SWARM DECISION MAKING

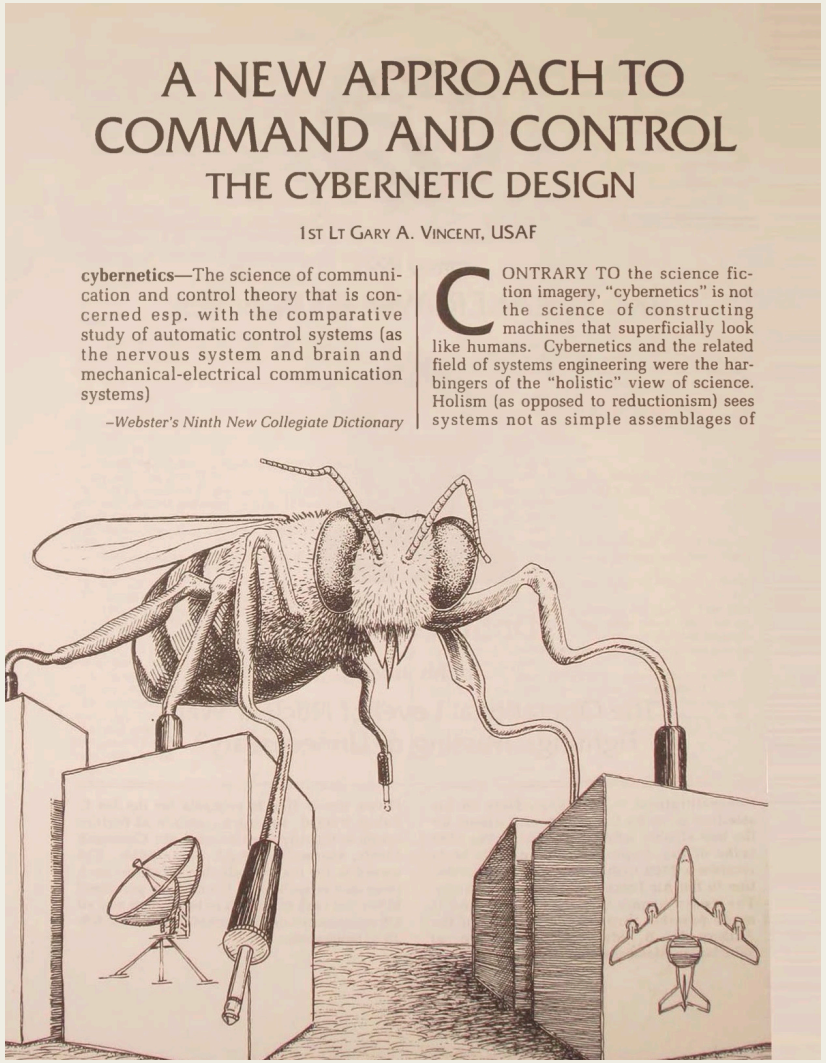
Gary Vincent

INCOSE-LA Virtual Speaker Meeting

July 13, 2021

About Me

- INCOSE CSEP, Los Angeles Chapter
- Member of Natural Systems Working Group
- Sr. Principal Systems Engineer, Northrop Grumman Defense Systems
  - Distributed Simulation at Nellis AFB
  - 20+ Yrs SE/ 10+ Yrs Simulation
  - *Standard Disclaimer* – Not representing my employer in this presentation
- Past Life: Air Weapons Director, USAF
- Not an expert on swarm systems



A NEW APPROACH TO COMMAND AND CONTROL

THE CYBERNETIC DESIGN

1ST LT GARY A. VINCENT, USAF

cybernetics—The science of communication and control theory that is concerned esp. with the comparative study of automatic control systems (as the nervous system and brain and mechanical-electrical communication systems)

–Webster's Ninth New Collegiate Dictionary

CONTRARY TO the science fiction imagery, "cybernetics" is not the science of constructing machines that superficially look like humans. Cybernetics and the related field of systems engineering were the harbingers of the "holistic" view of science. Holism (as opposed to reductionism) sees systems not as simple assemblages of

Airpower Journal, Summer 1993

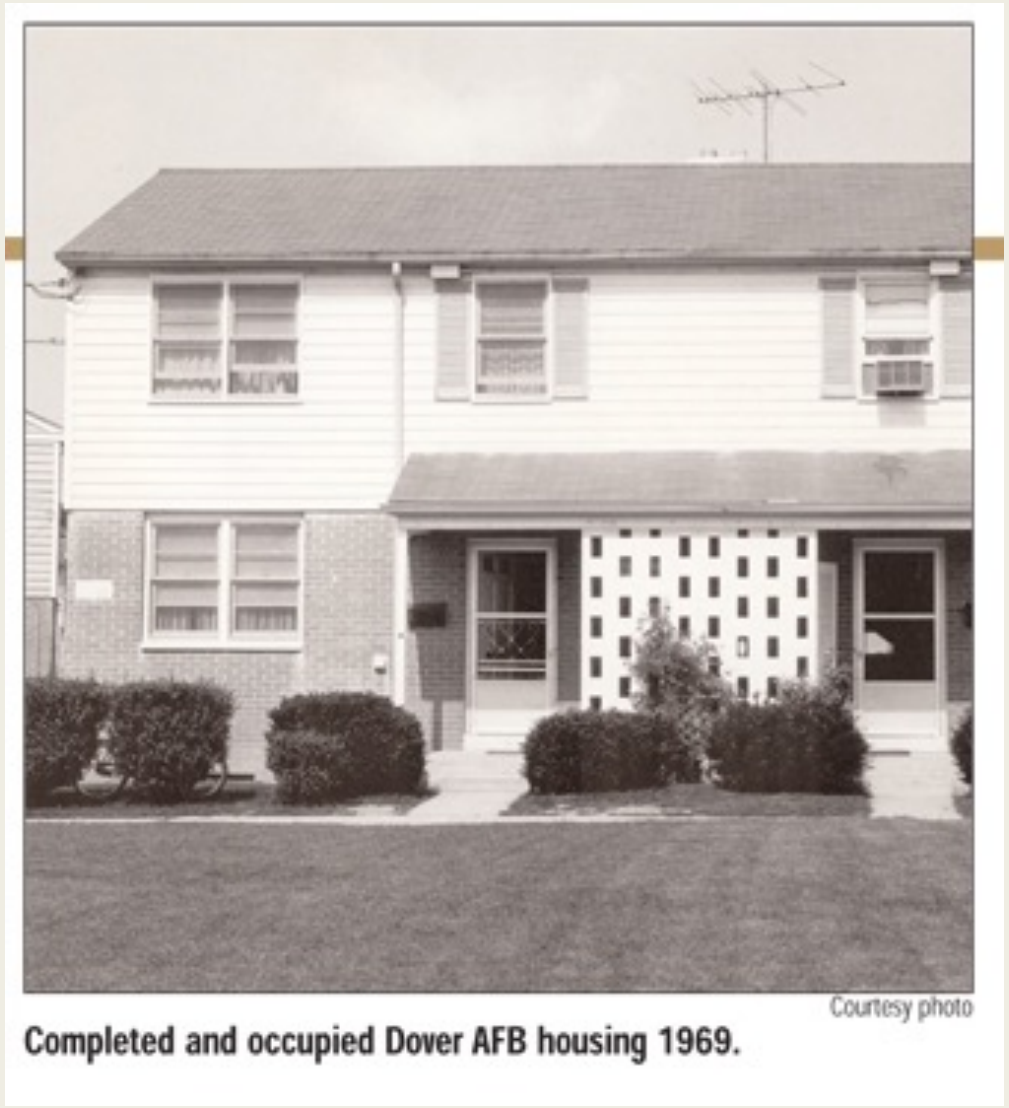
Natural Systems Working Group

- Charter: Investigate applications of natural systems data and concepts to SE issues and practices
- Major Goals:
  - *Facilitate increased dialog between SE and natural systems communities of practice*
  - *Influence SE processes to routinely consider and appropriately take advantage of natural systems data and concepts*

Natural Systems Working Group (cont.)

