論文の内容の要旨

論文題目: Experimental and Theoretical Analysis of Exogenous and Endogenous Bursts in Honeybee Hives

(セイヨウミツバチの外因性および内因性バーストの実験的/理論的解析)

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Social entrainment of the animal grouping is important for the group survival. The synchronization of circadian rhythms in groups has attracted attention and studied for a long time. However, there are few reports on social en- trainment on a smaller time scale than the circadian rhythm. Our collaborator Gernat *et al.* developed a high-throughput automatic monitoring system of honeybee hives. By attaching a "bCode" device (a custom matrix barcode) to the thorax of every individual bee in the hive, they succeeded in tracking each individual bee's positions, speeds and orientations using the recorded digital images. By analyzing their massive data set of the approximately 5,000 individuals tracking data of honeybees (*Apis mellifera*), we revealed that honeybees showed bursting behavior which is one of the social entrainment and the time-scale is smaller than the circadian rhythm regarding their locomotion activities (hereinafter, this is called "Burst").

In this thesis we analyzed and discussed the following questions:

1). How do the bursting behaviors of honeybees develop? (Chapter 2)

2). What is the cause of the individual-level activity that is transmitted through the hive? (Chapter 3)

3). What is the personality/characteristics of the individuals that trigger a global bursting pattern? (Chapter 4)

To visualize and analyze the activities of the individual bee's and the entire hive, we defined the individual bees ' kinetic energy K as follow:

$$K_i(t) = \Delta x^2 + \Delta y^2 , \quad (1)$$

where Δx, and Δy denote the respective displacement of x and y coordinates of each bee per second (i). The hive activity level $K_G(t)$ was defined as the mean kinetic energy:

$$K_G(t) = \frac{1}{n}\sum_{i=1}^{n} K_i(t), \quad (2)$$

We used $K_G(t)$ as the indicator of beehive activity (Fig. 1).

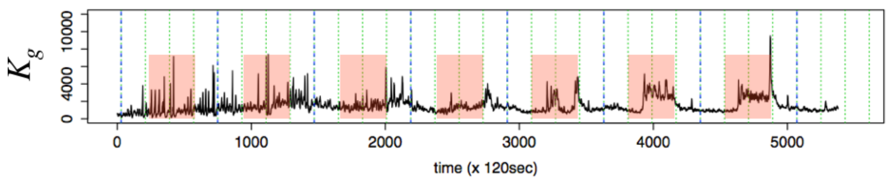

Figure 1: The example of the time series of the global kinetic energy $K_G(t)$. The part shaded in grey represents the daytime.

We found that the beehive occasionally showed bursting behavior. Since the bursting behavior was observed in all trials, it is suggested that the bursting is not a peculiar behavior.

These bursts are quantitatively classified as endogenous or exogenous based on their time evolutions $K_G(t)$. The features of exogenous bursts are sudden increases in $K_G(t)$, which happens because of external stimuli. On the other hand, the characteristics of endogenous bursts are gradual increases in $K_G(t)$, which happens spontaneously, potentially resulting from intrinsic bee interactions. Also, we demonstrate that the physical contact/close distance interaction is one of the cause for the endogenous bursts by both the experimental analysis and the agent-based model simulation inspired by the SIR model.

These results suggest that the bees which become active before the endogenous burst will become maximized trigger the endogenous burst. We named these bees "pioneer bee," and we used the non-negative factorization to identify pioneer bees.

Our interest is whether these pioneer bees are determined randomly or based on a kind of rules. We demonstrated the pioneer bees are not identified randomly but categorized into two types. One is the bees related to the so-called foraging behavior that brings some information from the outside into the hive, and the other one is a non-forager bee which is enhanced by returned forager and spreads the information to inside the hive.

To summarize our findings, we suggest that, at least about the social entrainment of the bursting behavior, the foragers (FP bee) carry a kind of information to their hive, and the foragers entrain the hive bees(trigger the burst) through physical or close distance interactions. Then the entrained hive bees (NFP bee) synchronize with other hive bees that have not encountered foragers.