Emergence of Multi-generational Migration Behavior by Adaptiogenesis to Environmental Changes

(Extended Abstract)

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ABSTRACT

The target of our study is the Monarch Butterfly, which is known for its multi-generational migration behavior: it migrates between southern Canada and Mexico over the course of one year within three to four generations. In spite of many reported studies, little is known about what influences their migration. We approach this subject by using an ecosystem model consisting of artificial agents and five areas. We simulate under the environmental condition that the average annual temperature rises every year, which is modeled on the current global temperature rise. Our agents emerge the migration behavior similar to the multi-generational migration of the actual Monarch. The migration process of the agents is discussed.

Categories and Subject Descriptors

I.2.11 [**Artificial Intelligence**]: Distributed Artificial Intelligence—*Multiagent systems*

General Terms

Agent design

Keywords

Artificial Life, Adaptive Behavior, Multi-agent Simulation

1. INTRODUCTION

The subject in our study is the Monarch Butterfly (*Danaus plexippus L., Nymphalidae, Lepidoptera*), which is known for its multi-generational migration behavior: it migrates between southern Canada and Mexico over the course of one year within three to four generations. In spite of many reported studies, little is known about what influences their migration. Our purpose of study is to reveal the reason why Monarchs migrate. It is believed that the gradual rise in air temperature is the triggers for the Monarch to migrate. In this study, we model an ecosystem consisting of artificial agents and five areas, and simulate Monarch behaviors over long periods of time.

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Table 1: Sensory information.

Variable	Variable is True if
X_0	Is it diapausing? ($state_j = \text{Dp}$)
X_1	Is it hungry?
X_2	Does a plant exist around there?
X_3	Does other agents exist around there?
X_4	Is daylight more than 12 hours?
X_5	Does it feel cold? ($s_j - ea_j < tmpr_i$)
X_6	Does it feel hot? $s_j + ea_j > tmpr_i$

Table 2: Actions.

	Behavior
W	Do not move
E	Move toward a plant and eat food.
R	Reproduce a new agent
D	Go into diapause / Stop diapausing
Mn	Migrate toward northern area ($area_i$ to $area_{i+1}$)
Ms	Migrate toward southern area ($area_i$ to $area_{i-1}$)

2. ECOSYSTEM MODEL

2.1 Agent

An agent can sense seven types of information in Table 1. By using sensory information, an agent decide its behavior only once in a day. In this paper, the action strategy is expressed by n-output binary decision diagram (n-BDD) [3], which is an extension of BDD. An agent $agent_j$ (j is identifier) has three genetic component and characterized as

$$agant_j(ea_j, cs_j, st_j), \tag{1}$$

where ea_j is a thermal sensitivity, cs_j is a cold resistance of the diapause agent, st_j is the action strategy. These genetic components are unique to each agent. An agent can reproduce a new agent by crossing, and genetic components of a child are generated from that of both parents by crossover and mutation. An agent is removed if it reaches its maximum life-span (200 days) or run out its energy.

An agent decides the action act_j by

$$act_j(t) \quad = \quad st_j(X_0(t), X_1(t), \cdots, X_6(t)), \tag{2}$$

where t is the number of steps. The variable X_m is true if the condition in Table 1 is met.

Six actions of an agent are shown in Table 2. After the action, the energy in_j is updated by

$$in_j(t) = in_j(t-1) + f(act_j(t), td), td = |s_j - tmpr_i|, \tag{3}$$

where function f is the update function of the energy level and is proportional to the difference in temperature between s_j and $tmpr_i$. E is an only action which increases its energy, and other actions decrease.

An agent has the state $state_j$ as its internal parameter. We defined three states — Cp, Dp, and Rp — which an agent can enter. The Cp state is the larval stage and is an initial state when it is first born. In the Cp state, only W and E are selectable actions and the agent can change its state to Rp after 30 days. The Rp state is an adult stage. In the Rp state, an agent can select all five actions. The Dp state is the reproductive diapause stage. Reproductive diapause is a period of rest or quiescence between phases of growth or reproduction. Diapausing Monarch halts reproductive development and is resistant to cold by reducing body temperature. In the Dp state, agent can select any action except R. By the D action, an agent changes its state from Rp to Dp or from Dp to Rp.

