APPLICATION OF INFORMATION THEORY FOR STUDYING NUMERICAL COMPETENCE IN ANIMALS: AN INSIGHT FROM ANTS

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ABSTRACT

Our long – term experimental study on ant "language" and intelligence fully based on ideas of information theory revealed a symbolic language in highly social ant species and demonstrated these insects as being able to transfer to each other the information about the number of objects and can even add and subtract small numbers in order to optimize their messages. We suggest that application of ideas of information theory can open new horizons for studying numerical competence in non-human animals.

1. INTRODUCTION

Since C. Shannon [1] published his influential paper "A mathematical theory of communication", the fundamental role of information theory has been appreciated not only in its direct applications, but also in robotics, linguistics and biology. Numerical competence is one of the main intriguing domains of animal intelligence. Recent studies have demonstrated some species, from mealy beetles to elephants, as being able to judge about numbers of stimuli, including things, and sounds, and even smells (see [2] for a review); however, we are still lacking an adequate "language" for comparative analysis. The main difficulty in comparing numerical abilities in humans and other species is that our numerical competence is closely connected with abilities for language usage and for symbolic representation. We suggested a new experimental paradigm which is based on ideas of information theory and is the first one to exploit natural communicative systems of animals [3]. Ants of highly social species are good candidates for studying general rules of cognitive communication. There are more than 12000 ant species on Earth, and the great majority of them use relatively simple forms of communication such as odour trails, tandem running,and so on. Only a few highly social species belong to the elite club of rare "cognitive specialists", and among them are several species of red wood ants (*Formica rufa* group), with their big anthills "boiling" with hundreds of thousands of active individuals [4].

2. IDEAS, METHODS AND RESULTS

In our experiments scouts of red wood ants were required to transfer to foragers in a laboratory nest the information about which branch of a special "counting maze" they had to go to in order to obtain syrup. The main idea of this experimental paradigm is that experimenters can judge how ants represent numbers by estimating how much time individual ants spend on "pronouncing" numbers, that is, on transferring information about index numbers of branches, that is, the information about which branch of a special "counting maze" they had to go to in order to obtain syrup. The main idea is that experimenters can judge how ants represent numbers by estimating how much time individual ants spend on "pronouncing" numbers, that is, on transferring information about index numbers of branches. The findings concerning number-related skills in ants are based on comparisons of duration of information contacts between scouts and foragers which preceded successful trips by the foraging teams.

It turned out that the relation between the index number of the branch (j) and the duration of the contact between the scout and the foragers (t) is well described by the equation

$$t = c\, j + d$$

for different set-ups which are characterized by different shapes, distances between the branches and lengths of the branches. The values of parameters c and d are close and do not depend either on the lengths of the branches or on other parameters.

It is interesting that quantitative characteristics of the ants' "number system" seem to be close, at least outwardly, to some archaic human languages: the length of the code of a given number is proportional to its value. For example, the word "finger" corresponds to 1, "finger, finger" to the number 2, "finger, finger, finger" to the number 3 and so on. In modern human languages the length of the code word of a number j is approximately proportional to log j (for large j's), and the modern numeration system is the result of a long and complicated development.

An experimental scheme for studying ants' "arithmetic" skills based on a fundamental idea of information theory, which is that in a "reasonable" communication system the frequency of usage of a message and its length must correlate. The informal pattern is quite simple: the more frequently a message is used in a language, the shorter is the word or the phrase coding it. This phenomenon is manifested in all known human languages

The scheme was as follows. Ants were offered a horizontal trunk with 30 branches. The experiments were divided into three stages, and at each of them the regularity of placing the trough with syrup on branches with different numbers was changed. At the first stage, the branch containing the trough with syrup was selected randomly, with equal probabilities for all branches. So the probability of the trough with syrup being placed on a particular branch was 1/30. At the second stage we chose two "special" branches A and B (N 7 and N 14; N 10 and N 20; and N 10 and N 19 in different years) on which the trough with syrup occurred during the experiments much more frequently than on the rest - with a probability of 1/3 for "A" and "B", and 1 /84 for each of the other 28 branches. In this way, two "messages" -"the trough is on branch A" and "the trough is on branch B"- had a much higher probability than the remaining 28 messages. In one series of trials we used only one "special" point A (the branch N 15). On this branch the food appeared with the probability of 1/2, and 1/58 for each of the other 29 branches. At the third stage of the experiment, the number of the branch with the trough was chosen at random again.

The obtained data demonstrated that ants appeared to be forced to develop a new code in order to optimize their messages, and the usage of this new code has to be based on simple arithmetic operations. The patterns of dependence of the information transmission time on the number of the food-containing branch at the first and third stages of experiments were considerably different. In the vicinities of the "special" branches, the time taken for transmission of the information about the number of the branch with the trough was, on the average, shorter.

For example, in the first series, at the first stage of the experiments the ants took 70–82 seconds to transmit the information about the fact that the trough with syrup was on branch N 11, and 8–12 seconds to transmit the information about branch N 1. At the third stage it took 5–15 seconds to transmit the information about branch N 11.

Analysis of the time duration of information transmission by the ants raises the possibility that at the third stage of the experiment the scouts' messages consisted of two parts: the information about which of the "special" branches was the nearest to the branch with the trough, and the information about how many branches away is the branch with the trough from a certain "special" branch. In other words, the ants, presumably, passed the "name" of the "special" branch nearest to the branch with the trough, and then the number which had to be added or subtracted in order to find the branch with the trough.

That ant teams went directly to the "correct" branch enables us to suggest that they performed correctly whatever "mental" operation (subtraction or addition) was to be made.

It is likely that at the third stage of the experiment the ants used simple additions and subtractions, achieving economy in a manner reminiscent of the Roman numeral system when the numbers 10 and 20, 10 and 19 in different series of the experiments, played a role similar to that of the Roman numbers V and X. This also indicates that these insects have a communication system with a great degree of flexibility. Until the frequencies with which the food was placed on different branches started exhibiting regularities, the ants were "encoding" each number (j) of a branch with a message of length proportional to j, which suggests unitary coding. Subsequent changes of code in response to special regularities in the frequencies are in line with a basic information-theoretic principle that in an efficient communication system the frequency of use of a message and the length of that message are related.

The obtained results show that information theory is not only excellent mathematical theory, but many of its results may be considered as Nature laws.

3. REFERENCES

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