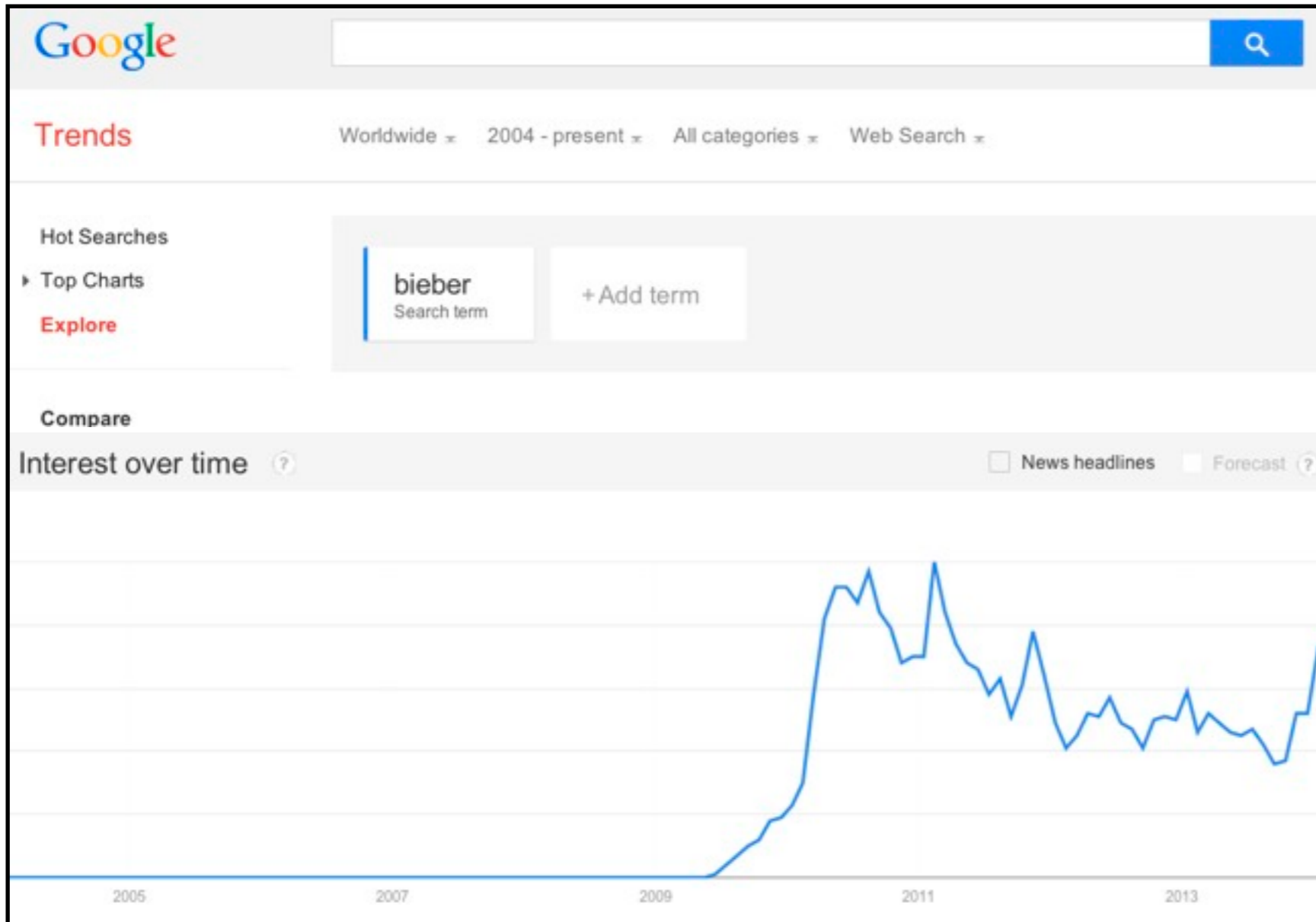
32 Metronomes

Meme *(noun)*

*An idea or behavior that spreads through cultural **coupling**.*

- Fashion
- Fads
- #hashtags
- Religion
- Reality TV
- Planking
- Bitcoins

Bieber Fever (Meme)



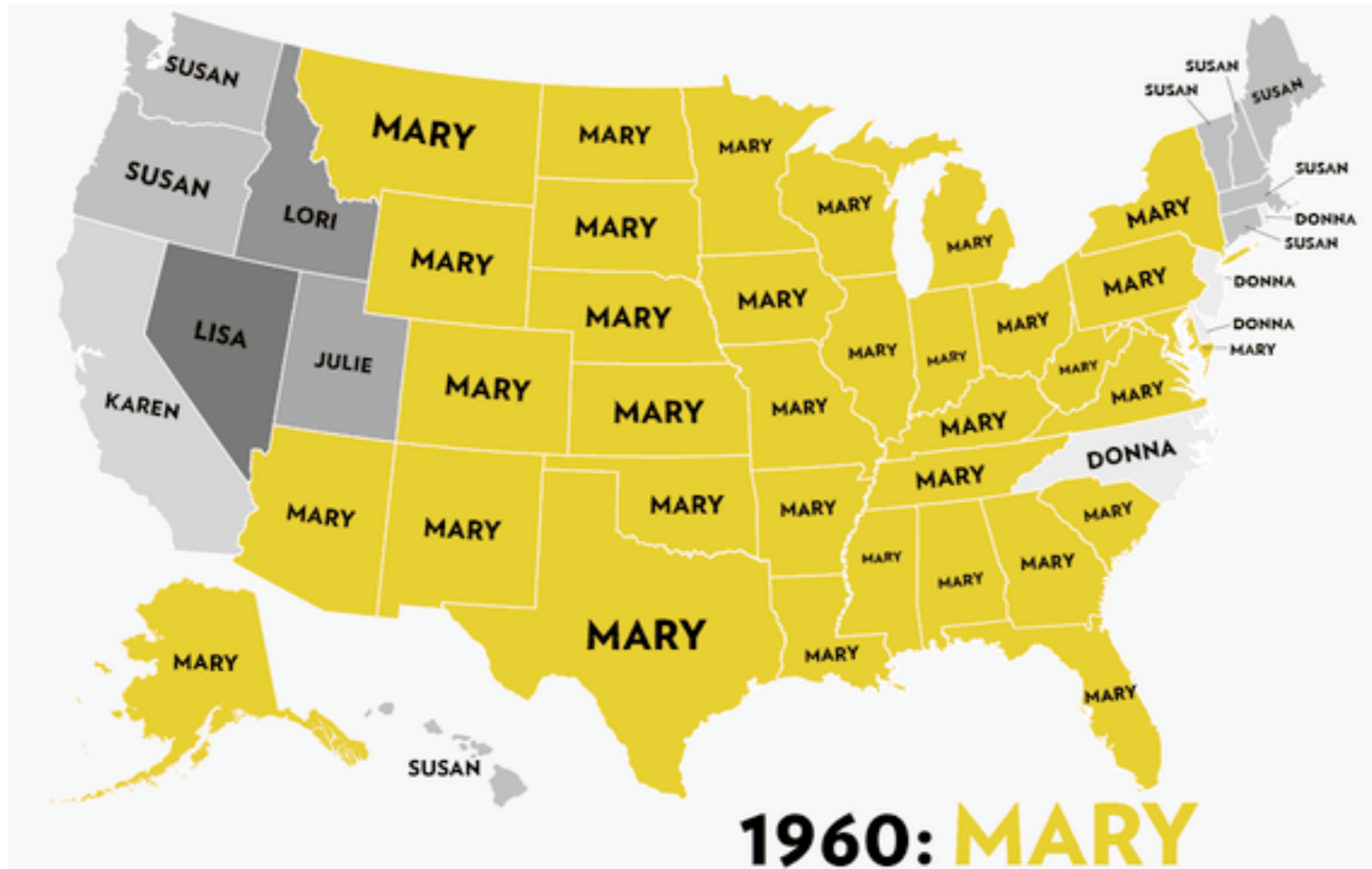
Understanding the Dynamics of Emerging and Re-Emerging Infectious Diseases Using Mathematical Models, 2012: 157-177 ISBN: 978-81-7895-549-0 Editors: Steady Mushayabasa and Claver P. Bhunu

