Simulating Swarm Intelligence in Honey Bees: Foraging in Differently Fluctuating Environments

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ABSTRACT

Honeybees forage for nectar in a fluctuating environment. Scouts search for new nectar sources and provide information about source location and food quality to the colony. Via a decentralized system, foragers are recruited to nectar sources in appropriate numbers. Without any global decision making, the bees are able to select from multiple available nectar sources the optimal one, the one offering the best ratio of gain to cost. Using our multi-agent simulation of this foraging system that includes nectar sources fluctuating in quality over time in a virtual environment, we found that the honeybee foraging system is robust over a wide variety of fluctuation patterns. We believe that this robustness of a purely decentralized system of decision-making can provide inspiration for technical applications.

Category & Subject Descriptors

Multiagent Systems, Biology and Genetics.

General Terms

Algorithms, Economics, Experimentation

Keywords

swarm intelligence, honeybees, foraging, algorithm, bionic

1. INTRODUCTION

1.1 Biological Background

Honeybees have evolved a decentralized system to collect nectar efficiently in fluctuating environments. This system is unique in the animal kingdom, as it is based on (waggle) dance recruitment performed by individual forager bees. The duration of the performed dances, and thus the strength of recruitment to the food source, is based on individual assessment of the source's quality. This assessment accounts for the energetic gain of a foraging trip and for the energetic costs associated to it. The cohort of foragers converges to the nectar source offering the optimal ratio of gain to cost.The goal of the study presented in this article was to evaluate the robustness of this foraging system by using our multi-agent simulation platform. We confronted a simulated colony with different patterns of environmental fluctuations. We investigated how the time-pattern of environmental fluctuations affects the foraging strategy and the efficiency of the foraging.

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2. MATERIAL AND METHODS

We used a multi-agent simulation platform that allows us to investigate a variety of honeybee foraging decisions. The internals of this simulation platform are described in [1], so we give here only a short description and mention only those parameters that deviate from the values given in [1]. The simulation is based on a multi-agent model of a foraging honeybee colony, in which the agents represent foraging bees. The simulation uses discrete time steps of 0.5sec. The simulation treats each forager bee (agent) as an independent finite state automaton. Each of its states is associated with a certain behavior and with a certain metabolic rate. The inclusion of metabolic expenditures (costs) enables us to measure the foraging decision of the simulated colony from an economic point of view.

2.1 The Experimental Setup

To investigate the robustness of the collective decisions, we confronted our simulated colony with several kinds of fluctuating environments. In all cases, we used two equidistant nectar sources (400m). We used 500 receiver bees and 400 foraging bees. We kept the amplitude of environmental fluctuations constant: In all runs, we turned one source from being "good" (2.5 Mol/L sucrose solution) to being "poor" (1.0 Mol/L), while we simultaneously turned the other source from being "poor" to being "good". In our simulation runs we varied the speed of changes in the environment: The parameter h represents the (time) length of this transitional period. The moments indicated as h^* (at t=4hours) are those points in time when both sources show equal qualities. A value of $h=0.01$ corresponds to a sudden change of quality, as described in [3]. A value of $h=8.0$ corresponds to a smoothly graduated change of the qualities of the two sources, so that the transition takes the whole simulation period.

3. RESULTS

In all simulations, the forager distribution on the nectar sources predicted by the simulation was comparable to the empiric data shown by Seeley et al. [3]: The number of simultaneously foraging bees within a 30 minute interval was approximately 125.

Regardless of the time pattern of the fluctuation ($0.01 \le h \le 8.0$), the colony first favored the better nectar source, which was source B, and then changed its decision (after $t = 4h$) by massively recruiting for the other nectar source, source A (see figure 1 for details). At the end of the simulation runs, 94.9 ± 11.2 foragers were visiting source A. The maximum standard deviation within all fluctuation scenarios ($0.01 \le h \le 8.0$) was 13.7 foragers (=14.4% of max.). On nectar source B, we found 32.8 ± 10.4 foragers at time t=8h. The highest mean forager peak was 83.7. The maximum standard deviation among the fluctuation scenarios was 13.2 foragers (= 15.8% of max.). Finally, the colony