- Co-Chairs: Curt McNamara, Dennis Tuckowski, Alex Wolf
- https://sites.google.com/site/incosenswg/home
- nswg-info@incose.org
- One of 50 INCOSE Working Groups
  - *https://www.incose.org/incose-member-resources/working-groups*
  - *Agile, AI, Healthcare, MBSE, Smart Cities, Space Systems, etc., etc…*

Children’s Tales

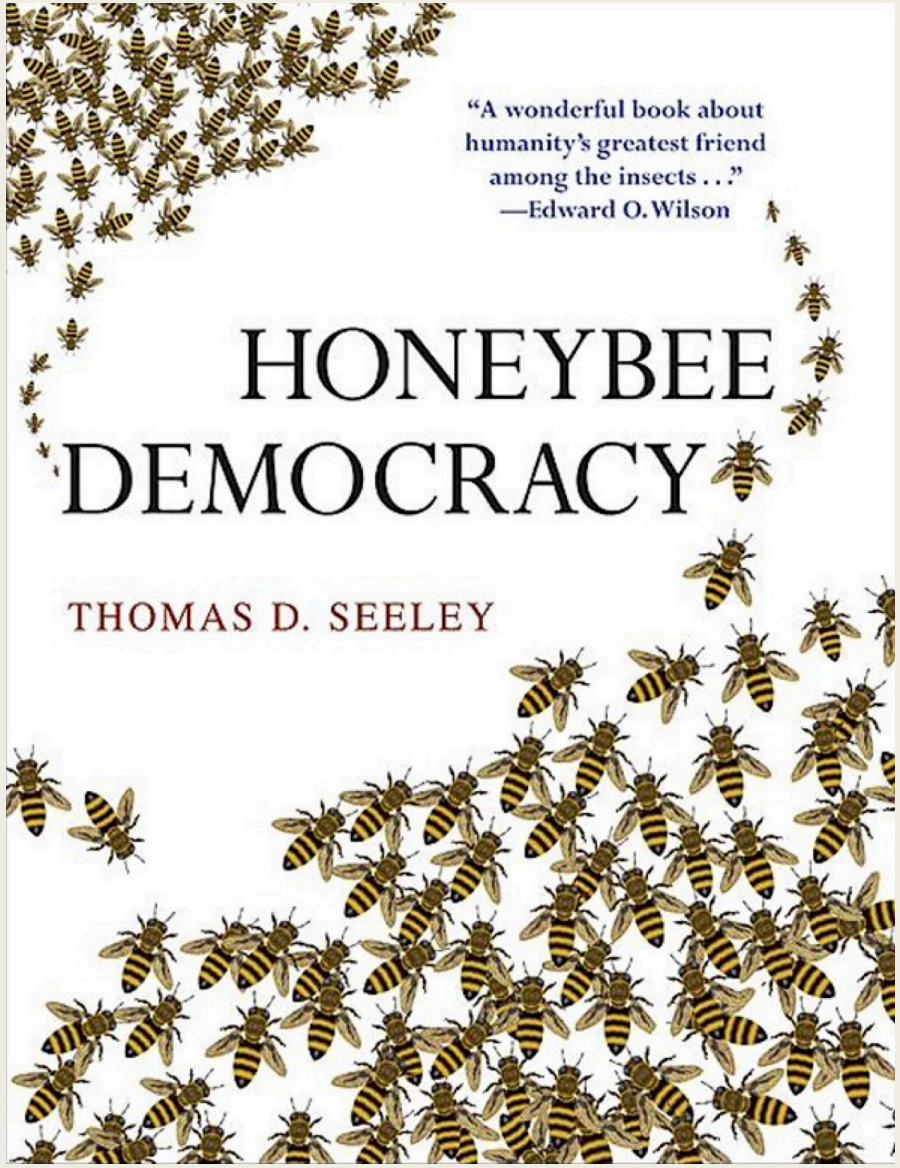


Courtesy photo

Completed and occupied Dover AFB housing 1969.

Topics

- Swarm Behavior
- Swarm Decision Making: Honeybee Nest Site Selection
  - *Sidebar: Monarch Navigation*
- Implications for Human-Designed Systems
- Implications for Human Systems

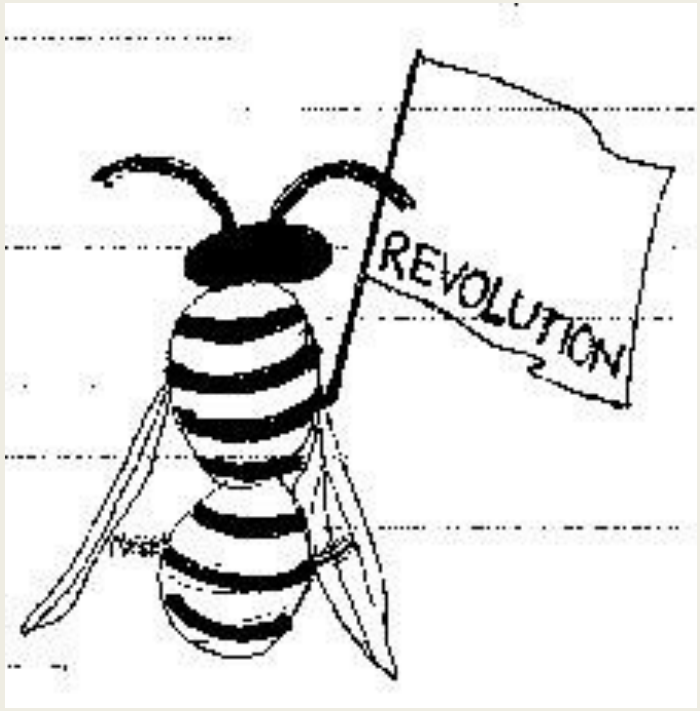


Swarm Behavior

- Collective behavior of decentralized, self-organized systems
- Largely tactical. Used by both prey and predators
- Simple rules executed by each swarm member in parallel:
  - *Fly towards center of flock*
  - *Match velocity with nearest 'x' neighbors*
  - *Maintain at least 'z' separation*

