Summary: Self-organized defensive behavior in honeybees.

Overview:

- The paper discusses the defensive behavior in honey bees observed under controlled experimental conditions. Positive and negative feedbacks are associated with the self organization observed in each honey bee leading to an emergent collective response.
- Experimental results and a model to describe the results are given in the paper.
- Explanation for characteristic features of the honey bee defensive response (viz. ability of colony to localize and focus its attack, inter- and intra-hive variability and ability of colony to amplify small differences between targets).

Experimental setup:

- 45 experiments on 5 hives with population between 20,000 and 40,000 worker bees (European honeybees: *Apis mellifera mellifera*)
- 3 sets of experiments were done. Targets were black leather patches. In first set, two identical targets were used. In second set, one of the targets had received 3 stings before the experiment began. And in the third set, a single larger target was used to observe the spatial distribution of the stings. Targets were connected to a pendulum system for motion.
- To get the hive responsive attack, the hive was struck in a uniform manner 3 times at intervals of 40 seconds and the targets were removed after 2 minutes.
- Intervals of 2 days were kept for each colony between each experiment.

Results:

- In first experiment, a relationship between the mean fraction of stings on the winning lure (L_{max}/N) and the total number of stings is given in fig. 1. N is the total number on stings on both the lures.
- A pitchfork bifurcation as a function of control parameter N is seen indicating a competitive positive feedback, which amplifies an initial fluctuation.
- The relation ship has 3 regions (a, b & c). Region a ($N<16$) represents the initial random, equal probability behavior of the bees. As N increases, due to an initial random fluctuation and the pheromone on the sting acting as an attractor for other

remaining bees, a preference towards a target is observed making it the winning target (region b: 15<N<200). The final region c (N>200), represents a distribution similar to binomial distribution representing a negative feedback.

- Experiment two shows that the target which had received 3 stings initially, turned out to be the winning target always.
- The third experiment, gives the spatial distribution of the stings, which is random and homogenous for small N, but a heterogeneous pattern develops when N is large. The bees tend to sting the edges and corners of the target, maybe due to any one or all of the following reasons: color contrast (black and white), due to random probability or due to motion of the targets.

Model:

- The model uses a basic positive feedback equation from chemical recruitment occurring in ants (It is a kind of sigmoid function).
- A new variable F_i is introduced in place of N, incorporating a parameter δ which represents the crowding at the target. Thus the observed negative feedback is modeled. F represents a perspective N and not the real N, to model the observed experimental relationship.
- The results of the model were similar to the actual experimental results.

Conclusion:

- Provides an understanding of the link between individual behaviors and the collective response of the hive.
- Defensive mechanisms of the colony are under genetic determinants that affect an individual's response threshold.
- Properties of the response arise on a collective level that cannot be gleaned by a study of the individual characteristics alone. These properties may be derived in an economical manner without the need for explicit genetic coding.
- Some of the collective responses maybe may be strongly related.
- The colony's collective response is an emergent property of the dynamics and nonlinear interactions at the individual level.