7. A mathematical model of Bieber Fever: The most infectious disease of our time?

Valerie Tweedle¹ and Robert J. Smith²

¹Department of Biology, The University of Ottawa, 585 King Edward Ave, Ottawa ON K1N 6N5 Canada; ²Department of Mathematics and Faculty of Medicine, The University of Ottawa 585 King Edward Ave, Ottawa ON K1N 6N5, Canada

Girl baby names (Meme)

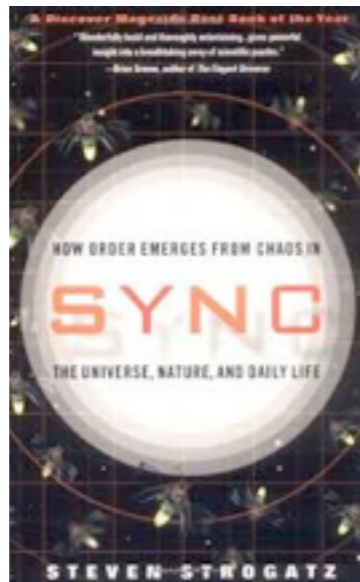


Most popular names of baby girls in each state by year

What have we learned so far . . .

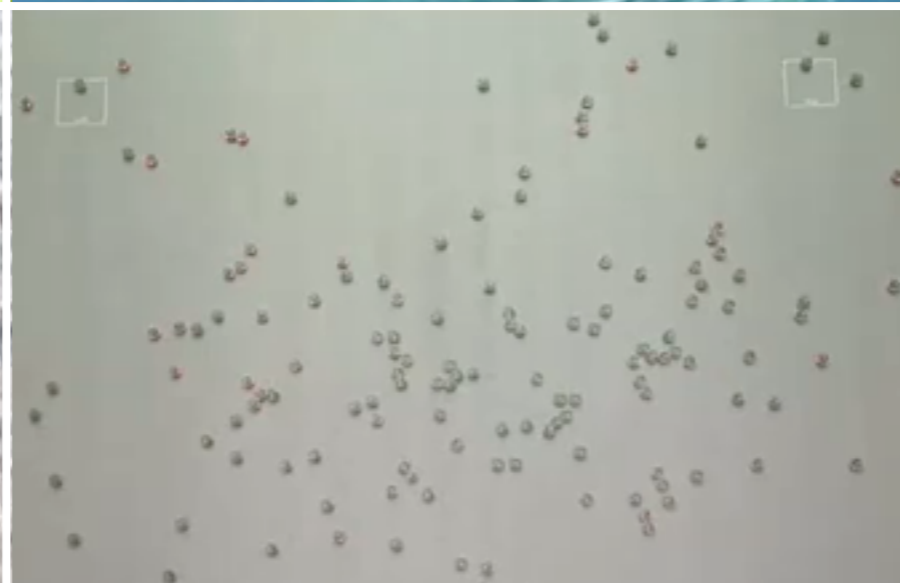
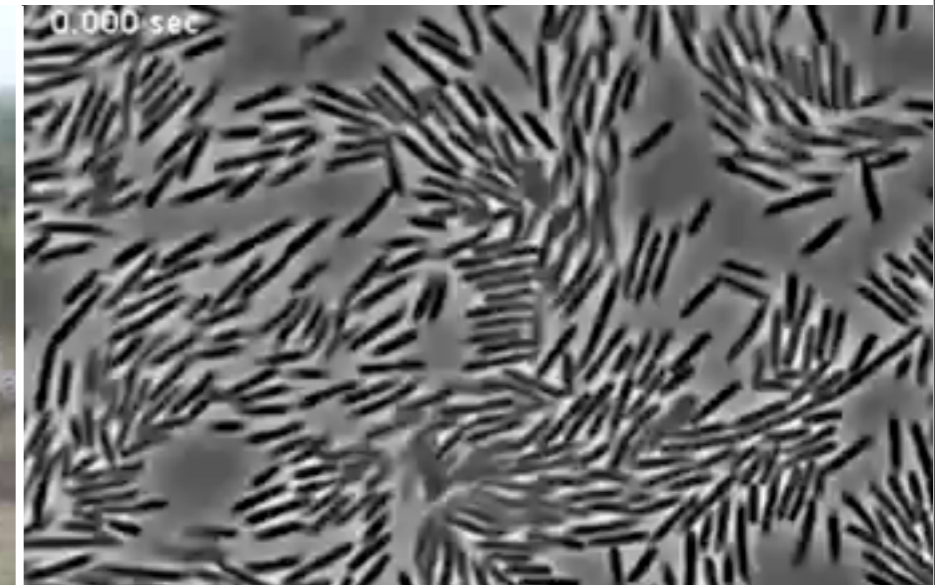
- **Coupling** can lead to **synchronization**.
- The **coupling** of human behavior can lead to **memes**.
- Humans are definitely **coupled** - we seem programmed to imitate each other.

What does this mean for animal behavior?



Want more? See Steve Strogatz's TED talk & book!!

Coupling of behavior leads to swarming



Swarm

(noun)

The aggregation (grouping) of coupled objects, often animals.

- Bird flocks
- Animal herds
- Schools of fish
- Insect swarms (bees, ants, locusts)
- Robotic swarms

Biological aggregations move in a coordinated manner.



Parrish & Keshet, Nature, 1999

Aggregations propagate without a leader.



Social interactions are key to the formation of groups.



Social interactions are key to the formation of groups.



Aggregations may have sharp edges, nearly constant density



Sinclair, 1977

Plate 3. Wildebeest massing in a grazing front on the Serengeti Plains. March 1973.

Aggregations may have sharp edges, nearly constant density



Group Activity: Human Swarming I

WALK slowly toward (what you perceive to be) the center of the group.

SLOW DOWN if you are within two feet of another person.

STOP if you are within one foot of another person.

Group Activity: Human Swarming II

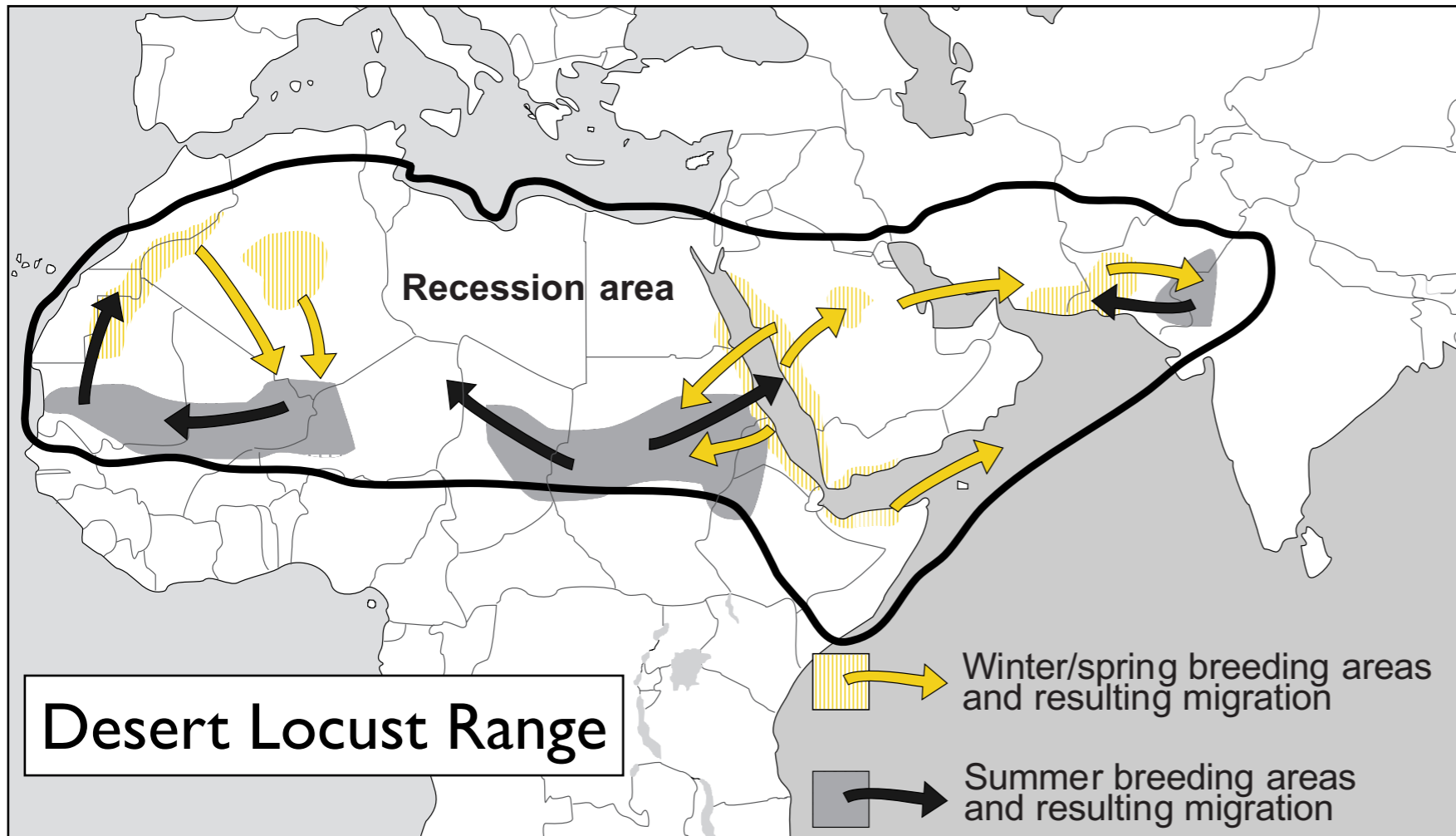
WALK at a slow, constant speed.