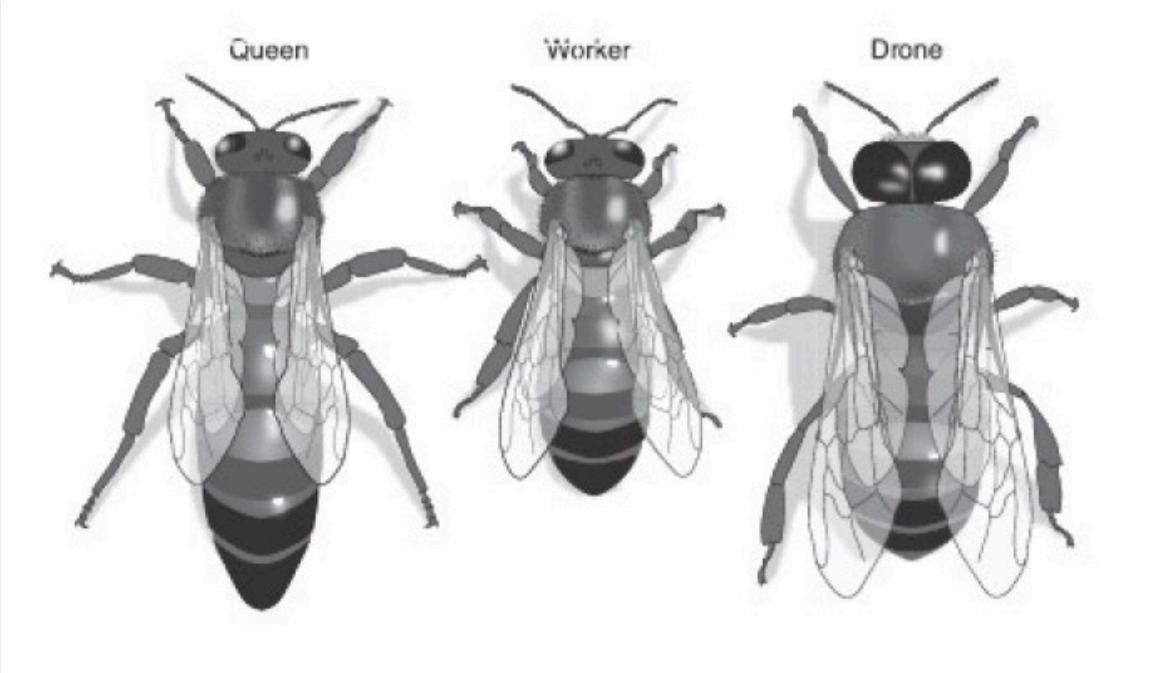
Swarm Decision Making

- The act of identifying, evaluating, and selecting among alternative solutions to a problem *without centralized control*.
  - Anarchy*: From the Greek* anarkhos *[an-: 'without', arkhos: 'master']*
  - *Making a decision without any one entity being 'in charge'.*
- Case Study: Selection of new hive site by bee colonies



Don’t Bees Have a Queen?

- Honeybee Caste System: *Queen* (lay eggs), *Drones* (mate w/Queens), *Workers* (everything else)
- Queens grow from worker bee larvae specially fed (Royal Jelly) by workers
  - *Multiple larvae selected (3-4)*
- Relatively simple role compared to workers
  1. *Kill rivals (sisters)*
  2. *Mating Flight*
  3. *Lay Eggs*
  4. *GOTO (3)*
  5. *[Maybe] Establish new colony*



Don’t Bees Have a Queen? (cont.)

- Underperforming Queens can be replaced (“Supersedure”)
- The colony *manufactures* Queens if it needs them, and decides whether to accept new Queens (“Requeening” by beekeepers)
- *Do not confuse* ***stature*** *(size/lifespan/diet) with* ***decision-making authority***
- ***The colony makes decisions collectively***

The Problem: Finding a New Home

- In successful hives, in spring the Queen and 50-70% of the hive depart to relieve overcrowding and start a new colony
  - *Existing hive will create a new Queen*
  - *Current Queen and swarm will nest temporarily on/in any convenient shelter*
    - Exposed to elements
    - Exposed to predators
    - Limited food
- The clock is running: *Where will they live?*

The Ideal Home

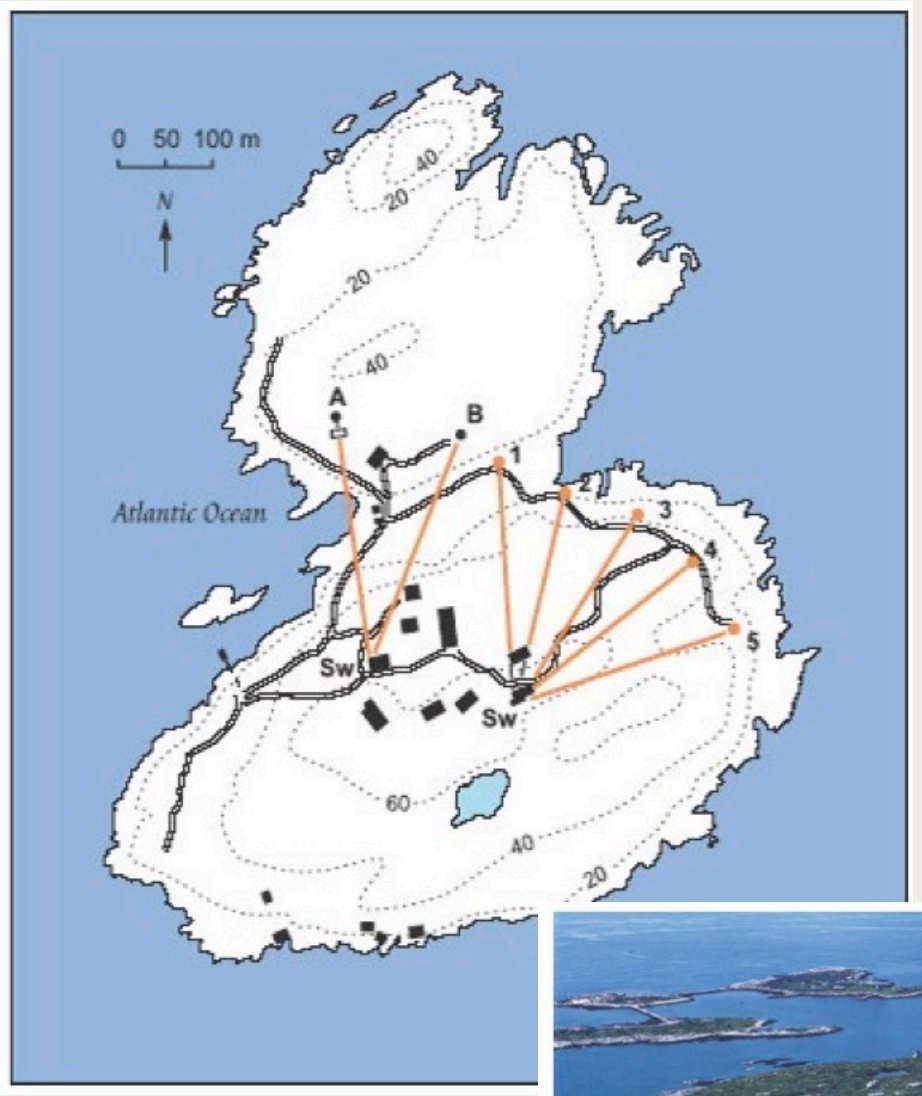
- ~40 Liters is ideal volume
- Small opening entrance
  - *~5 m high*
  - *South-facing*
  - *Defense*
  - *Thermoregulation*
- Hollows of trees are a favorite location

Seeley Study of Swarm Decision Process

- Series of studies to determine how bee swarm selects a new home
- Advent of video cameras made study of bee behavior much easier
- How to make a controlled environment in which to study?

