A Study on Neural Circuit Model of Insects for Adaptive Behavior Selection
- Verification of Action Selection Model in Multi-individual Environments -

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Abstract: This research aims to model adaptive behavior selection in crickets fighting behavior from physiological knowledge. We have already proposed an action selection model by NO/cGMP cascade which can explain the relationship between the Octopamine level in cricket's brain and its behavior. In this paper, we run some computer simulations in multi-individual environments to evaluate the model and the emerging behaviors.
Key Words:cricket, NO/cGMP cascade model, multi-individual environment, behavior selection

1. Introduction

Organisms select behaviors adaptively according to their external environment and realize such processing in real time. This is attributable to the plasticity of neural circuit networks. Concerning adaptative behavior selection among individuals, an example is the fighting behavior of crickets (Fig.1), which is a representative pheromone behavior in insects. Pheromone behavior emerges when pheromones are detected. The purpose of this study is to clarify the mechanisms of adaptive behavior selection by modeling neuromodulator function in the fighting behavior of crickets.

In this kind of behavior selection, nitric oxide (NO) is thought to function as a neuromodulator for extracting a specific behavior program from polymorphic circuits in the brain and that the NO(nitric oxide) /cGMP(cyclic guanosine monophosphate) cascade plays an important role [1]. It is also considered that octopamine (OA) is important for behavior selection. Therefore, in previous work, we proposed an adaptive behavior selection model which is inspired by the NO/cGMP cascade and OA [10].

Fig.1 Fighting behavior in male cricket

In this paper, we attempt to run some computer simulations in multi-individual environments to evaluate our proposed neuromodulation model. Emerged swarm behavior from the interaction among the individuals is observed and discussed.

2. Cricket Fighting Behavior

In recent years, it is becoming clear that the insect pheromone behaviors indicate plasticity by modification, and cricket fighting behavior is a typical example of this. A body surface of cricket is covered with cuticular substances(pheromone), probably for individual identification [2]. When a male cricket comes across another cricket, it first touches the body surface of the other cricket using antennae and discriminate whether the cricket is male or female. The cricket then shows fighting behavior if it is male. The ranking of two crickets, determined by fighting, is known to persist for about 15 to 30 minutes [3]; if the defeated cricket senses the same pheromone within this period, it shows avoidance behavior. The experience of defeat thus made the cricket select different behavior for the same stimulus.

In the neural systems of organisms, various neurotransmitters and neuromodulators are used. NO is thought to play an important role in selecting program behavior from polymorphic circuits. In the brain, NO diffuses in three dimensions to control the emission of neurotransmitters [4]. NO is generally considered to be involved in neural plasticity [5].

The NO/cGMP cascade is particularly considered to be closely related to fighting behavior selection by crickets. To demonstrate this, fighting behavior is observed when an NO synthesis inhibitor is injected into the heads of the crickets. When two male crickets encounter one another, fighting starts as usual and soon ends. If the crickets again encounter one another after a 15-minute interval, even the defeated cricket may exhibit fighting behavior. Because the defeated cricket should show avoidance behavior, however, this indicates that the appropriate behavior is not selected if the NO/cGMP cascade does not function normally. Even under these circumstances, the pheromone is identified and NO is closely related to the pheromone behavior modified by past experience [6].

The NO/cGMP cascade is considered to mediate efficacy of neural pathways and one of these is to affect OA concentration in the brain[7],[8]. As recent research result(*Aonuma's data, not published*), in cricket fighting behavior, the amount of OA significantly differs before and after fighting. There is also different between winner's OA level and loser's one. Therefore, the NO/cGMP cascade-OA system is considered to be deeply related to behavior selection through OA.

