How an insect colony works

An introductory tutorial

by

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1st: What are social insects?

- Social insects are often defined by 3 characteristics:
  1. reproductive division of labor (some individuals reproduce while other do not)
  2. cooperative care of the young.
  3. Overlapping generations (the young do not leave the nest when they mature)

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- Ants, wasps, bees, and termites make up the major groups of these animals.

Members of the colony

A social insect colony is made up of several different classes of individuals

1. Queens: they lay the eggs
2. Workers: they do all the work
3. Larva: the immature young
4. Males: they just hangout until mating time

Why are Social Insects so Interesting?

- Ecological dominance
  - Up to 70% of all the animal biomass in some tropical forests like the Amazon are composed of these creatures

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    - Think about it. In you everyday life, the animals you most often see are ants, bees, and wasps. They're everywhere.

Why so Interesting: Part 2

- Although workers are tiny, they can make huge structures like the termite mound above. Some workers, like those of the honey bee, can even talk to each other with their own waggle dance language of buzzes and runs (shown on the right).

How can we understand them?

- A conceptual model illustrates general principles and can serve as a guide for scientific exploration. We will cover two conceptual models that are useful for understanding an insect society.

1. Social insects are superorganisms
2. Social insects collectively solve their problems

Let's explore them one at a time.

Superorganism concept

- The basic idea is that an ant or bee colony is like a single organism.
- Although an organism might appear to be just one animal, it is actually a huge society of cells.
- Although the cells all have the same DNA (instructions), they are specialized for different roles.
- Lets see how a social insect colony is like this.

Reproductive specialization

1. Just like a body has specialized reproductive cells, called gonads, a social insect colony has a specialized reproductive individual called the queen.

2. The rest of the cells, called somatic cells, cannot reproduce and neither can the workers in many groups of social insects.

Honey bee queen surrounded by workers

Somatic / Worker specialization

- In an organism, the somatic cells are specialized
  - Liver cells detoxify toxic compounds, for example, while stomach cells secrete acid
- Social insect workers are also specialized
  - Soldiers for defense
  - Food processors
  - Nurses care for the young

Army ant soldiers guarding a trail of workers

Coordination of action

- A huge problem for an organism or superorganism is making sure everyone is doing what they are supposed to be doing.
  - An individual can only do one thing at a time.
  - A group, however, can do many things at once.
    - This means that the individuals working on different tasks need to keep each other updated about how work is progressing.
    - Otherwise, too much of one type of work might get done and not enough of another.

Let's see how an organism solves this problem first.

Organismal Coordination of Action

- Organisms have two main systems by which the cells communicate with each other.
  1. The Endocrine System
     - Uses chemicals called Hormones
  2. The Nervous System
     - Uses specialized cells called neurons

The Endocrine System

- Hormones are released into the bloodstream for transport throughout the body.
    1. Adrenaline for example, tells all the cells to speed up, more energy is needed.
    2. Insulin, in contrast, tells the cells to take in more sugar from the blood for storage.

- What is conceptually important is that hormones often (not always) mediate whole organism processes

The Nervous System

- Neurons are specialized cells that carry information from one place to another.
  - They are often connected to specialized "sensory cells" that turn environmental patterns, such as sound or light, into biochemical patterns that the nerve cells can read and pass on.
  - Neurons can carry lots of information very quickly

- What is conceptually important is that nerves cells usually facilitate communication between particular cells and transmit a lot of information fast.

Do social insects have something like an endocrine system?

- Organisms have hormones to organize whole body processes, but what about social insects?
  - Do they have colony wide coordinating mechanisms?

- Yes, they have pheromones that can serve the same role as hormones.
  - A pheromone is a chemical that transmits information from one whole organism to another

Pheromones or Social Hormones

In solitary animals, pheromones often transmit mating or territorial information, which can be non-cooperative, but in social insect these chemicals often serve purely cooperative coordination purposes.

1. A queen releases pheromones to let the colony know she is healthy.
2. Workers release pheromones to let other workers know what to do

Social insect pheromones therefore serve the same role as hormones in organisms and could accurately be called social hormones

Do social insects have something like a Social Nervous System?

- Can workers send lots of information fast to other members of the colony?
  - Yes, but they don't use specialized individuals. Instead they use complex signals. These signals are usually based on shaking movements and buzzing sounds. Sometimes special pheromones can transit information fast.