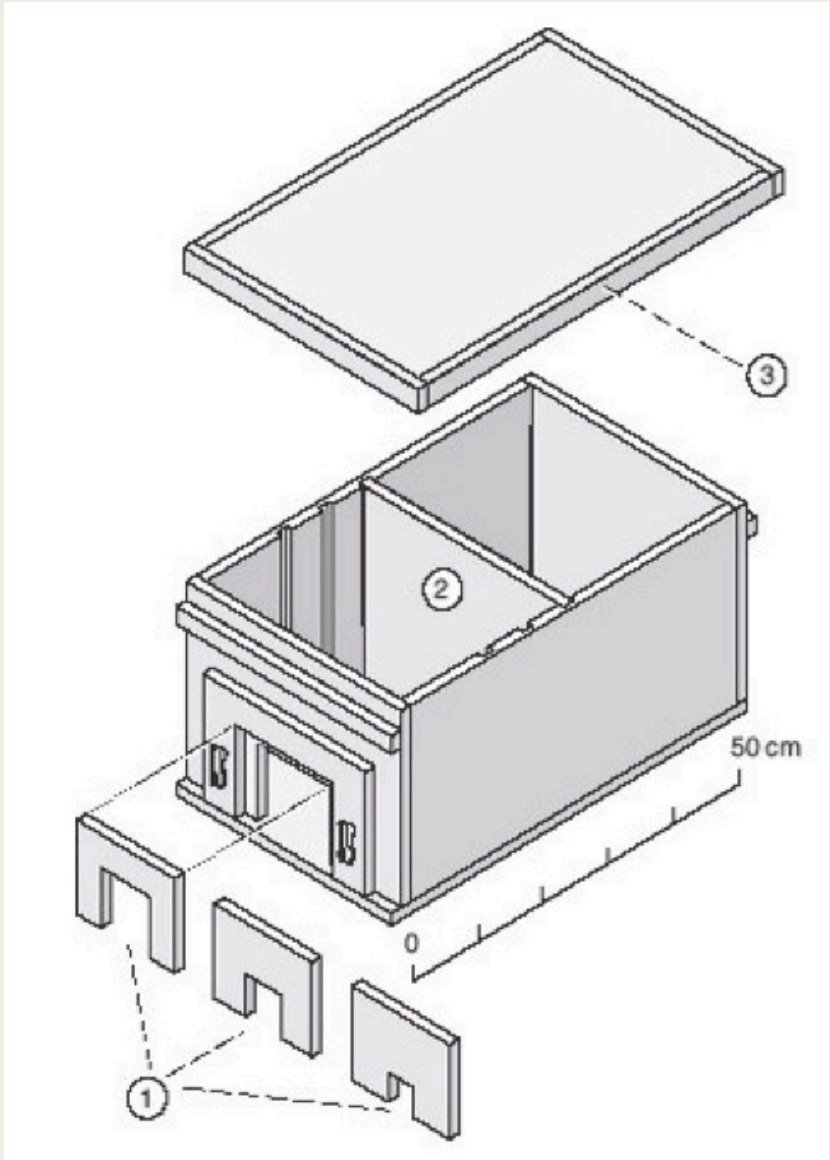
The Laboratory

- Appledore Island, off the coast of Maine, ~50 miles NE of Boston
- No trees
- Too far to fly back to mainland
- Create candidate nesting sites in predetermined locations



The Ideal (Manufactured) Home

- Reconfigurable for both volume and opening size
- Move/reconfigure boxes to present different problems

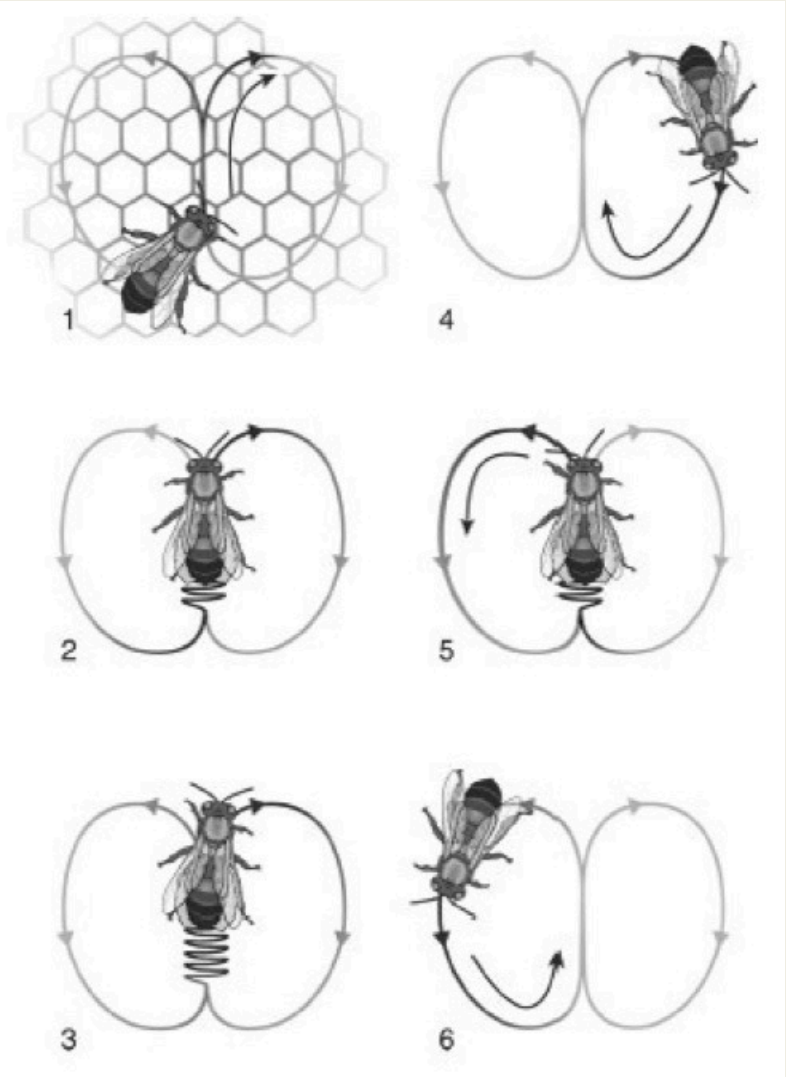


Search Process

- Scouts search for nesting sites
  - *Only 300-500 out of 10,000+ in swarm*
  - *Most experienced bees*
- After finding and evaluating a site, scouts return and communicate their find by…*dancing*

The Waggle Dance

- How bees communicate direction, distance, and quality of resources
  - *Nectar sources*
  - *Water*
  - *Potential hive sites*



The Waggle Dance

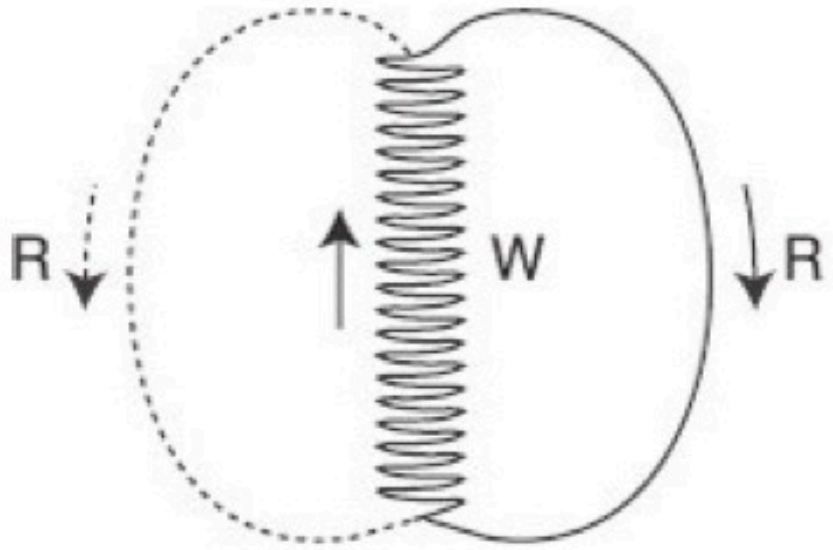
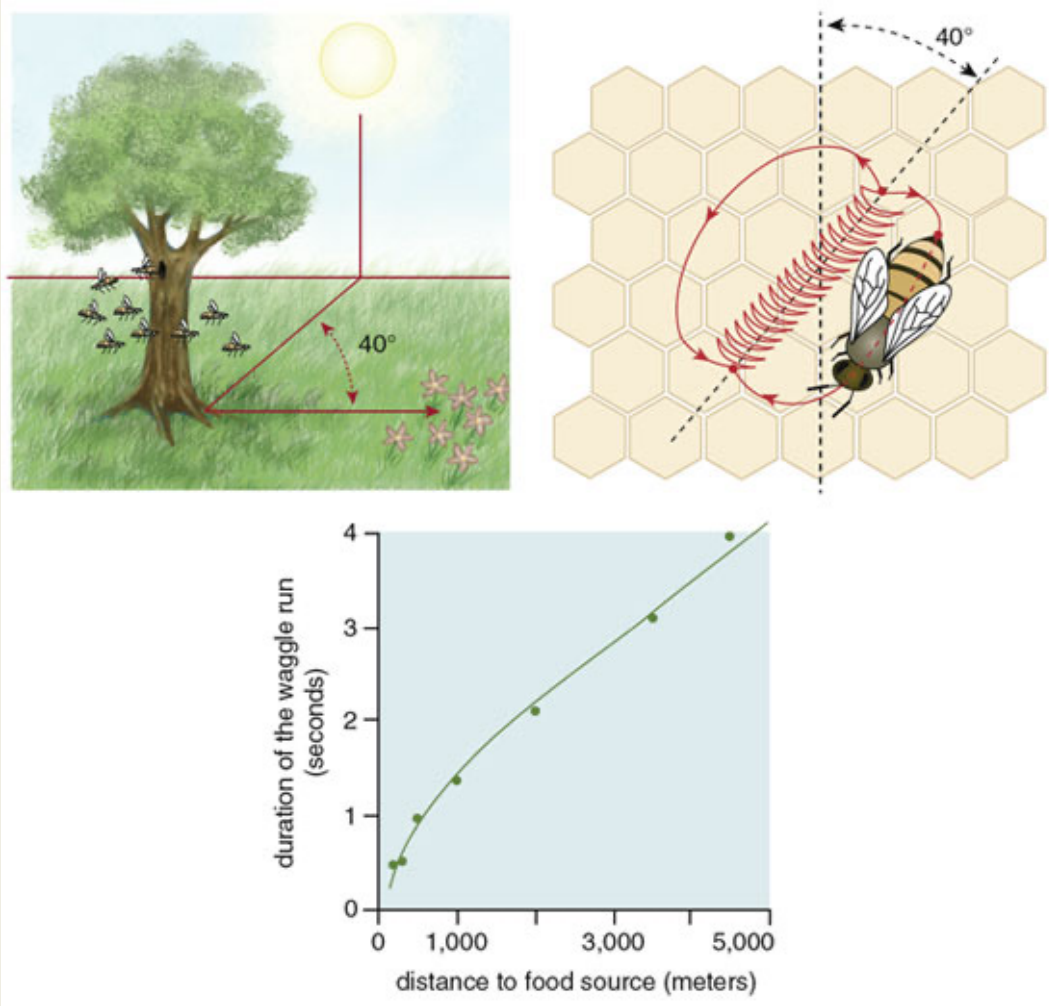


