行政院國家科學委員會專題研究計畫　期中進度報告

四紋豆象(Callosobruchus maculatus)之繁殖行為與生活史策略(2/3)

計畫類別：個別型計畫
計畫編號：NSC92-2313-B-002-061-
執行期間：92年08月01日至93年07月31日
執行單位：國立臺灣大學昆蟲學系暨研究所

計畫主持人：洪淑彬

報告類型：精簡報告

處理方式：本計畫可公開查詢

中　華　民　國 93年5月27日

行政院國家科學委員會專題研究計畫期中進度報告

四紋豆象 (*Callosobruchus maculatus*) 之繁殖行為與生活史策略

計畫編號：NSC 92-2313-B-002-061
執行期限：92 年 8 月 1 日至 93 年 7 月 31 日
主持人：洪淑彬　　　　台灣大學昆蟲系

一、中文摘要

豆象（*Callosobruchus* spp.）內食性的生態特性，使得雌豆象對寄主的選擇行為一直被視為攸關子代的存活競爭的一種適應性行為。因此，雌豆象搜尋的行為法則一直是產卵行為研究的主要課題之一。本研究以行為錄影記錄及彙整豆象搜尋經歷資料，配合功能性編碼分析方式建立模式以瞭解豆象搜尋過程中之訊息處理與決策。此行為分析系統的建立預期將對探討生物訊息處理過程及對行為生態學之研究有相當助益。

Abstract

Animal cognition involves information processing and decision-making in a dynamic fashion. An apparatus to reveal the structure of cognitive processing is to encode the sequential behaviors into functional schemes so that the behavioral database can be dissected and reassembled without being constrained by unrealistic model assumptions. Specifically this set of new analyzing techniques is applied on the cognitive processing of the female bean weevil, *Callosobruchus maculatus*, which explores environment mainly for the ovipositional purpose. First, using functional coding schemes, individual female bean weevil's longitudinal behavioral trajectory across a geometric landscape is coded into a two-level hierarchy code sequences. With each code standing for a biological state and, at the same time, representing a random generating algorithm, the main use of this algorithmic composition is to serve as a spatial-temporal platform to explore pattern recognitions on the beetle's cognitive processing. The underpinning is that statistically this hierarchy is a new way of summarizing behavioral data by mapping out possible non-stationarity of the underlying cognitive mechanisms behind the observed behavioral database. Consequently our approach is very useful to preserve the individual beetle's local as well as global cognitive templates and patterns, and its temporal orders driven by physiological outputs as responses to the changes in environmental conditions. As a final product, a structural system of recognized patterns on a coherent data-driven timescale potentially is a very valuable model in cognitive science and behavioral ecology.

Keywords: *Callosobruchus maculatus*,

algorithmic composition, functional coding scheme, pattern recognition.

二、緣由與目的

From the viewpoint of behavioral ecology, classic models such as Cox’s proportional hazard model, logistic regression model and others, are based only on the part of data from decision making and experienced environmental information to make inferences on what experienced information is important in animal decision-making (Haccou and Meelis, 1994; Visser, 1993; Horng, 1999). Basically corresponding statistical analyses conclude with identifying local patterns. However these local patterns could play some role in certain periods of animal decision making, while being little or of no importance at all on other periods especially when the animal is exploiting an inhomogeneous and depleting environment. The main reason is that local patterns are most often derived under strong independent assumption between decision-makings. This homogeneous assumption ignores the possibility of global and adaptive changes in animal behavior under environmental changes.

Recently in landscape ecology an animal’s movement trajectory for reproducing or foraging is recognized as a link between animal behavior and its landscape (Lima and Zollner, 1996). However many interesting results in this research are derived from computer-simulated comparison among several models under study. The agreement between empirical data and chosen model is not yet widely confirmed in literature. The main obstacle might have been lack of a data analyzing approach to identify mechanisms linking adaptive behaviors to global movement shifts in a dynamic fashion to reflect state or phase changes in internal variable of animal cognition amid the depleting environment.

