Using Ideas of Kolmogorov Complexity for Studying Animal Behavioural Patterns

Sofia Panteleeva
psofia@mail.ru

Zhargal Danzanov
danzanov.zhargal@gmail.com

Zhanna Reznikova
zhanna@reznikova.net

Institute of Systematics and Ecology of Animals
Frunze, 11, Novosibirsk, Russia, 630091

ABSTRACT

We suggest a method for evaluating the complexity of animal behavioural patterns based on the notion of Kolmogorov complexity, with ants' hunting behaviour as an example. We compared complete (successful) and incomplete hunting stereotypes in members of a natural ant colony and in naïve laboratory-reared ants. We represent behavioural sequences as "texts", and compress them using a data compressor. Behavioural units (10 in total), singled out from video records and denoted by letters, served as an alphabet. Successful hunting stereotypes appeared to be characterized by smaller complexity than incomplete ones. A few naïve "born hunters" which enjoy "at once and entirely" complete hunting stereotypes are characterized by a lower level of complexity of hunting behaviour. We conclude that innate complete stereotypes have less redundancy and are more predictable, and thus less complex.

Author Keywords

Kolmogorov complexity, data compressor, redundancy, behavioural sequence, ants, hunting.

INTRODUCTION

The concept of complexity of animal behaviour is still mainly intuitive. First of all, one has to distinguish between the complexity of flexible and stereotypic behaviour. In the first case we mean levels of complexity of problems to solve and decisions to make, whereas in the second case we mean the inner coordination and regularity of species-specific repertoire [5]. Surprisingly, despite many attempts to examine the organizational complexity of signal repertoires [1], there are no reliable tools for studying the complexity of animal behavioural patterns. Ants can serve a good example here because these insects exhibit diverse behavioural patterns, both flexible and instinctive.

In this study we apply the ideas of Kolmogorov complexity to compare species–specific hunting stereotypes in experienced and naïve ants. Informally, Kolmogorov complexity is the length of a minimal program generating this sequence [a formal exposition in: 2]. In our case the alphabet is a whole set of species-specific behavioural units, and a sequence of letters corresponds to a displayed behaviour. Intuitively Kolmogorov complexity of a text is the length of this text compressed by an "ideal" data compressor; an ideal data compressor is a compressor that finds every possible regularity in the data. As ideal compressors do not exist, we use real ones. Real data compressors can find many regularities that commonly occur in textual data. The concept of Kolmogorov complexity is widely applied in different fields of science [3]. However, although many authors have tried to apply ideas of information theory to animal communication [4], an experimental study of ant "language", that is, ants' ability to "compress" messages based on the "alphabet" consisting of two letters R (right) and L (left), still remains the sole application of Kolmogorov complexity to animal behaviour [7].

METHODOLOGICAL APPROAHES AND MATERIALS

Let us define the notions that we use to describe behaviour. We selected elementary movements and postures as minimal units of behaviour ("*behavioural elements*", for brevity). We call a "*behavioural sequence*" an arbitrary sequence of successive behavioural elements, and a "*behavioural stereotype*" - a relatively stable chain of behavioural elements. The display of behavioural stereotypes in the context of species-specific behaviour is somewhat stochastic: some elements can be duplicated or dropped out; they also can be "diluted" with accessory behavioural elements ("noise"). *Fixed action pattern* (*FAP*) is defined as an instinctive behavioural sequence that is invariant and indivisible [8]. It is possible that a behavioural sequence includes a behavioural stereotype, and the latter includes a FAP.

№	Complete (successful) stereotypes	Incomplete stereotypes
1	RACACKCRUACKCKCC CCCP. RARURACKCKCKCP.	WARURW. RTARW. RARTRRW.
2	RUACCKKCWTTWCUCP . RUACRUTURACRURCP. RURBRARRACKCKCCP.	RTRACTTRAUT RAC.
3	-	WBBAT.
4	RARWTTRACCKCKCCK KCKCTP. RURAAACTCKCKCCKC KCCCP. RACKCKCCCCP.	RARRURAARW. WRSA. RTRUA.
5	-	RART.
6	RAUURRTRACP.	RARAK. RUWRAW. RARRUAR.
7	RACKSSWSSSCCCCCCP. RACKCKCP. RACCCP. RURARCKCKCCKCCCCP .	RARAK. WCKCKR.
9	RTRACCKCP. RARACP.	RWTAAU.
11	RARARRACKKCCP. RTACKCCKCP.	RTARATW. SWATAW. RARUARAK.
13	-	RTAAUAU. RUARAW.
14	RACWKSSKCCP. RAACCKKKCCP.	-

Table 1. Behavioural sequences denoted by letters in 14 'wild' ants.