Fig. 6.2 Movement pattern of a bee performing the waggle dance. Each dance consists of a series of dance circuits. Each dance circuit contains a waggle run (W) and a return run (R, alternating right and left). The duration of the waggle run depends on the distance to the target (food source or nest site). The duration of the return run depends on the desirability of the target. As target desirability increases, return run duration decreases, making the dance appear livelier.

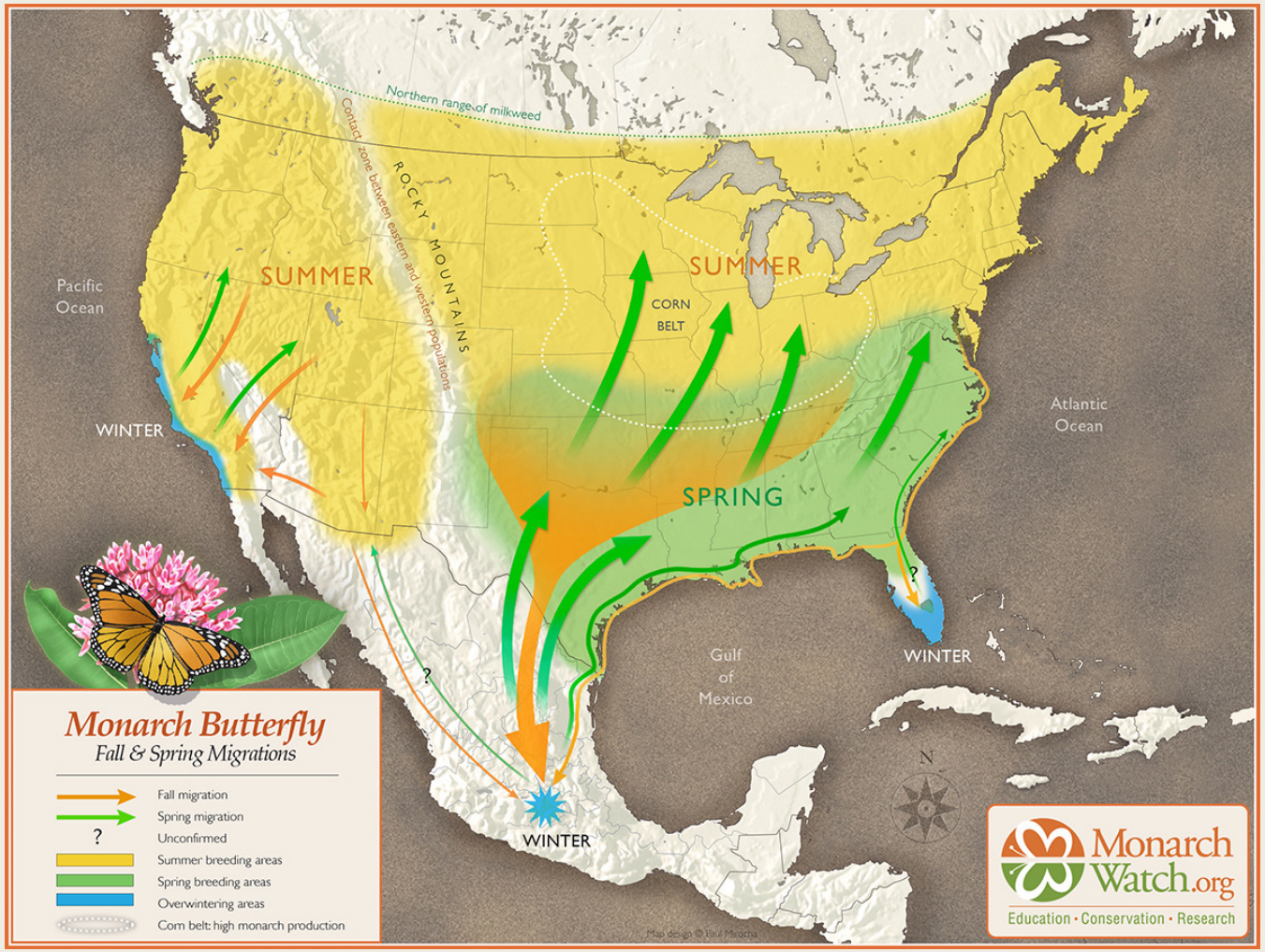
The Waggle Dance

- Direction: Angle from vertical indicates angle from the Sun
- Distance: Length of run indicates distance
- Quality: Quickness of return to waggle run and number of runs indicates scout rating of resource



Sidebar: Monarch Mystery

- Monarch Butterflies migrate from overwintering locations in California, Florida, and Michoacán, Mexico
- In the Spring, initial generation migrates north into the Southern US
- In Summer, subsequent generations migrate to Northern US, even Canada
- In Fall, their grandchildren, great-grandchildren, etc. migrate all the way back to Michoacán (aka, *Super Generation*)
- How do they know where to go?



Super Monarch Generation

- Changing season triggers females to lay Super Monarch eggs
- This larger generation makes return migration all at once
- Due to hormonal changes, lives 8x longer and cannot breed until hormonal profile changes back
- How do they know where to go?

The Solution (we think)

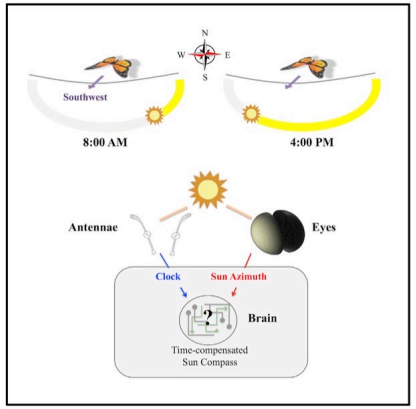
- Monarch antennae act as internal clock
- Antennae (clock) and Eyes (azimuth) wired into neural circuit creating a time-compensated sun compass
- Super Monarch migration in the Fall holds the sun in the opposite (mirrored) position from spring/summer migration
- Instead of storing the data, they simply reverse the process
- Sun again used as reference
- But how do they get back to that same valley?