The dynamics intricately linking information processing and decision-making, when animals are coping with the changing environment, is better first studied by using a data-driven method to look into and to unravel the networks responsible for an animal’s decision making along their observed movement trajectories without imposing any prior constraints possibly from any given model. The reason underlying is that neither verification nor validation of numerical models of natural systems is possible without almost complete knowledge about the system (Oreskes *et al.*, 1994), since models confirmed by agreement between observations and predictions are inherently biased.

This standpoint is especially parsimonious when scientists still lack workable models for animal behavior involving adaptation and learning in a resource-depleting environment. By setting the goal on acquiring a realistic understanding in animal cognitive ecology, the primary task is to analyze the key properties of the complex systems and then at least mathematically try to reassemble the structural systems (Wilson, 1998; Strogatz, 2001).

Callosobruchus spp. reproduce by laying eggs on host beans. The larvae hatch and feed within the host bean. After several developmental stages, the adult emerges and mates. Female bean weevils then spend main part of their lifetime searching for suitable hosts. This species of female beetle has been observed to equip with cognitive capacities to distribute her eggs rather uniformly on available resources (Visser, 1993; Horng, 1997). Like solitary parasitoid wasp, their foraging decision-makings have much direct quantitative as well as qualitative effects on the offspring. Hence their cognitive capacities will therefore be under very strong natural selection forces. One other characteristic makes the bean weevil ideal animal for cognitive study is that they usually do not feed after emerging out as adults.

A female bean weevil's behavioral process is digitally encoded from video recordings. With the digital data base, a data-driven technique called behavioral programming is proposed to transform the movement trajectory into a hierarchy of algorithms. These algorithms in different level are derived via functional coding schemes as spatial-temporal manifestations of the unobservable physiological mechanisms. Functionally this hierarchical structure dissects the whole movement trajectory into a sequence of internal states that exhibit exploiting and exploding movements. Stochastically the hierarchy maps out the non-stationarity underlying the movement trajectory. For this reason, no classical time series models are applied here.

Furthermore the behavioral programming provides a platform not only for local and global cognitive patterns recognition by embedding female beetle's decision making process onto the hierarchy, but also for reassembling identified patterns into a dynamic network. Such pattern recognitions and the resulted network would surely serve to better understand animal's cognitive processing. Especially some identified global movement patterns can be reasonably seen as phase changes of an internal variable in animal cognition. They are therefore relevant to evolutionary adaptation in animal cognitive processing.

三、結果與討論

Pattern recognition in cognitive processing based on algorithmic composition that uses the behavior sequence of a bean weevil, no. cc28 as an example (Fig. 1). Schematic illustrating behavioral programming of an animal's cognitive processes (Fig. 2). Cumulative and segmental networks of a bean weevil were shown in Fig. 3a and 3b. Watts and Strogatz (1998) quantified the structural properties of the graphs of networks by their characteristic path length, L, and clustering coefficient, C. L has the global property of measuring the typical separation between two vertices in the graph. We calculated the cumulative C round by round. As for the increasing connection number of vertices, the shortest number of connections between any two vertices will be decreased which cause L to approach 1 (Fig. 3c). C has the local property of measuring the cliquishness of a typical neighborhood. We calculated the cumulative C value round by round. For the C value, the k_v of any vertex approaches the most edges can exit of its neighbors as the number of connections increases which causes the C value to approach 1 (Fig. 3d). We evaluated the observed signal to noise ratio of the L value by calculating the 10% to 90% range of the L value for each of 100 simulated rounds (Fig. 3e). Nearly all observed L values were in the 10% to 90% range of the simulated values. Thus, the simulated results were very similar to the observed data, indicating the programming method is adequate and reliable. The evaluation of the C value showed the same (Fig. 3f).