WALK toward the person or people you see in front of you.

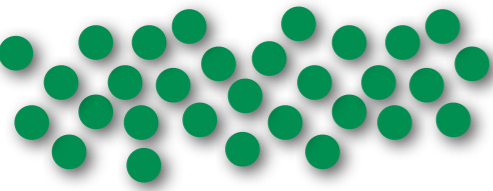
TURN RIGHT if you are going to collide.

Models can shed light on locust swarming.

Amongst natural aggregations, locust swarms are arguably the most devastating.



10^{10} locusts



100 km²

10 - 100 km/day



Locusts menace already hunger-stricken Mali and Niger

Los Angeles Times, June 6, 2012



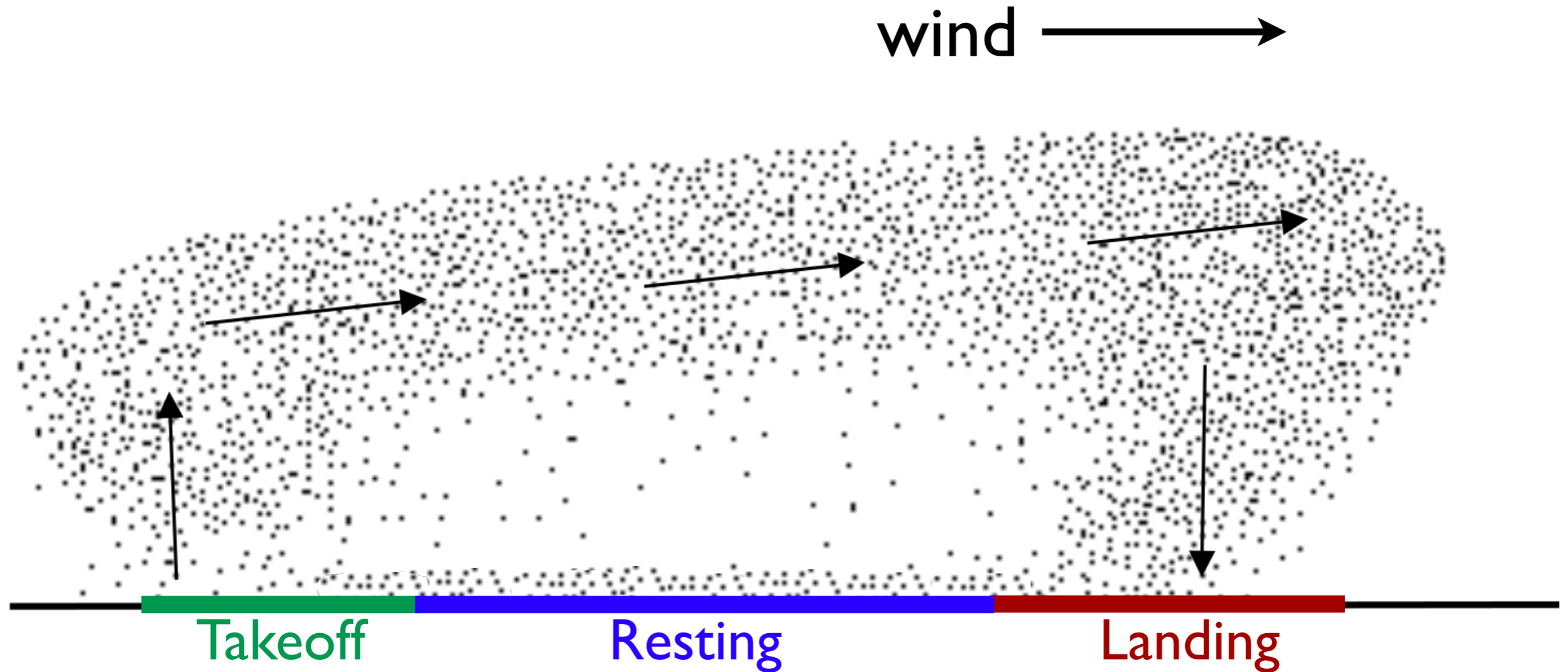
Mali is already bedeviled by the messy aftermath of a military coup, Tuareg rebels who've declared their own state, Islamists trying to impose strict religious law in the north, and waves of hunger.

Now **Mali and neighboring Niger are facing swarms of locusts, which were left uncontrolled while Libya and Algeria, which normally keep local locusts from moving south, grappled with conflicts and insecurity of their own.**

The swarming desert locusts, which can eat their own weight in fresh food every day, threaten to devastate crops in a region where millions of people are already menaced by food shortages. In some stretches of northern Mali and Niger, **some people have resorted to eating plant leaves**, the International Committee of the Red Cross and the World Food Program have said...

The onslaught is especially alarming in Mali because the unrest has crippled its ability to fight them off. Bloomberg News reported Thursday that **the equipment Mali needs to stop the swarms was destroyed during the Tuareg rebellion...**

Locust swarms migrate with a rolling motion.



Uvarov, Grasshoppers and Locusts (1977)

Kennedy, Proc. Roy. Soc. Lond. B 235 (163) (1951)

Albrecht, Polymorphisme Phasaire et Biologie des Acridiens Migrateurs (1967)

Rainey, Flight Behavior and the Atmospheric Environment of Locusts and other Migrant Pests (1989)

Eur. Phys. J. Special Topics **157**, 93–109 (2008)
© EDP Sciences, Springer-Verlag 2008
DOI: 10.1140/epjst/e2008-00633-y