Cell Reports

Report

Neural Integration Underlying a Time-Compensated Sun Compass in the Migratory Monarch Butterfly

Graphical Abstract



Authors

Eli Shlizerman, James Phillips-Portillo, Daniel B. Forger, Steven M. Reppert

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In Brief

Migrating monarch butterflies use a time-compensated sun compass to maintain southerly flight. Shlizerman et al. present a model that integrates neuronal oscillations of the sun's horizontal position and the circadian clock to direct flight. The model explains flight simulator tracks and proposes a space-time integration mechanism for directional flight.

Highlights

- A model for time-compensated sun compass used by monarch butterflies is developed
- Neural oscillations encoding solar azimuth and time of day are proposed
- Special integration of neural oscillations enables correction to southwest flight
- The model explains flight simulator tracks and supports northeast remigration

Shlizerman et al., 2016, Cell Reports *15*, 683–691
April 26, 2016 ©2016 The Authors
http://dx.doi.org/10.1016/j.celrep.2016.03.057

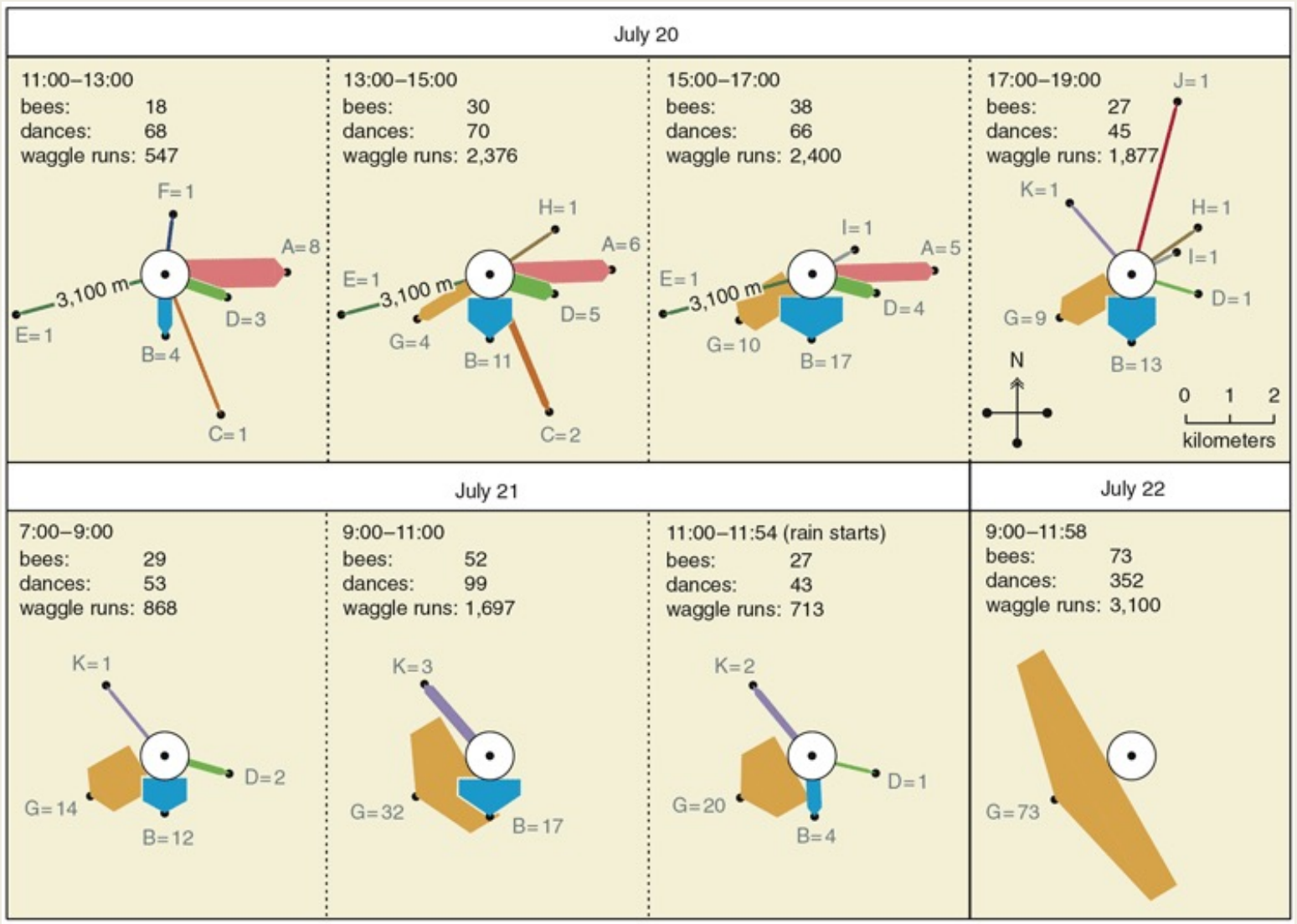
The TENET Hypothesis

- From the movie *TENET* – objects have “inverted” entropy and move backwards in time
- Monarch System Entropy: Spring/summer migrations disperse from origin point – entropy increases
- Reversal of process (*Super Monarchs*) decreases entropy of system
  - *Averaging of tens of million reverse processes removes errors*
  - *Terminal effect: Increasing density of Monarchs as they approach origin may allow swarming behavior to take over*
  - *Accident of Geography: Funneling effect of Continental Divide and Gulf of Mexico*