The functional regularity of the cognitive template can be clearly seen as an intrinsic mechanism that, after 0-egg-bean encounter, only this quality of bean is acceptable despite of increasing probability of encountering lower quality 1-egg-bean. Not until enough frustrations from continuously failing to find 0-egg-bean, the female beetle would adaptively accept this lower quality 1-egg-bean as hosts (Fig. 4). Pearson's Chi-squared tests were performed to discern the disproportion of the first and second order differences among the observed oviposition events (O) with respect to the background proportion (P) of them (Table 1a, b). These results clearly indicate that experiencing a bean’s quality one and two memory windows back is important for acceptance of the currently encountered bean as a host. Correspondingly it can be concluded that the size of the weevil’s memory window is at least 2.

四、計畫成果自評

The potential importance of behavioral programming proposed here is its capacity of constructing structural system based on the empirical behavioral database in animal cognitive researches. This structure system would allow scientists to reassemble all their findings and knowledge on cognitive patterns and templates into a computer algorithmic composition, and actually perform the simulation study and compare with observed database. Immediately the behavioral programming also provides an ideal animation with bio-intelligence related purpose.

The main engine of this behavioral programming is the algorithmic composition derived by using functional coding schemes as a spatial-temporal platform. Specifically two main objectives of the algorithmic composition are achieved here. The first is to provide a new method for summarizing an animal’s behavioral trajectory such that it can be evaluated for pattern recognition as well as mapping out the underlying non-stationary mechanism of animal behavior. The second is to unravel the reassembled construct of an animal's cognitive processing, and adaptive learning behaviors.

This approach of behavioral programming together with algorithmic composition is very useful to preserve the individual beetle’s behavioral patterns and its temporal orders. More importantly it allows scientists to identify global patterns as adaptive learning driven by physiological responses to the changes in environmental conditions. These global patterns usually are much more essential than local ones for understanding animal behavior under of environmental pressure.

From algorithmic information theory (Chaitin 1987), we know that the shortest general computer program capable of exactly generating C^0 does not exist. Theoretically we need to know all the patterns hidden in C^0 and capture them into algorithms in order to shorten a computer program having exactly the same capacities. Here the algorithmic composition is a way to compress data to achieve a shorter computer program. Although it would have error when it is decompressed, in fact, this perspective goes hand in hand with a brand new statistical analysis for animal behavior. Further implication of functional coding schemes used here could be potentially limitless, especially for “robot” insect with realistic cognitive processing as the ultimate goal.

Potentially this approach can be also applied to large-scale landscape ecology topics, such as habitat selection, mate choice and host selection with suitably defined topology. Furthermore time duration can be embedded on each code of C^0 into the computer program, and then to have an artificial beetle behavior on real time scale.

五、參考文獻

Bakeman, R. 2000. Behavioral observations and coding. In: Reis HT, Judd CK (eds) Handbook of research methods in social psychology. New York, Cambridge University Press.

Chaitin, G. J. 1987. Algorithmic Information Theory. Cambridge University Press.

Horng, S. B. 1997. Larval competition and egg-laying decision by the bean weevil, *Callosobruchus maculatus*. Anim. Behav. 53: 1-12.

Krebs, J. R., and N. B. Davis. 1997. Behavioural Ecology: An Evolutionary Approach. The Blackwell Science Ltd, London.

Lima, S. L., and P. A. Zollner. 1996. Towards a behavioral ecology of ecological landscapes. Trends Ecol. Evol. 11: 131-135.

Oreskes, N., K. Shrader-Frechette, and K. Belitz. 1994. Verification, validation, and confirmation of numerical models in the earth sciences. Science 263: 641-646.

Real, L. A. 1993. Toward a cognitive ecology. Trends Ecol. Evol. 8: 413-417.

Strogatz, S. H. 2001. Exploring complex networks. Nature 410: 268-276.

Watts, D. J., and S. H. Strogatz. 1998. Collective dynamics of “small-world” networks. Nature 393: 440-442.

Wilson, E. O. 1998. Consilience. Knopf, New York.

Fig. 4.