THE EUROPEAN
PHYSICAL JOURNAL
SPECIAL TOPICS

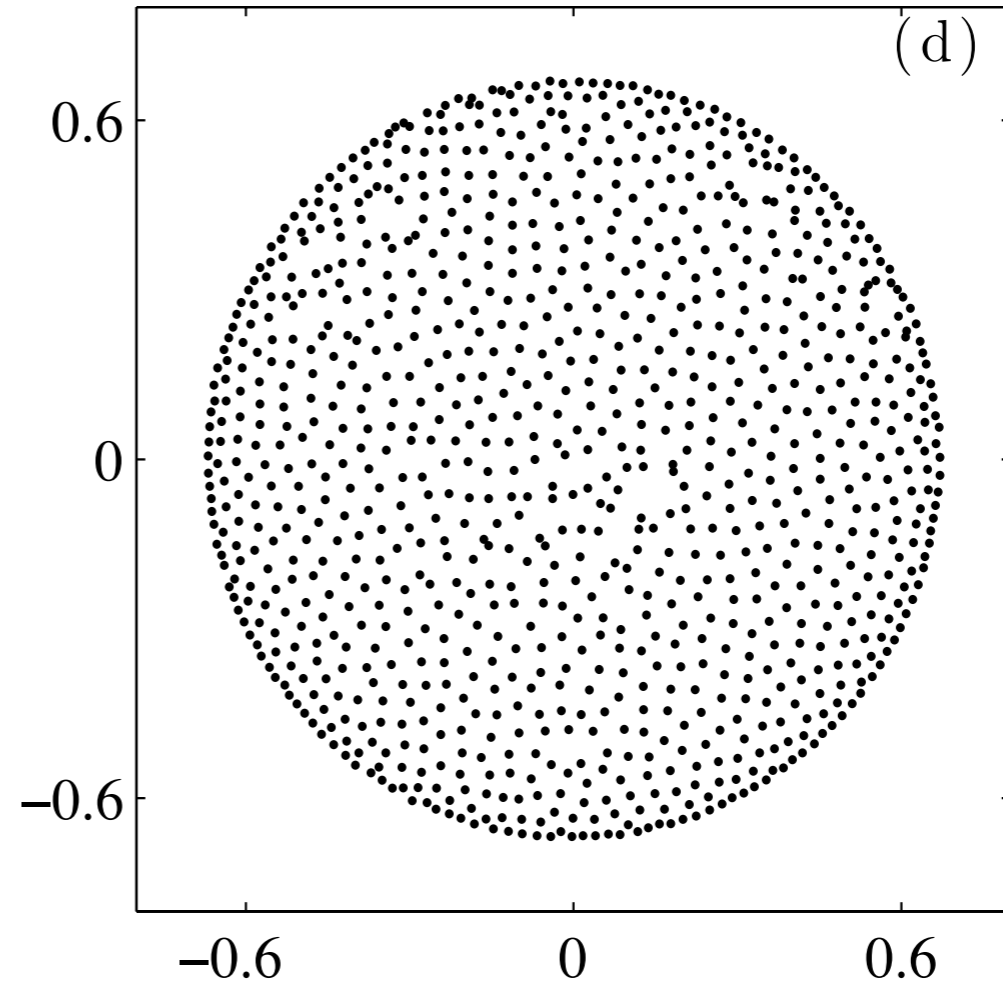
A model for rolling swarms of locusts

C.M. Topaz, A.J. Bernoff, S. Logan, W. Toolson



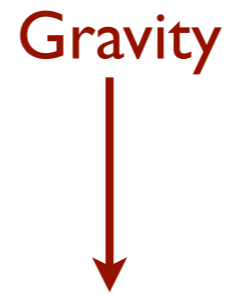
Attraction/Repulsion

1. Individuals are **attracted** toward neighbors.
2. Individuals are **repelled** if they get too close.



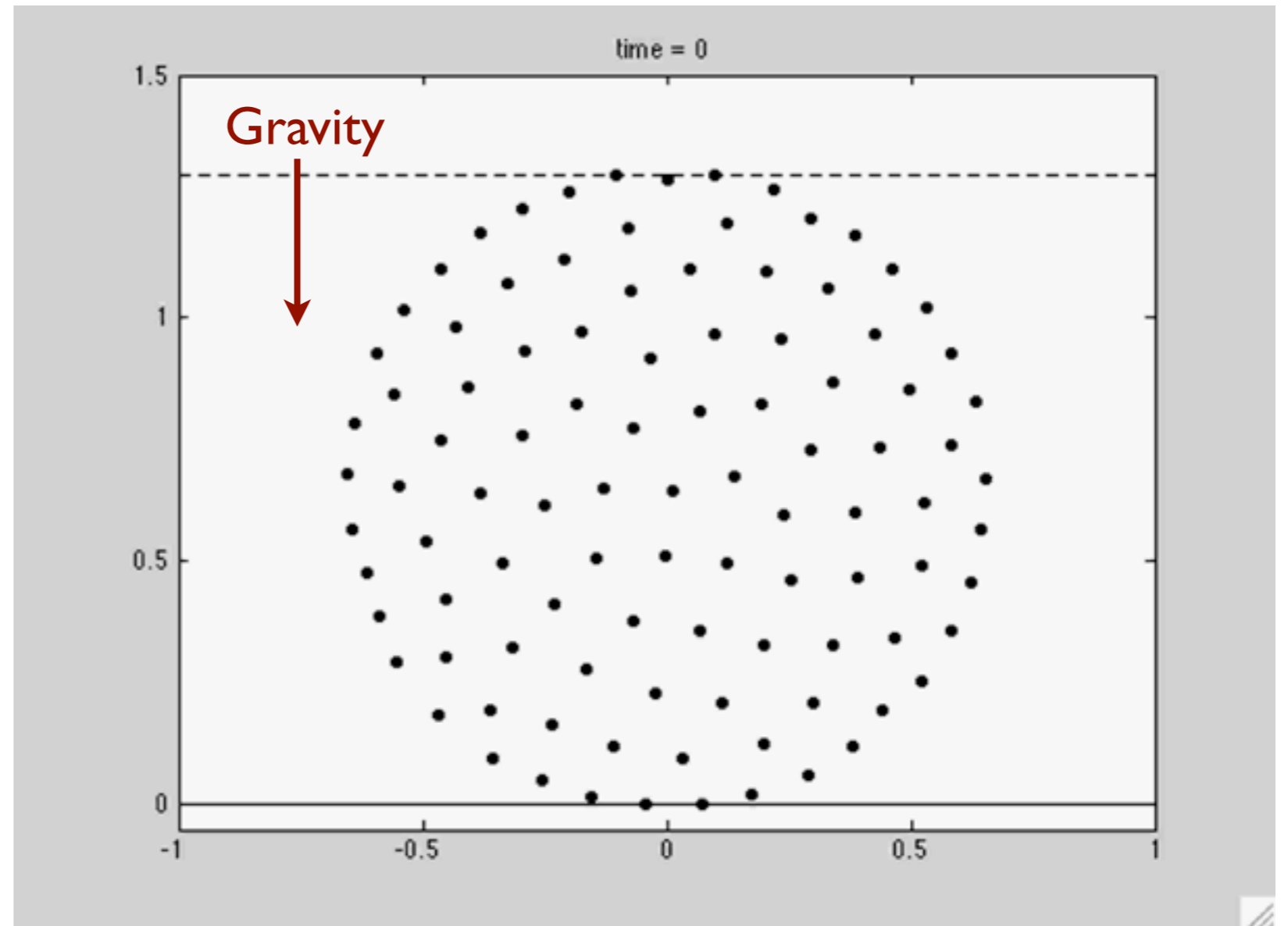
Attraction/Repulsion + Gravity

Model
Simulation:



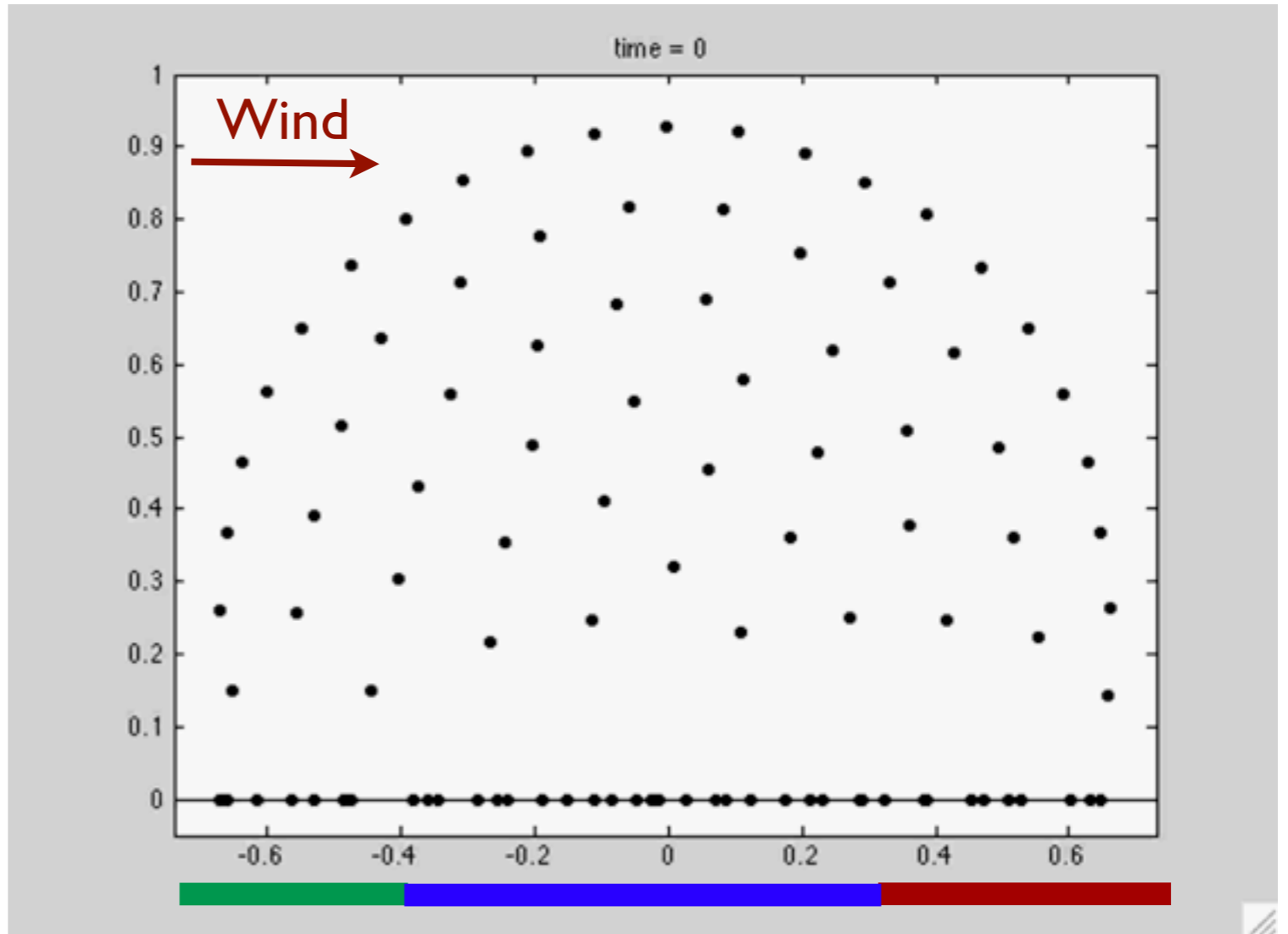
Attraction/Repulsion + Gravity

Model
Simulation:

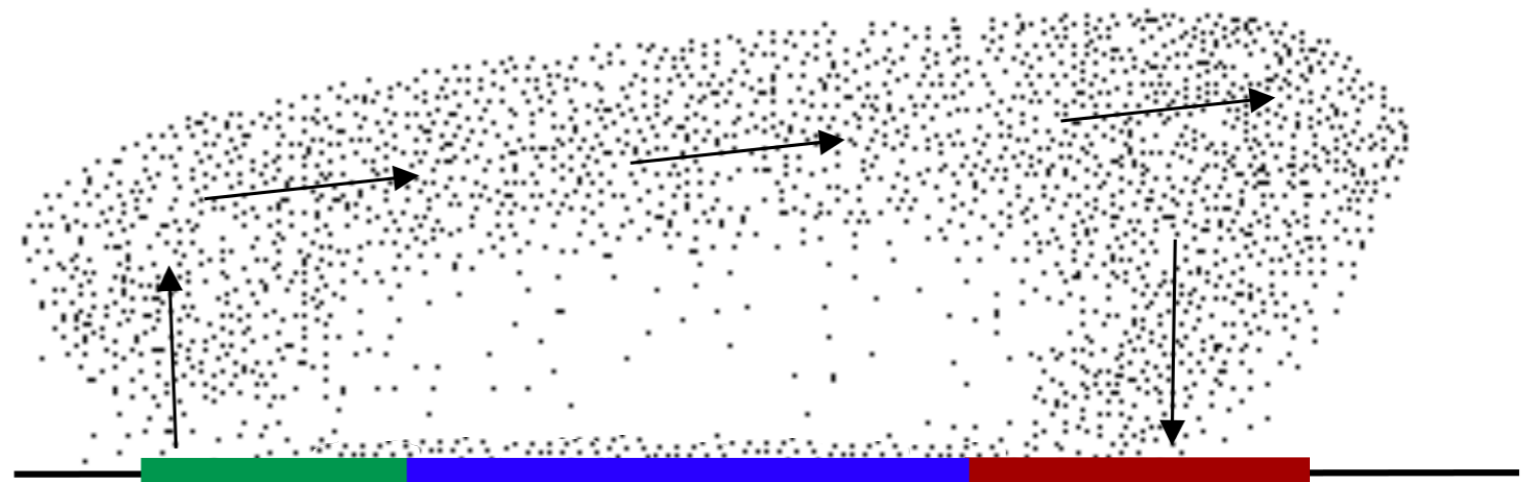


Attraction/Repulsion + Gravity + Wind

Model
Simulation:



Field
Observation:



Mill

(noun)

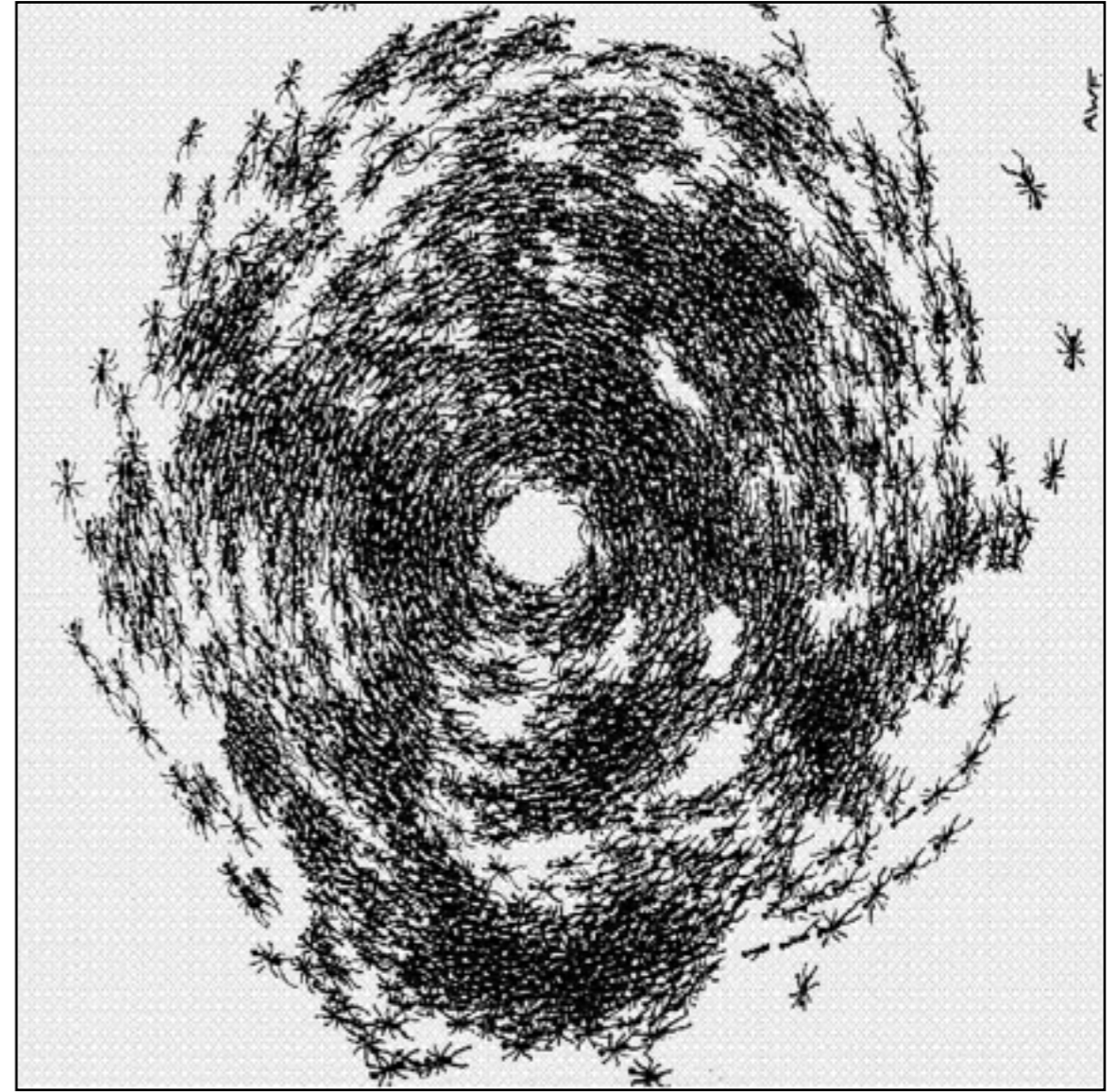
A rotating circular swarm.