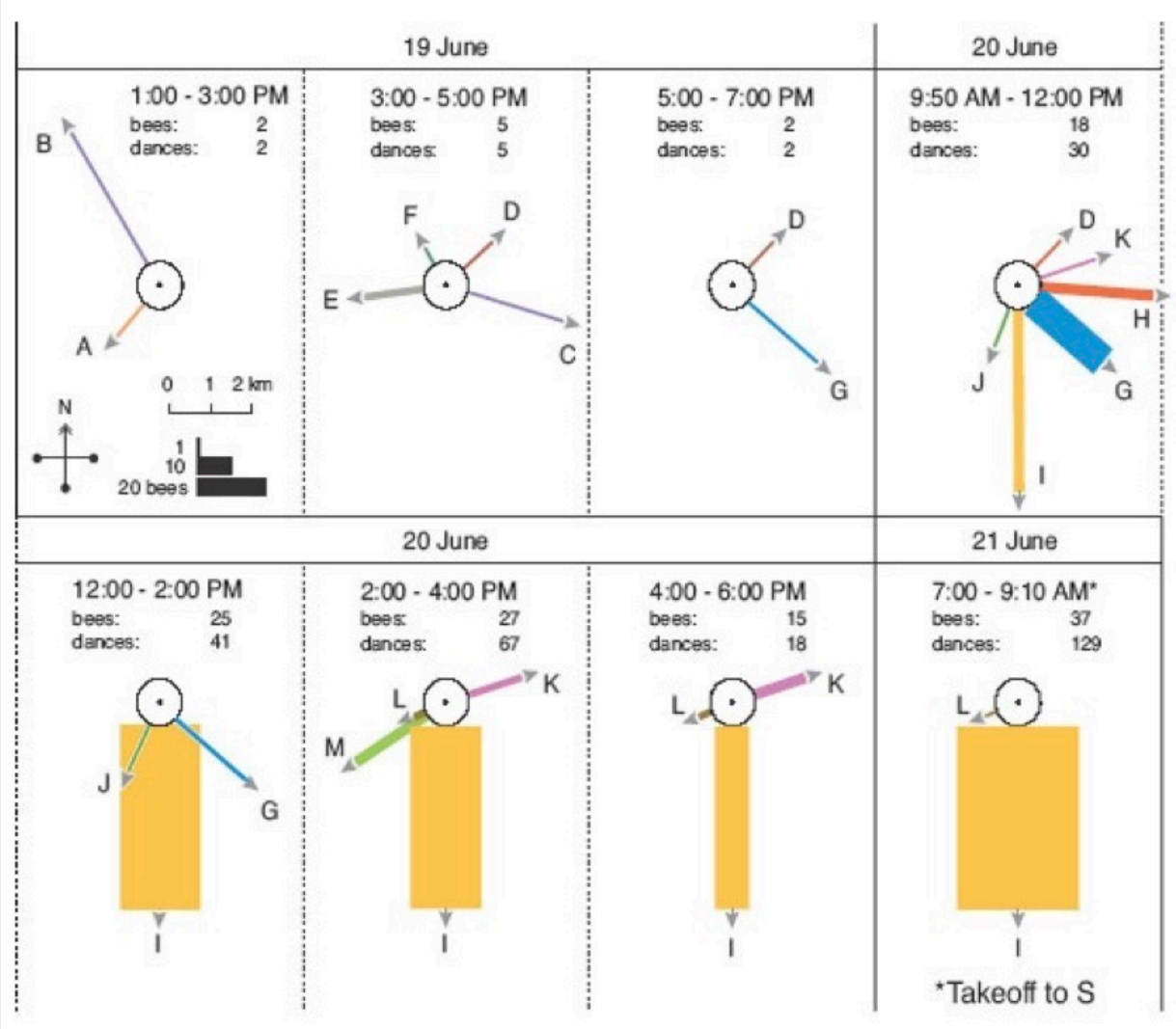
Back to the Bees: Voting Process

- Returning scouts dance to advertise the sites they have found
- Scouts act as both ‘sensory organ’ and ‘neurons’ in the Hive Mind
  - *Positive Feedback: More energetic dances encourage other scouts to visit site*
  - *Negative Feedback: Scouts will headbutt and interrupt dances for competing sites*

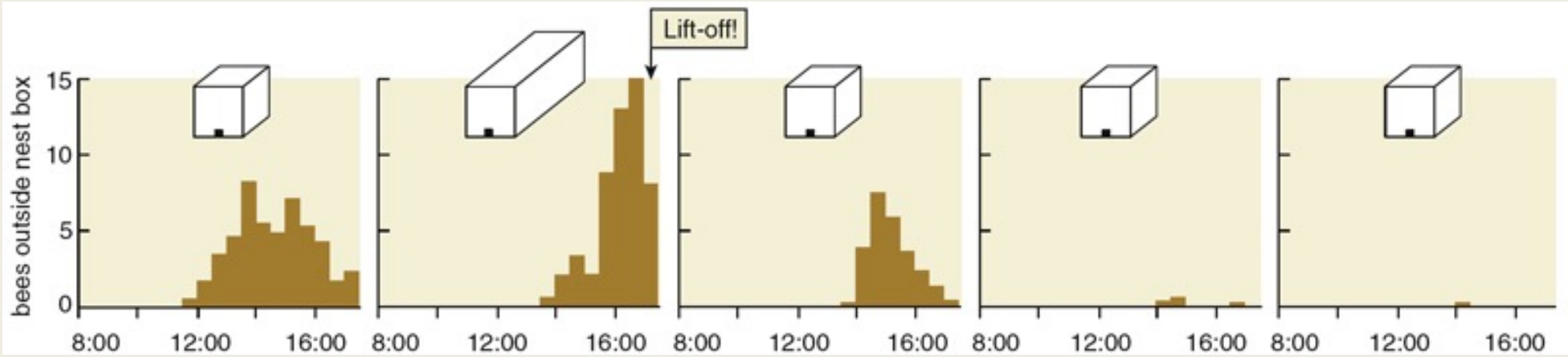
Voting Process



Voting Process



Site Visitation Over Time



Scout Variability?

- Marquette University study (published July 2020): Individual Bees tend to be ‘Curious’ or ‘Focused’
  - *Curious: Low Latent Inhibition (LI)*
  - *Focused: High Latent Inhibition*
- Curious bees seek out novel food sources, Focused bees return to established food sources over and over
- Researchers created colonies of exclusively one type or the other, plus a 50/50 colony

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RESEARCH ARTICLE

Individual learning phenotypes drive collective behavior

Chelsea N. Cook, Natalie J. Lemanski, Thiago Mosqueiro, Cahit Ozturk, Jürgen Gadau, Noa Pinter-Wollman, and Brian H. Smith

PNAS July 28, 2020 117 (30) 17949-17956; first published July 15, 2020; https://doi.org/10.1073/pnas.1920554117

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Article Figures & SI Info & Metrics PDF

Significance

Variation in individual cognition affects how animals learn about and communicate information to others. We provide evidence that differences in how individual honey bees learn influences the collective foraging dynamics of a colony. By creating colonies of distinct learning phenotypes, we evaluated how bees make foraging choices in the field. Colonies containing individuals that learn to ignore unimportant information preferred familiar food locations; however, colonies of individuals that are unable to ignore familiar information visit novel and familiar feeders equally. Colonies with a 50/50 mix of these phenotypes prefer familiar food locations because individuals who learn the familiar location recruit nestmates by dancing more intensely. Our results reveal that cognitive variation among individuals nonlinearly shapes collective behavioral outcomes.

Abstract

Individual differences in learning can influence how animals respond to and communicate about their environment, which may nonlinearly shape how a social group accomplishes a collective task. There are few empirical examples of how differences in collective dynamics emerge from

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ARTICLE CLASSIFICATIONS

Scout Variability? (cont.)

- Single-type colonies behaved like member type
- 50/50 Colonies tend towards ‘Focused’ behavior due to ‘enthusiasm gap’
- Is there an effect on nest site selection? Does the swarming portion have a different composition than the larger colony? Do the scouts? (*TBD*)

(Honey Bee) Swarm Decision Making

- Over the course of multiple days…
  - *Search for*
  - *Identify*
  - *Assess*
  - *Select the best*
- …from approximately a dozen candidate sites
- Without central direction
- Or Zillow™