Diapausing agent has cold resistant and other states does not. The suitable temperature s_j is given by

$$s_j \;=\; \begin{cases} \mathrm{S_A} - cs_j, & \text{if } state_j = \mathrm{Dp} \\ \mathrm{S_A}, & \text{otherwise} \end{cases} \qquad (4)$$

where S_A is the temperature suitable for nondiapausing agents.

2.2 Area

The ecosystem has five areas that we label as $area_0$ to $area_4$ from south to north. Each area is modeled on the area of North and Central America where the migration of Monarchs actually occurs. $area_i$ has three environmental parameters, which are temperature, day length, and foods. These three environmental factors have significant effects on the migration of the Monarch.

Temperature is decided by two kinds of environmental changes: long-term and short-term. A long-term change is an annual temperature rise. A short-term change is a daily temperature changes. Thus, we define a temperature $tmpr_i(y, d)$ in $area_i$ at year y and day d as

$$tmpr_i(y, d) \;=\; long_i(y) + short_i(d). \qquad (5)$$

where $long_i(y)$ is a long-term change, $short_i(d)$ is a short-term change, y is a year ($y = t\ /\ 365$) and d is a day ($d = t \bmod 365$). To configure a short-term change, we used real data from the past 20 years in each original area (collected by [2]) and calculated the average annual data by trigonometric function. The day length is defined as the time difference from sunrise to sunset. We compute the time of sunrise and sunset by an approach in reference [1]. Food is a source of vital energy for the agents. Amount of foods is large if temperature is suitable for foods. A food is removed when it is eaten by an agent or reaches its maximum life-span.

3. EXPERIMENTS AND DISCUSSION

In this section, we present simulation results. We placed 200 agents with randomly generated genetic components in $area_0$. We simulated our proposed model under the environmental condition that the average annual temperatures of each area rise every year (Experiment 1). In Experiment 1, long-term environmental change $long_i(y)$ is given by

$$long_i(y) = 0.01 \times y, \qquad (6)$$

Fig.1 shows the number of agents that stay in $area_0$ or migrate from $area_0$ to the others for 2000 years. Agents gradually expanded their migration range toward north with a temperature rise. In later simulations, 74.5 % of the agents migrated to $area_3$ or $area_4$, and agents migrate between $area_0$ and $area_4$ within 3.76 generations on an average. We can say that agents' migration is closely similar to actual Monarchs' migration because general migration route of Monarchs is from wintering places in Mexico (which is $area_0$ in our simulation) to areas located at a latitude of more than 40 degrees north (which are $area_3$ and $area_4$), and their one round-trip migration requires 3 to 4 generation.

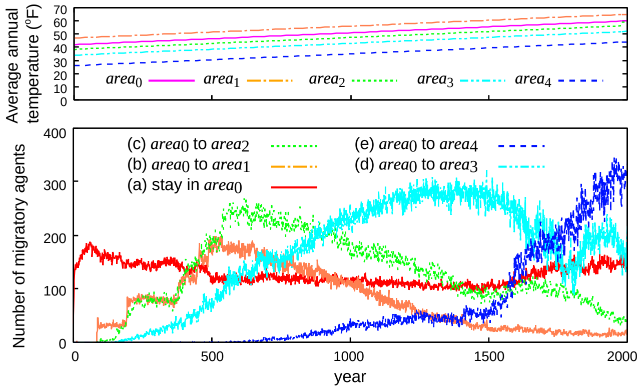

Figure 1: The number of agents that stay in $area_0$ or migrate from $area_0$ to $area_n$ for 2000 years. Data was obtained after 30 experimental runs.

To examine the relation between the migration and the temperature rise, we simulated under the condition that the average annual temperatures are constant (Experiment 2). We simulate with $long_i() = 1.0, 2.0, \cdots, 20.0$. As a result, we found that 21.5 % of the agents migrate to $area_1$, 25.8 % migrate to $area_2$ and 3.7 % migrate to $area_3$ when $long_i(y) = 7.0$, and no agents migrate from $area_0$ when $long_i(y) \geq 8.0$. These results show that Monarchs' migration pattern is not emerged under the environmental condition in which the average annual temperatures are constant. A comparison of Experiments 1 and 2 leads us to conclude that the average annual temperature rise is a trigger for the multi-generational migration of the Monarch.

4. CONCLUSION

We have designed the agent model to reveal the migration of the Monarch Butterfly in computer simulation. Agents emerged the multi-generational by adapting to temperature rises. We confirmed similarities between the agents' migration and the actual Monarchs' migration.

5. REFERENCES

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