- Ants
- Fish
- Occasionally people

Minimal models describe fundamental aspects of patterns.



Fish school
(Parrish & Keshet, 1999)



Ant mill
(Schnierla, 1971)

Math modelers cull parsimoniously from the real world.

Fish neurobiology

Fish behavior

Ocean current profiles

Fluid dynamics



D'Orsogna, Chuang, Bertozzi & Chayes PRL (2006).

Math modelers cull parsimoniously from the real world.

Fish neurobiology
Fish behavior
Ocean current profiles
Fluid dynamics



Self-propulsion
Attraction/repulsion



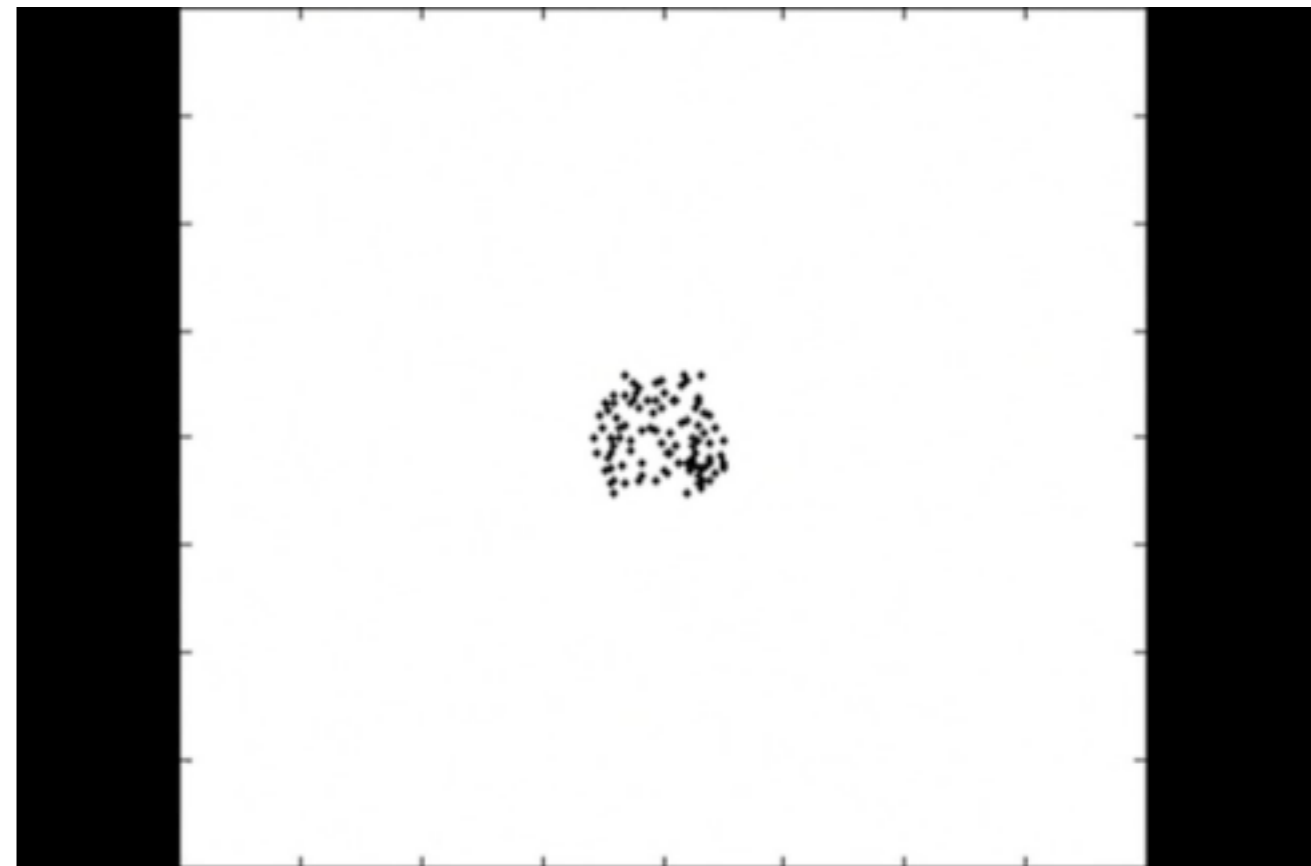
D'Orsogna, Chuang, Bertozzi & Chayes PRL (2006).

Math modelers cull parsimoniously from the real world.

Fish neurobiology
Fish behavior
Ocean current profiles
Fluid dynamics



Self-propulsion
Attraction/repulsion



D'Orsogna, Chuang, Bertozzi & Chayes PRL (2006).

Humans exhibit mill behavior also



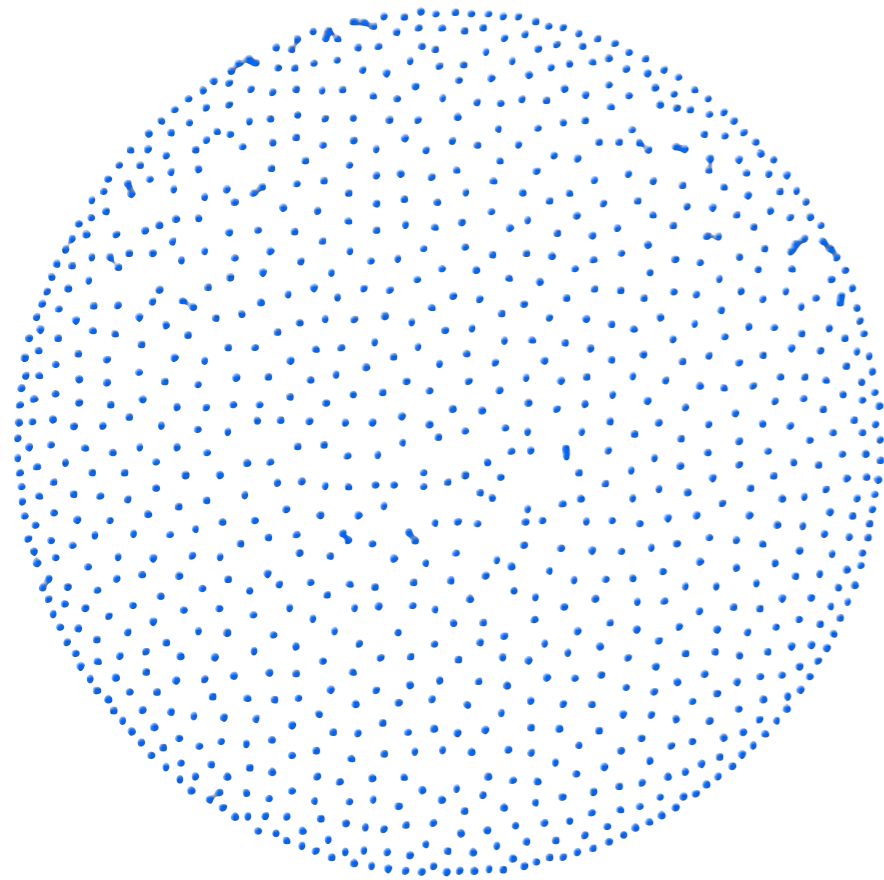
Frontiers

(noun)