Implications for Human-Designed Systems

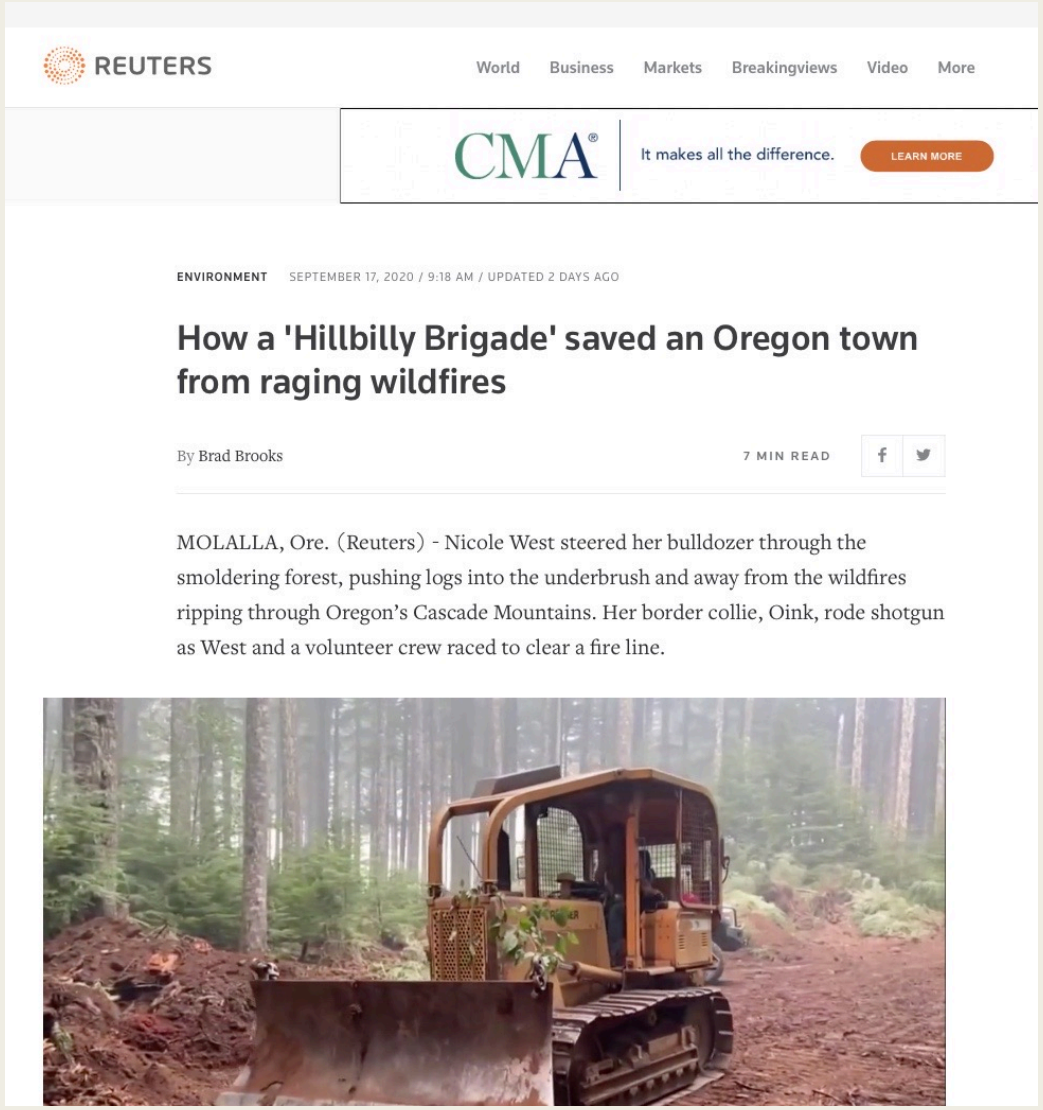
- Internet of Things and other swarm-like systems
- Sensing and decision (‘neuron’) encapsulated in same unit
- Iterative voting for
  - *Resource allocation*
  - *Search allocation (e.g., Search and Rescue)*
- Global References/Local Data
  - *Discriminator between swarm behavior and swarm decision making*
  - *Communication about distant information*
- Alternatives to usual human-designed solutions

Implications for Human-Designed Systems: Challenges

- Literalism
  - *Processing power of nodes?*
- Bees enjoy homogeneity (literally sisters)
- Runaway positive reinforcement (e.g., Tulip Mania)
- Lack of threats/infiltration

Implications for Human Systems: Self-Organization

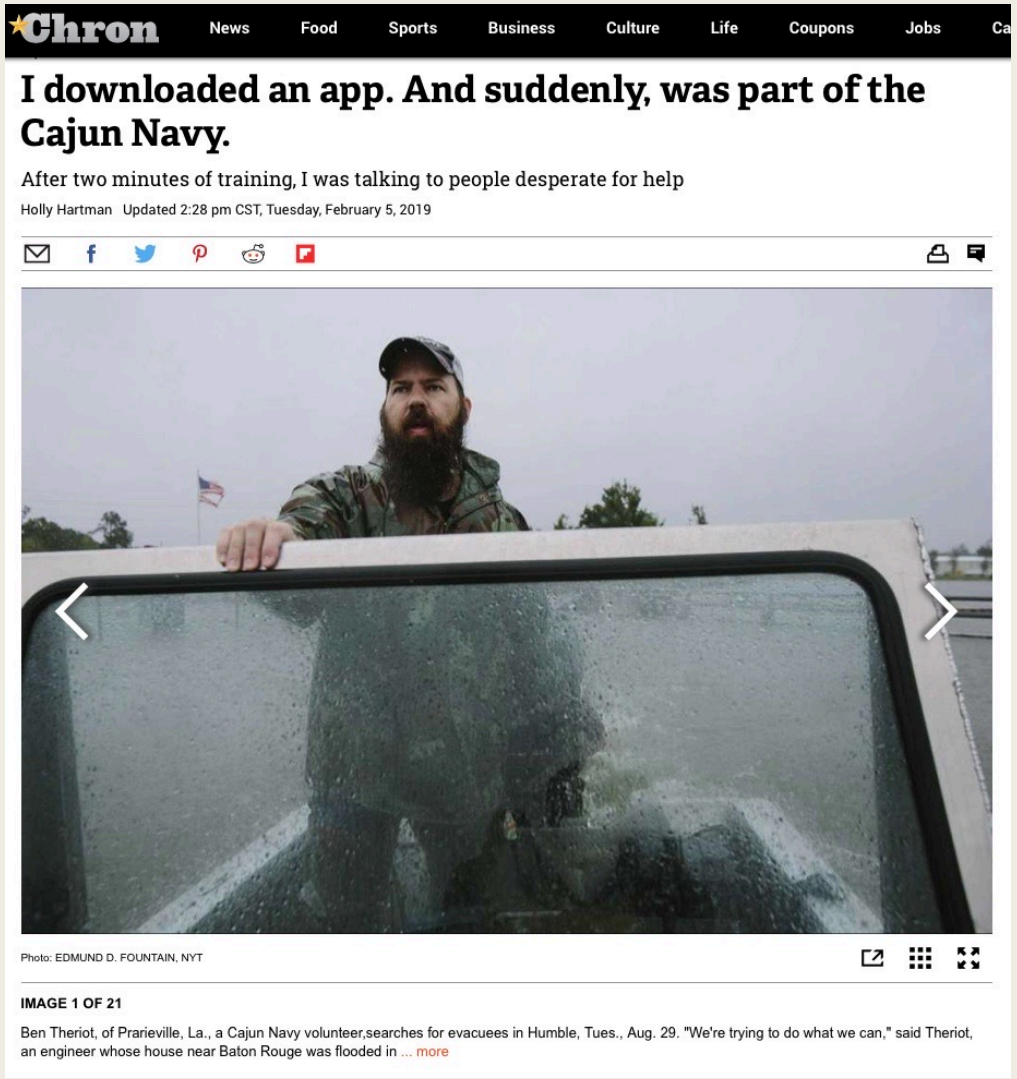
- Communities frequently Self-Organize during natural disasters
  - *'Hillbilly Brigade' during 2020 summer wildfires*
  - *'Cajun Navy' during recent hurricanes*
- Frequently based on existing community social ties
  - *'Self-Organization' has already occurred*



Reuters.com

Implications for Human Systems: Self-Organization

- Leverage existing apps/social media
- What if applications were optimized for these purposes?
  - *Communication*
  - *Allocation of resources*
  - *Status of efforts*
- Self-organized communities of interest could tackle increasingly complex issues
  - *'Next Generation' NGO*



Next Steps/Topics for Further Study

- Characterization (taxonomy) of Self-Organized Systems
  - *Natural*
    - Other species: Ants, termites, etc.
    - Other types: Systems with leaders/social training (wolves, orcas, etc.)
  - *Human and human designed*
    - Hierarchy
    - Permanence
    - Mission
    - Project Complexity (Are tasks partionable/decomposable?)
- Develop catalog of processes/topologies
  - *Suitability for given set of circumstances*

Discussion/Questions

- Gary Vincent
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Resources

- Honeybee Democracy (Amazon): https://a.co/7yoCHit
- https://www.americanscientist.org/article/group-decision-making-in-honey-bee-swarms
- https://www.reuters.com/article/us-usa-wildfires-molalla/how-a-hillbilly-brigade-saved-an-oregon-town-from-raging-wildfires-idUSKBN26820F
- https://www.chron.com/local/gray-matters/article/I-downloaded-an-app-And-suddenly-I-was-talking-12172506.php
- Monarch Migration: https://www.cell.com/cell-reports/pdfExtended/S2211-1247(16)30328-X
- https://theconversation.com/some-bees-are-born-curious-while-others-are-more-single-minded-new-research-hints-at-how-the-hive-picks-which-flowers-to-feast-on-144900
- Individual learning phenotypes drive collective behavior: https://www.pnas.org/content/117/30/17949