1. Honeybees use the waggle dance to tell each other where to find food.
2. All types of social insect use alarm pheromones to quickly call for help
3. In leaf cutting ants, vibrations sent through the leaves call for help with cutting

Social Anatomy and Physiology

In summary

- The cells in organisms show specializations, which results in anatomy.
  - Likewise social insect workers are specialized for particular tasks in a comparable social anatomy system.

- The cells in an organism communicate with one another through two systems of physiology.
  - Likewise, social insect workers also communicate with each other for the same purposes using communication systems that we can call Social Physiology.

Summary of Superorganism Concept

- As we've seen, a social insect colony is basically a diffuse body. The individual insects are like cells.

- The main difference is that in a body the cells are physically connected, while in a social insect colony the workers are separate whole organisms.

Collective Decision Making

- We have seen how a colony is like a body with individual specialized individuals for different tasks.
- Now we will look at an example of how all these parts work together to solve the problems that societies face.
- Collective decision making is the name for the process whereby a society make one decision that is the result of many simple partial individual decisions.
- Lets explain with an example.

Apis mellifera: the common honey bee

- We'll explore how the honey bee organizes itself for honey collection for our example of collective decision making. Its perfect for two reasons:
  1. We know more about honey bees than any other species of social insect.
  2. They are highly complex and use lots of communication signals, which are often the basis of collective decision making

Coordination of Nectar Collection and Processing?

- As we saw earlier, colonies divide labor between specialized individuals (social anatomy)

- The specialized groups then coordinate their activities with each other via signaling and information collection (social physiology).

The Social Anatomy of Nectar Collection

- For nectar production, we have two specialized groups:
  - Foragers: they collect the nectar, but do not store it. Instead they transfer it at the entrance to the other group.
    - Foragers bodies are specialized for flying and being outside the nest. They never work in the nest.
  - Middle age bees (MAB): they process the nectar into honey and build comb so the honey has some place to go
    - Their bodies are specialized for turning nectar into honey and making wax. They only leave the nest after they quit being a middle age bee.

The Coordination Problem

- For honey production to be maximized, the number of foragers and MAB must be optimal because:
  - If there are too few MAB acting as receivers, for example, then the foragers will have to wait a long time to unload their nectar.
  - If there are too many receivers, in contrast, then the colony should recruit more foragers (as long is food is available in the field).
  - If the colony runs out of comb space, then foraging must stop until more comb is produced.

The Social Physiology

- Foragers use two signals to change the behavior of middle age bees
  - Tremble dance
    - Recruits more nectar receivers
  - Shaking signal
    - Increases the work rate of MAB

- The question is how do they know when to produce each?

Shaking Signal

- The shaking signal is performed by foragers each morning.
  - Each of many foragers perform hundreds of the signals all throughout the nest.
- Current research supports the view that the signal tells the bees to increase their work effort.
  - Hence, the signal ensures that the work rates of foragers and receivers is balanced.

Tremble Dance

- But what if the balance of work between foragers and MAB is disrupted?
- Studies show that when the number of receivers is suddenly decreased, the number of foragers doing tremble dances shoots up.
  - This supports the view that the tremble dance increases the number of receivers.

- But how can a forager know when there are too few receivers? It can't go around and count them all—there are thousands.

Information collection

- Foragers use the time it takes them to find a receiver to unload their nectar to measure the ratio of foragers to receivers.
  - When the time is long, there are too many foragers and not enough receivers
  - When the time is short, there is either a good balance or too few foragers. The foragers will then recruit more foragers if there is nectar available in the field.

- Thus, the information that is collected is an indirect measure of the number of receivers. We call such indirect measures, cues.
  - Cues are used in most situations to collect information.

Collective Decision Making Summary

- In order to ensure coordination between the different specialized groups that make up a colony, each group collects information via cues and then determines if they need to either change their own behavior or send a signal to individuals in another group to let them know to change their behavior.

- In this way, the whole colony is able to function as one cohesive unit.

Suggestions for future reading

- Seeley (1995) The Wisdom of the Hive. Cambridge, Harvard University Press.
- Hölldobler and Wilson (1990) Journey to the Ants. Cambridge, Harvard University Press.
- Hölldobler and Wilson (2009) The Superorganism