3. A Neuromodulation Model of Cricket Fighting Behavior

3·1 NO/cGMP cascade-OA system

Based on the above observations, we modeled NO/cGMP cascade function in cricket fighting behavior with regard to the relationship between OA concentration and behavior selection [10](Fig. 2). According to sensory information from antennae, a cricket first generates NO, and pheromones from another individual increase NO concentration in the antennal lobe (AL). NO is a radical that reacts with metal ions immediately after diffusion throughout the brain, after which it disappears. To express this effect, diffusion equation is utilized.

$$\frac{\partial \mathcal{N}}{\partial t} = D\frac{\partial^2 \mathcal{N}}{\partial x^2} - \ {}_{N}\mathcal{N} + \mathcal{N}_{in} - \mathcal{N}_{out} \qquad (1)$$

where, $\mathcal{N}_{in}$ and $\mathcal{N}_{out}$ represent the amounts of NO generation and consumption. Because NO mainly remains inside the membrane enveloping AL, the following reflecting boundary is given:

$$\mathcal{N}^0 = \mathcal{N}^1, \quad \mathcal{N}^n = \mathcal{N}^{n-1} \qquad (2)$$

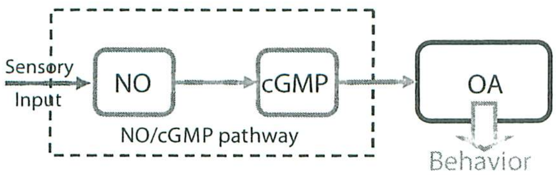


Fig.2 Model of action selection from NO/cGMP cascade

As a scalar, the amount of cGMP, C, is expressed by using the constant $\ _C$ based on the idea that an excess amount of cGMP is decomposed in the body:

$$\frac{\partial C}{\partial t} = - \ {}_{C}C + C_{in} - C_{out} \qquad (3)$$

where, C_{in} and C_{out} represent the amounts of cGMP generation and consumption. Likewise, the amount of OA is expressed by using constant the $\ _A$:

$$\frac{\partial A}{\partial t} = - \ {}_{A}A + A_{in} - A_{out} \qquad (4)$$

The relationship between input and output amounts is obtained. We assume that the amount of NO generation $\mathcal{N}_{in}^x$ at position x is determined for position set $\mathbb{I}$ at the source:

$$\mathcal{N}_{in}^x = \begin{cases} 0.0 & \text{if } x \notin \mathbb{I}, \\ 1.5 & \text{if } (x \in \mathbb{I} \wedge fighting), \\ 1.0 & \text{otherwise.} \end{cases} \qquad (5)$$

Considering that NO is completely consumed in cGMP production, NO consumption depends only on NO concentration. Therefore, the amount of NO consumption $\mathcal{N}_{out}^x$ at position x is determined for position set $\mathbb{O}$ at the source:

$$\mathcal{N}_{out}^x = \begin{cases} a \times (1 + \tanh(50 \times (\mathcal{N}^x - 0.4)))/2 & \text{if } x \in \mathbb{O}, \\ 0 & \text{otherwise.} \end{cases} \qquad (6)$$

where, a is a constant. As cGMP is a scalar, C_{in} is expressed by the total amount of NO consumption.

$$C_{in} = \sum_x \mathcal{N}_{out}^x \qquad (7)$$

Based on physiological experiments, OA can be divided into 2 types; one that is not dependent on NO and one this is dependent on NO. Especially, in case of cricket, if A is normalized to [0:1], the amount of the NO-dependent type is about 0.4(*Aonuma's data, not published*). As cGMP suppresses OA production, cGMP consumption is:

$$C_{out} = b \times (1 + \tanh(10 \times (C - 0.64))/2) \qquad (8)$$

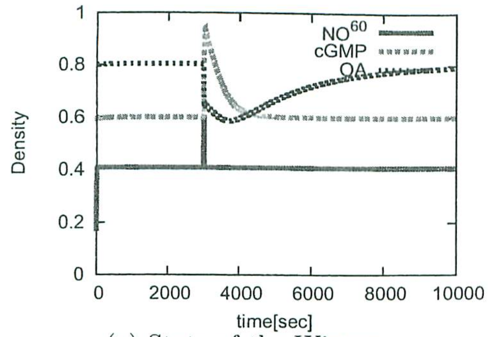
$$A_{in} = b - 0.6 \times C_{out} \qquad (9)$$

where, b is a constant. In the cricket body, OA is used to obtain energy from fat. By using the constant c, A_{out} is:

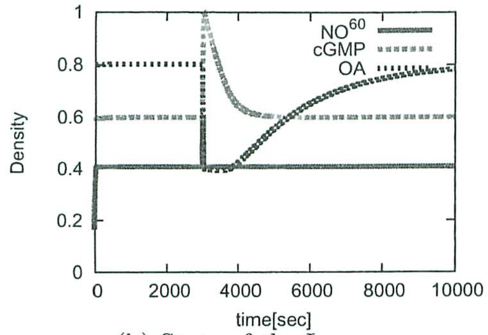
$$A_{out} = \begin{cases} c & \text{if } fighting, \\ 0 & \text{otherwise.} \end{cases} \qquad (10)$$

This indicates that fighting behavior consumes large amounts of energy.

The simplest model also assumed behavior selection based only on the amount of OA. Based on the assumption that a cricket selects behavior at every



(a) State of the Winner



(b) State of the Loser

Fig.3 Example of the internal state after fight

step during fighting, the probability P of fighting behavior at the next step is:

$$P = \mathrm{sgn}(A - 0.5) \quad (11)$$

In addition, we introduce assumptions that a penalty of $-\epsilon_{lose} \times T$ is given to the amount of OA of the defeated cricket and ϵ_{win} is given to the amount of OA of the winner as a reward. Here, T[sec] indicates fighting period.

3·2 Simulation Result

The internal state of the crickets was compared between victory and defeat in fighting behavior for changes. Figure 3 shows the results of the simulation. Fighting behavior starts at $time = 3000$ in each figure. The loser cricket exhibits avoidance behavior after a loss and fighting behavior after sufficient time has passed. The time effect is a little over 30 minutes, similar to actual observations, which is necessary for a defeated cricket to again exhibit fighting behavior or for recovery of $A = 0.5$. If NO synthesis is inhibited, this model behaves that recovery time of OA become short. It means that a sort of the memory based on the experience is weakened by blocking NO/cGMP cascade.

4. Simulation in Multi-individual Environment

In previous section, we explained an action selection model by NO/cGMP cascade-OA system according to the physiological knowledge, and examined an association between cricket's behavior and its OA level in the brain. It can be considered that the present model appears sufficient to explain adaptive behavior selection in crickets [10].

Ashikaga *et. al.*[9] reported that the behavior of each individual appears difference acoording to population density of the crickets. Therefore, in this section, we run multi-agent simulations where the agent with our proposed model interacts with the other ones, and discuss the emerging swarm behaviors by comparing with real cricket's behavior.

4·1 Settings

There are four artificial cricket agents with our proposed internal model in a square simulation field (Figure 4), on a side. An agent's movement is selected randomly from 3 behaviors (go straight, turn around, and stop)(Figure 5,[9]). If any other agent is found within one's sensing area, antennal sensory input is brought to the agent and changes its state to fighting behavior or avoidance behavior according to its internal state. This fighting behavior continues until one agent selects avoidance behavior. The escaped agent is the loser, and the other agent recognizes its victory. The detailed description of this simulator is in the bibliography [9].

Agents' density is changed by moving X in the range of $2^7 \le X \le 2^{13}$. A trial is terminated after 1000[sec], and the simulation is run for 50 times in each conditions.