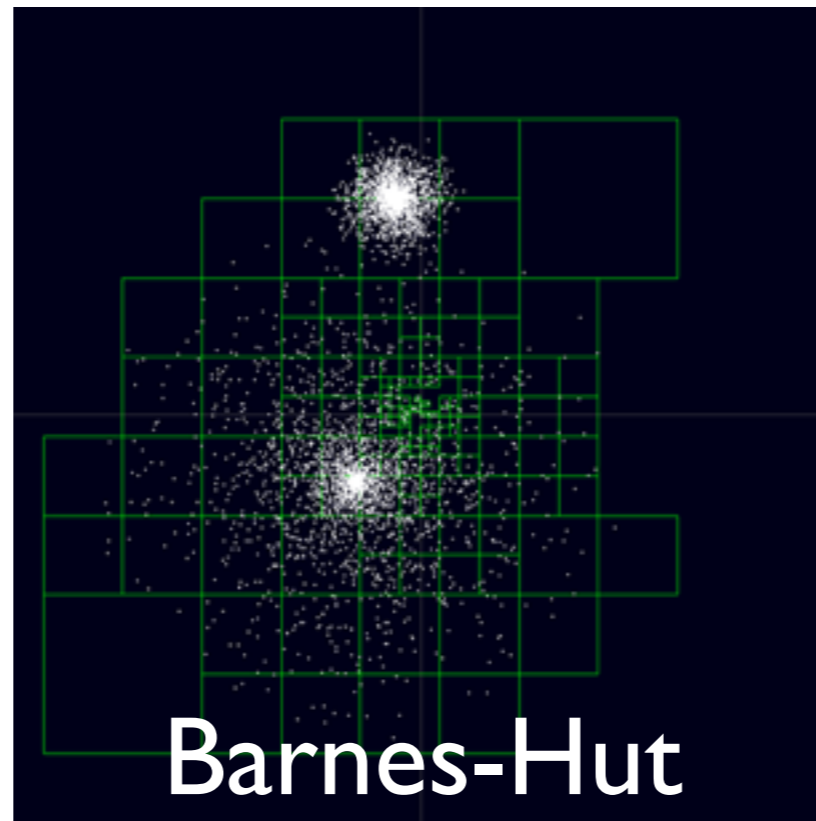
The limits of knowledge - where the action is.

Frontier #1: Efficient computation of swarms

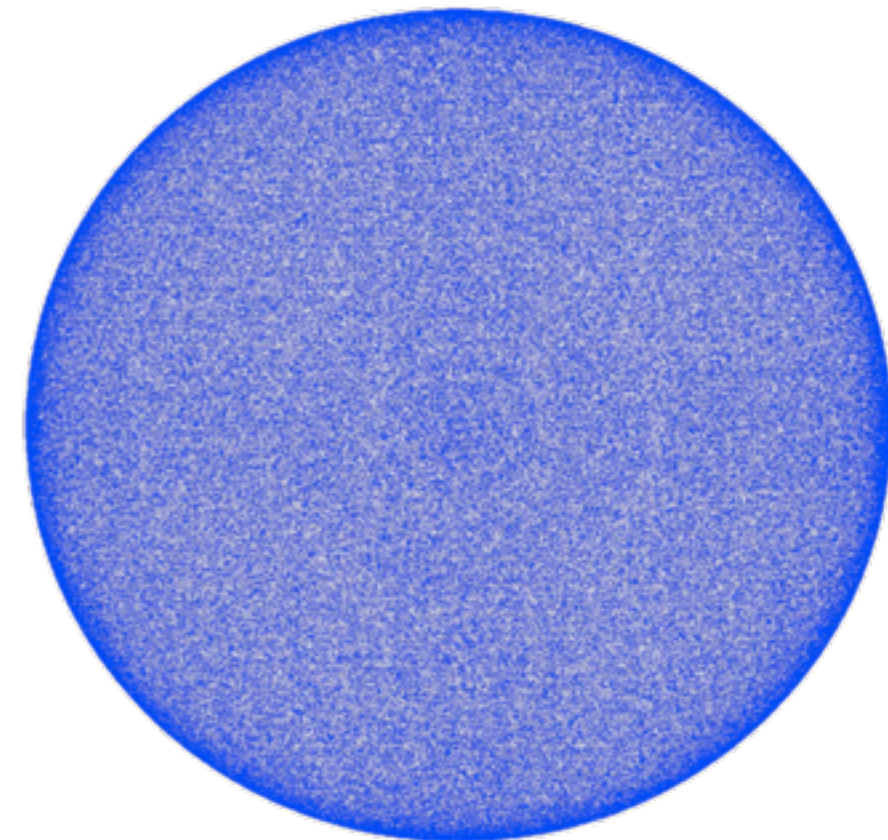
N = 1 thousand



GPU Computing



N = 1 million



Difficulty: Pairwise interactions means
calculation scales like N^2

Frontier #2: Quantitative lab/field measurements



Inferring individual rules from collective behavior

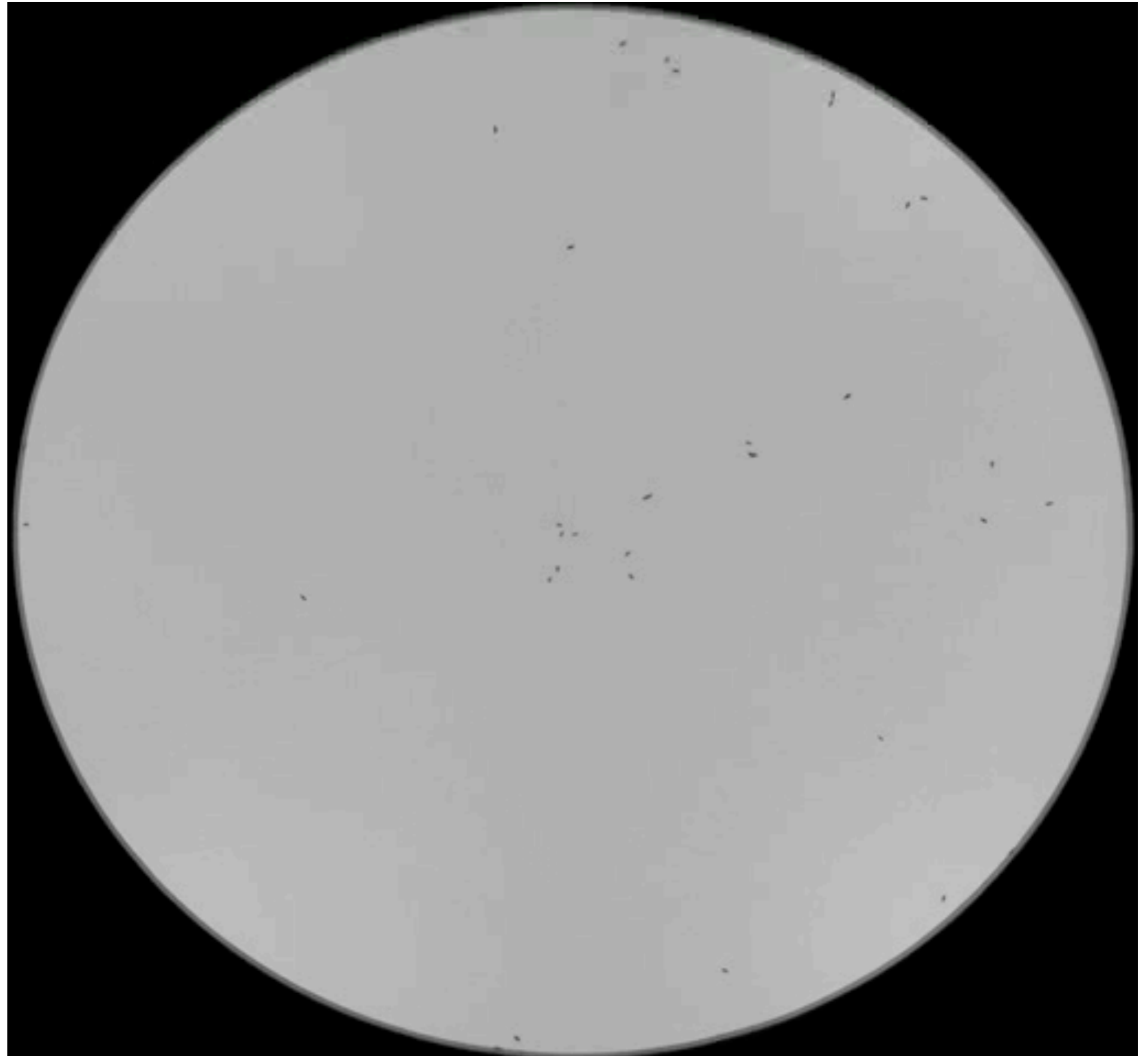
Lukeman, Li & Edelstein-Keshet
(PNAS 2010)

What is a minimal model
for duck movement?

