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
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](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](https://www.incose.org/incose-member-resources/working-groups)
  - Agile, AI, Healthcare, MBSE, Smart Cities, Space Systems, etc., etc...
Children’s Tales
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 anarchos [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?
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

### July 20

<table>
<thead>
<tr>
<th>Time</th>
<th>Bees</th>
<th>Dances</th>
<th>Waggle Runs</th>
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<tbody>
<tr>
<td>11:00–13:00</td>
<td>18</td>
<td>68</td>
<td>547</td>
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<tr>
<td>13:00–15:00</td>
<td>30</td>
<td>70</td>
<td>2,376</td>
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<td>15:00–17:00</td>
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<td>66</td>
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<td>45</td>
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### July 22

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<tr>
<td>9:00–11:58</td>
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<td>362</td>
<td>3,100</td>
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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
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
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 partitionable/decomposable?)

- Develop catalog of processes/topologies
  - Suitability for given set of circumstances
Discussion/Questions

- Gary Vincent
  - galvin@mac.com
  - https://www.linkedin.com/in/gary-vincent-68286421/
Resources

- Honeybee Democracy (Amazon): https://a.co/7yoCHit
- https://www.americanscientist.org/article/group-decision-making-in-honey-bee-swarms
- 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