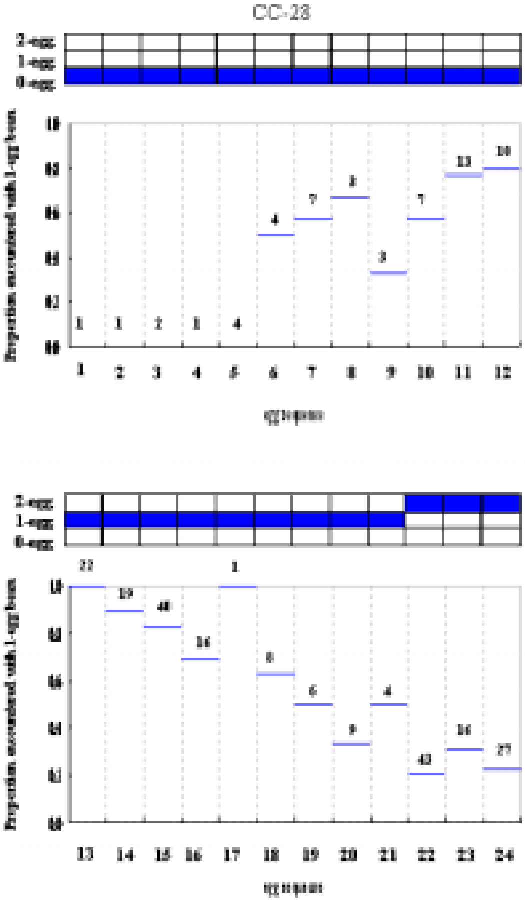


Fig. 1.

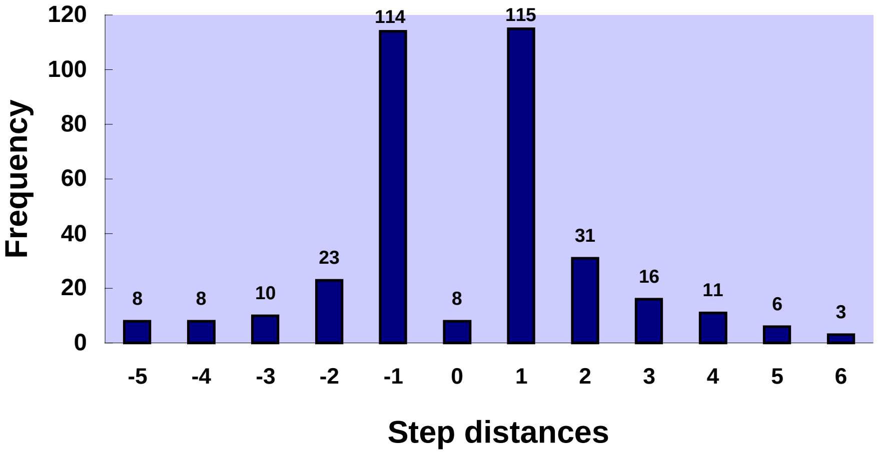


Fig. 2.