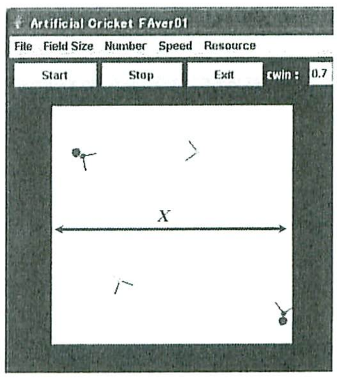


Fig.4 A Snapshot of the Simulatior

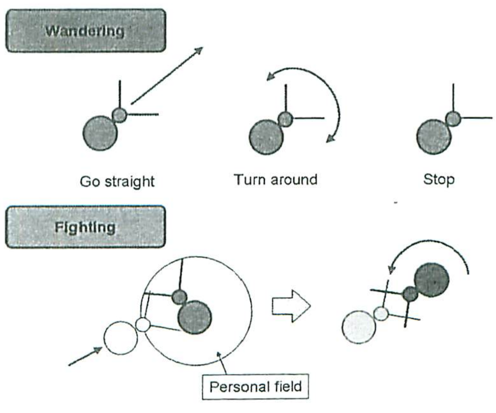


Fig.5 Cricket Actions

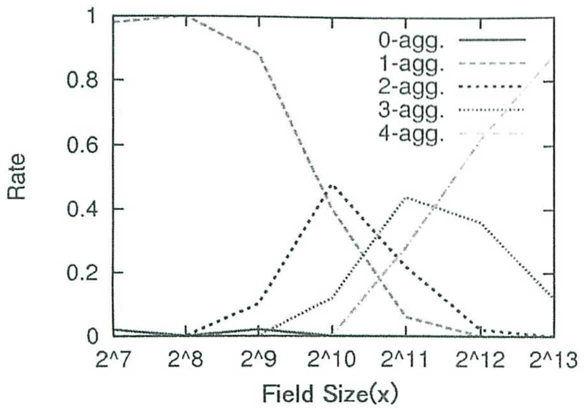


Fig.6 A Simulation Result of Swarm Behavior: Rate of Aggressive Agents

4·2 Simulation Result and Discussion

We utilized the number of aggressive agents when a simulation ended as an index of the characteristics of the population. Here, an aggressive agent means the agent which shows aggressive behavior against another agent, in other word, the agent whose OA level is over 0.5. Thus, this index is an integer between 0 and 4. Figure 6 shows the rate in 50 simulations in each X. For example, 2-agg. means that there were two aggressive agents when a simulation ended.

There is a tendency to increase the number of aggressive agents as the agents' density decline. This tendency can be found in real crickets with exception of next two points. Firstly, result doesn't change dramatically in $2^7 \leq X \leq 2^{10}$. Especially, almost all the real cricket show aggressive behavior in low-density environment like $X = 2^9, 2^{10}$, so that the rate of 4-agg. should be dominant in those areas. Secondly, the rate of 0-agg. is always low in every conditions, contrary to the real crickets don't show aggressive behaviors in high-density environment like $X = 2^7$.

The simulation shows only the influence of the encountering frequency and doesn't take agents' perception in to account, which seems to be the cause of this difference. In real crickets, they percept another cricket's pheromone and determines whether to fight or not according to one's state and the other's state. Our result shows the importance of perception of other agents' state to form the global order of the crickets.

5. Conclusion

This current research is attempting to model the cricket's neural system for accelarating psyological reseach and understanding the principle of adaptive behavior selection mechanism. Therefore, we examined and proposed a model of adaptive behavior selection by NO/cGMP cascade and OA system in cricket fighting behavior. In this paper, we also evaluate the model by computer simulations in a multi-individual environment. As the result, there is difference between simulated behavior and observed behavior of real cricket. The internal model can be considered as an appropriate one. Thus, it is important to introduce a sort of perception process based on individual interactions.

In future works, we must be attempting to establish more accurate model of the neural system for sustaining the consistency between the behavior of developed model and psyological experimental result of the cricket.

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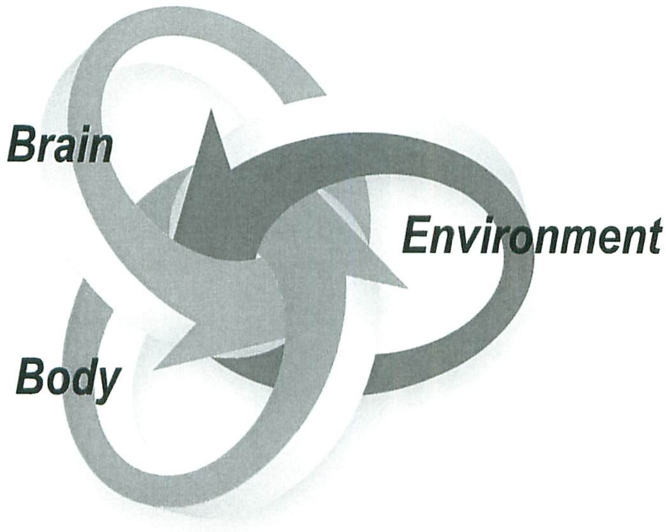

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