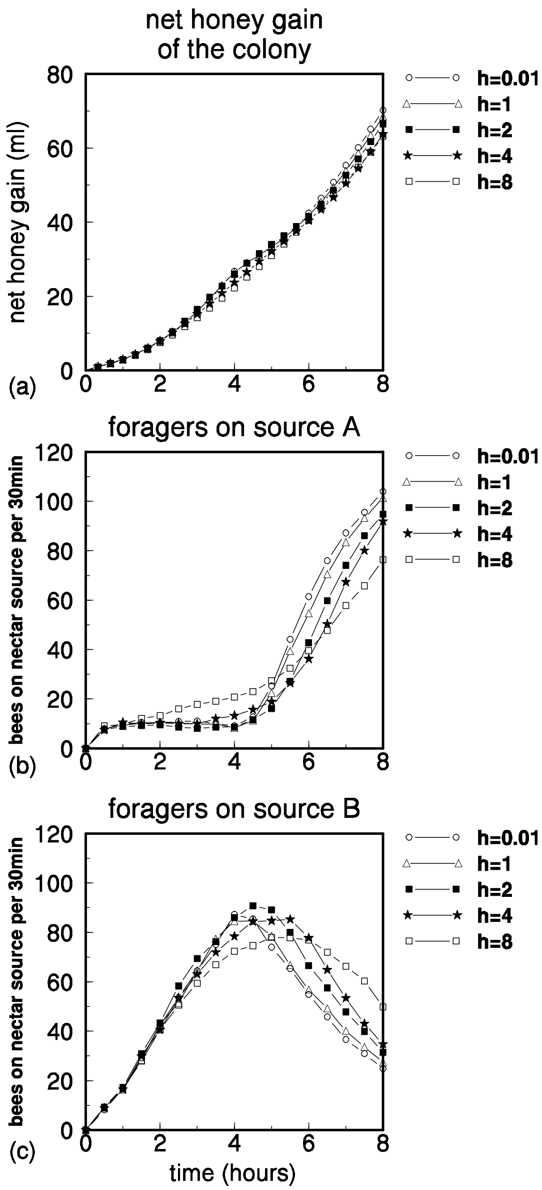

Figure 1: Results of the single fluctuation scenario (mean values are displayed). (A) The net honey gain of the colony during the simulation runs. (B) Foragers on nectar source A and (C) foragers on nectar source B. N=20 per setting.

accumulated 66.7ml ± 3.1ml of honey. The highest gain was found with h=0.01, and the lowest gain was found with h=6.0 (see figure 2 for details).

4. DISCUSSION

Using our multi-agent simulation, we were able to find interesting features of honeybee foraging. The emerging foraging patterns (figure 1b,c) varied to a much higher extent than the net honey gain (figure 1a). We conclude that the simulated bees (following the implemented proximate rules) adapted automatically their collective foraging strategy to maximize the colony efficiency. We did find a significantly higher net honey gain in those simulation runs where fluctuations happened more suddenly (figure 2, $h \leq 1$). This can be explained by the foraging patterns depicted in figure 1b,c. The steeper the environmental fluctuation (that is, the smaller *h)*, the quicker the bees switched from source B to source A. The quicker the switching decision, the smaller the collective energetic costs during the decision-making period. In all tested situations, the simulated honeybee colony was able to reach a foraging decision, that is, to massively recruit to the better one of the two sources. In the study presented here, we have shown that the collective foraging strategy of a honeybee colony is robust and adaptive, and that its emergent features allow the colony to find optimal (previously unknown to them) solutions. These characteristics can be summarized as "swarm intelligence".

5. ACKNOWLEDGEMENTS

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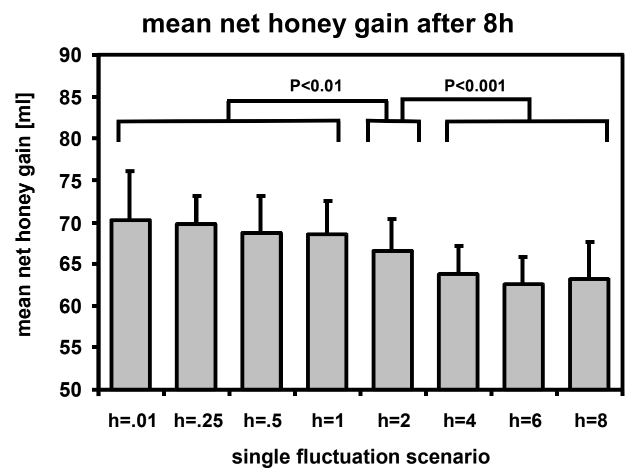

Figure 2: Mean net honey gain (and standard deviation) after 8 hours in all simulated single fluctuation scenarios. N=20 per setting. Statistics: Two-tailed Mann-Whitney U-test.