Legend: **W – waiting/ stopping; S - slow walk; R – running; T – turning ; U – turning around; B - belligerent posture (an ant stands on four legs raising two legs highly over its head); A – attack (falling on a victim); C – capturing: S – stinging; T – transporting a prey; point means the end of a stereotype; dash – lack of a stereotype. The №№ 8, 10, 12 wild ants did not hunt.**

We analysed a hunting stereotype of *Myrmica rubra* ants towards jumping springtails. This stereotype includes determining the victim, approaching it, and then performing the FAP that we call "tip-and-run attack": the ant attacks the prey, bend the abdomen and head to the thorax, jumps to the springtail, falls on it abruptly, and stings. Then the ant intercepts the victim and transports it to the nest. In laboratory we compared two groups of highly genetically variable ants: members of a natural colony ('wild' for brevity) and naïve (laboratory reared) ants of age from 3 to 12 days. It is worth to note that not all naïve ants were tested. It was shown in [6] that within ant colonies about 5% of all members are "born hunters", and they display the hunting stereotype "once and entirely". In this study we intentionally chose the most active ants, and from 12 individuals there were 6 that demonstrated the completed hunting stereotype ended with killing the prey (see Table 1 and 2). All ants were placed one by one into glass containers with 30 live springtails, and each individual was tested once. To analyze ethograms from video records, we used the Observer XT 7.0 (version: 7.0.214, Noldus Information Technology). Using an "alphabet" of 10 behavioral units, we expressed the hunting stereotypes as text files. Every sequence (file) was constructed manually (by the researchers) from the corresponding video fragment. As the starting point of a hunting stereotype we considered the ant's approach to the victim and the display of purposive movements; transportation of a killed victim was considered the end of the complete stereotype. All cases of loss of a victim and switching to another one were considered ends of incomplete stereotypes. We reduced files to equal initial length, compressed them with the use of KGB Archiver (v.1.2) and compared ratios of compression in different stereotypes. The length of a compressed "text" can be thought of as an estimate of its Kolmogorov complexity.

RESULTS AND DISCUSSION

We obtained 4 files which included: 19 complete and 20 incomplete hunting stereotypes in "wild" ants and, correspondingly, 20 and 31 stereotypes in "naïve" ants (see Table 1 and 2). The successful (complete) hunting stereotype in "wild" ants appeared to be characterized by smaller complexity than the incomplete stereotype: the compression ratio is 63.27% for the first file, and 70.07% for the second one. It is likely caused by a greater frequency of key elements and less "noise" in complete stereotypes. The complete stereotypes also have less redundancy and are more predictable. The same was found in naïve ants: 56. 4% and 68.03%, correspondingly. Of particular interest is that naïve "born hunters" which enjoy "at once and entirely" hunting stereotypes are characterized by a lower level of complexity of hunting behaviour. Their hunting stereotypes are possibly most "laconic" and clear. This supports the hypothesis of Reznikova and Panteleeva [6] that a few carriers of the whole hunting stereotype to be spread within an ant colony, can serve as catalysts of social learning for other individuals which possess only fragments of relevant behavioural patterns.

Evaluation of the complexity of behavioural stereotypes has already enabled us to reveal discrete behavioural variability within an ant colony. In perspective, the use of ideas of

№	Complete (successful) stereotypes	Incomplete stereotypes
1	-	STAW. STAR. RWARU. WARW.
2	-	WCCCCW.
4	RTRACKUCCP. WTACKCCCCP. RACKCP.	RURAU. RARRTAR. RAUR. RAUW.
5	RTACKUP. RACTTTP. RTACKRTRRCCP. RTRACKCP.	RATWRAT. RTRAT. RTRAT. WTAK.
6	RACKCCKCP. RACKCKCP. RACKCCKCCCP. RACKCP. RACKCCP.	WTARTUR. WAKW. RTACKCKCR.
7	RUACKCP. RACKCCCCCCCCCCC CCP. RTATACCUKCCCCCP. RACKP.	RTACKRU. RAUR. RACRU. RUACKCKCR. RACKKTCCCCCCC CCCR. RACKCCKCCR. RACKRARACKUR.
9	RACKCP.	-
12	SACCCCP. STACCKCP. STAACKCP.	WAW. STAR. STATS. WUAUTS. SARURW. SAKS. SATUTS. SASU.

Table 2. Behavioural sequences denoted by letters in 12 naïve ants. The №№ 3, 8, 10, 11 naïve ants did not hunt.

Kolmogorov complexity for studying animal behaviour is a promising tool to be used in different areas of behavioural and evolutionary research. In particular, this method can help to extract "basic" (completely innate) behavioural patterns by comparing behavioural sequences of different levels of complexity and flexibility. This is particularly important for evolutionary and ethological studies in the field.

REFERENCES

1. DeVoogd T. J. Neural Constraints on the Complexity of Avian Song. *Brain, Behaviour and Evolution, 63* (2004), 221–232.
2. Kolmogorov, A.N. Three approaches to the quantitative definition of Information. *Problems in Information Transmission 1* (1965), 1-7.
3. Li M., Vytanyi P. An Introduction to Kolmogorov Complexity and Its Aplications. Springer Verlag. 2008.
4. McCowan B., Hanser S.F., Doyle L.R. Quantitative tools for comparing animal communication systems: information theory applied to bottlenose dolphin whistle repertoires. *Animal behaviour 57*, 1999, 409-419.
5. Reznikova, Zh. *Animal Intelligence: From Individual to Social Cognition.* Cambridge University Press: Cambridge, MA, USA, 2007.
6. Reznikova Zh., Panteleeva S. An ant's eye view of culture: propagation of new traditions through triggering dormant behavioural patterns. *Acta Ethologica 11*, 2 (2008), 73-80.
7. Ryabko B., Reznikova Zh. Using Shannon Entropy and Kolmogorov Complexity To Study the Communicative System and Cognitive Capacities in Ants. *Complexity, 2* (1996), 37-42.
8. Tinbergen N. *The Study of Instinct.* London and New York: Oxford University Press. 1951.