Frontier #2: Quantitative lab/field measurements



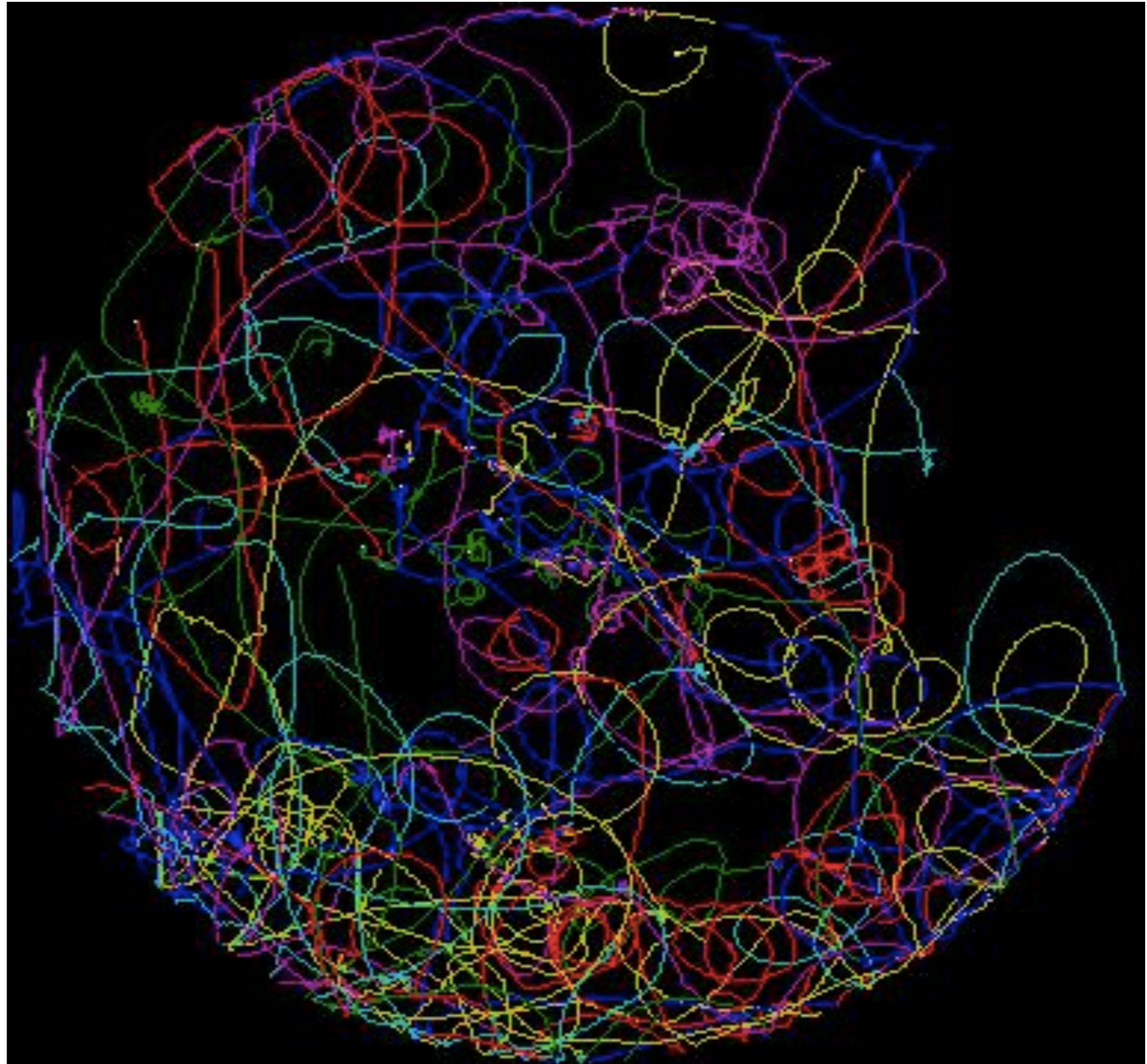
**Motion
tracking of
pea aphids**



XMAC lab - Chad Topaz, Macalester College

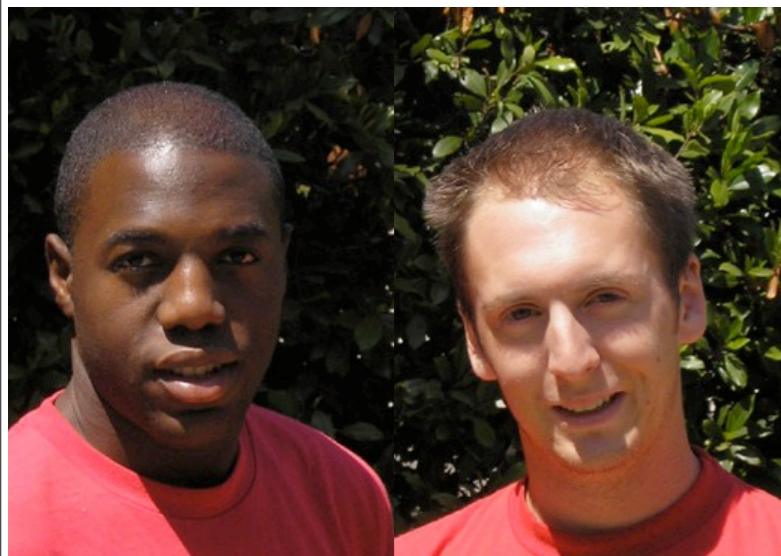
Frontier #2: Quantitative lab/field measurements

What is a minimal model for pea aphid movement?



Main messages

- **Coupling** can lead to **synchronization** of oscillators.
- **Coupling** in social networks can create **memes**.
- **Coupling** in biological networks can create **swarms**.
- **Swarms** are social groups of organisms that are biologically significant and that inspire applications.
- Swarms can be **modeled parsimoniously**.
- Models can shed light on biological systems, including **locust swarming**.



Sheldon Logan Wyatt Toolson

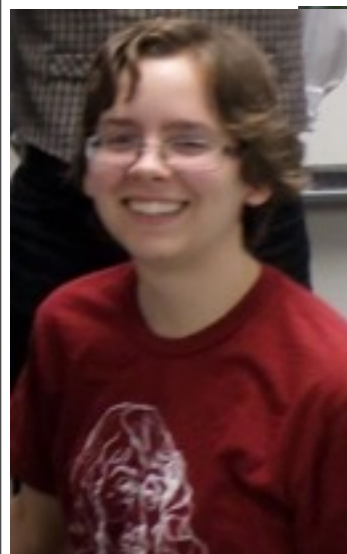
Undergraduate swarmers



Elise Delmas



Jon Bassen



Christa Nilsen



Matt Lam



Olivia Warner



John Paige



Ben Mayhew



Ryan Sutley



Aaron Laursen

My amazing team of collaborators!!

Faculty swarmers



Leah Keshet



Chad Topaz



Maria D'Orsogna