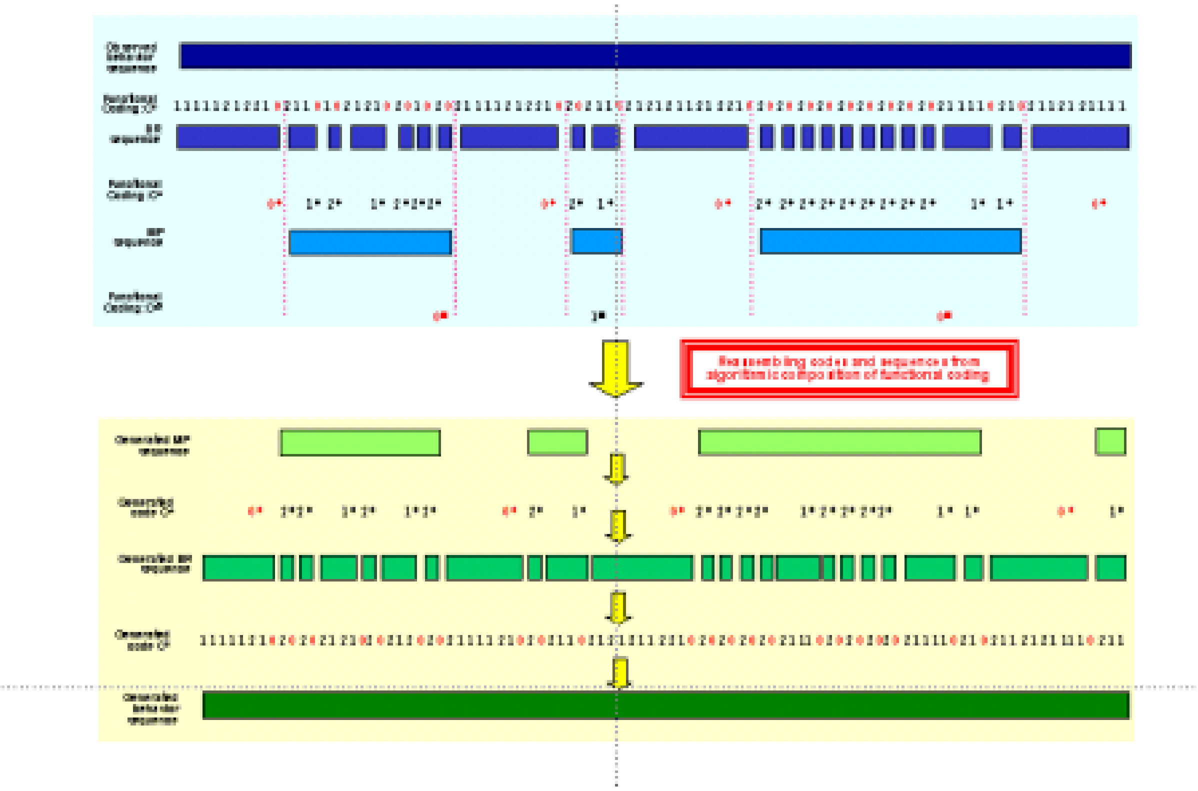
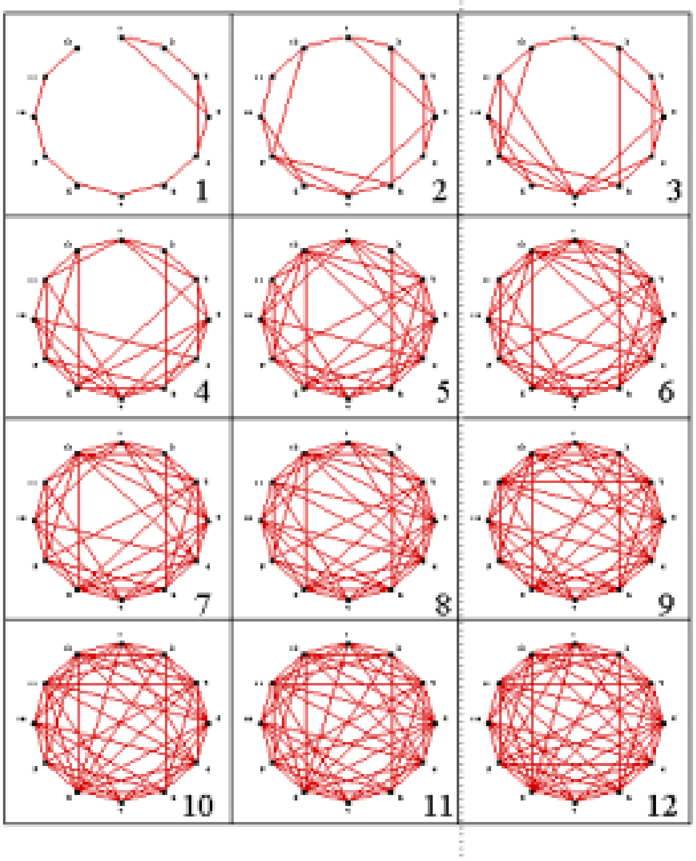

Re assembling codes and sequences from algorithmic composition of functional coding

Fig. 3.


1
2
3
4
5
6
7
8
9
10
11
12