THE POWER OF IDEAS FROM INFORMATION THEORY FOR STUDYING ANIMALS' NATURAL COMMUNICATION

ZHANNA REZNIKOVA [*1,2]

[*]zhanna@reznikova.net
[1]Institute of Systematics and Ecology of Animals, Novosibirsk, Russia
[2]V. Zelman Institute for Medicine and Psychology, Novosibirsk State University, Russia

Evolutionary linguistics has emerged as an attempt to answer questions concerning language evolution and human nature based on an interdisciplinary collaboration (Bickerton, 1990; Tomasello, 2008; Gong et al., 2014). The fundamental question about the uniqueness of human language is still far from being understood (Wacewicz & Żywiczyński, 2015). One of the possible paths forward suggested by Hauser et al. (2014) includes observations and experiments of naturally communicating animals and experiments assessing animals' computational and perceptual capacities, focusing on abilities necessary for human language processing. Here I compare three main experimental paradigms in studying animal language behavior and highlight the new dimension in this field provided by information theory.

The first approach is aimed at direct decoding the function and meaning of animal signals, which is a notoriously tricky problem. Two types of natural messages decoded up to the present concern the symbolic honeybee "dance language" (for a review, see Kohl et al., 2020) and fragments of acoustic communications in several species such as monkeys (review in Fischer, 2020) and dolphins (King & Janik, 2013). Girard-Buttoz et al. (2022) recently revealed a highly versatile vocal system in chimpanzees; however, larger datasets are still needed to prove animals' capacity to produce flexible vocal sequences that support numerous differentiated meanings. The second approach based on artificial intermediary languages uncovered significant "linguistic" and cognitive potential in some species that contradicts limitations in understanding their natural communications. The third approach applies ideas of Shannon entropy and Kolmogorov complexity. The main point is to study natural communications and evaluate their capabilities by measuring information transmission rates (details in: Ryabko & Reznikova, 2009; Reznikova & Ryabko, 2011). Without studying the nature of the signals used for communication, this approach provides a new dimension for understanding the essentials of animal communication systems.

Ants appeared to be even better candidates for studying general communication rules than the iconic honeybee. Among about 15 000 ant species, the majority of which display relatively simple modes of communication, a few *Formica rufa* species possess the leader-scouting system based on a consistent personal difference between scouting and foraging individuals (Reznikova, 2021). The idea of experiments is that the experimenters know the quantity of information (in bits; Shannon, 1948) to be transferred, which corresponds to the number of turns in a “binary tree” maze towards a “leaf” containing syrup. There were no cues that could help the ants find the food (including olfactory ones) except the information contacts with scouts. The duration of the contacts between the scouts and foragers appeared to be $ai + b$, where i is the number of turns, a is the time duration required for transmitting one bit of information, and b is an introduced constant. The rate of information transmission was about 1 minute per bit in ants, which is at least 10 times smaller than in humans. Ants appeared to be able to grasp regularities in the “text” (sequence of turns, see below) to be transferred and use them to “compress” and thus optimize their messages. This series of experiments was inspired by the concept of Kolmogorov complexity (Kolmogorov, 1965) applied to words (or “texts”) composed of the letters of an alphabet, for example, consisting of two letters: L (left) and R (right) corresponding to a sequence of turns in a “binary tree”. Informally, the Kolmogorov complexity of a word (and its uncertainty) equates to its most concise description. For example, the word “LRLRLRLR” can be represented as “4LR”, while the “random” word of shorter length “LRRLRL” probably cannot be expressed more concisely, and this is more complex. The hypothesis being tested was H_0, that is, the time for transmission of information by the scout does not depend on the complexity of the “text”. The alternative hypothesis was H_1 that this time actually depends on the complexity of the “text”. The hypothesis H_0 was rejected ($P = 0.01$), thus showing that the more time ants spent on the information transmission, the more complex – in the sense of Kolmogorov complexity – was the message. This surprisingly resembles “learning with chunking and generalization” during the foraging process in structured environments suggested by Kolodny et al. (2015). In sum, ideas from information theory help to evaluate cognitive and flexible aspects of natural communication systems and thus understand better the evolution of language.

Acknowledgements

This work was funded by Russian Fund for Basic Research (No. 20-04-00072) and the Federal Fundamental Scientific Research Program for 2021-2025 (122011800268-1).

References

Bickerton, D. (1990). *Language and species*. Chicago: The University of Chicago Press.

Fischer, J. (2020). Nonhuman primate alarm calls then and now. *Animal Behavior and Cognition*, *7*(2), 108-116.

Girard-Buttoz, C., Zaccarella, E., Bortolato, T., Friederici, A. D., Wittig, R. M., & Crockford, C. (2022). Chimpanzees produce diverse vocal sequences with ordered and recombinatorial properties. *Communications biology*, *5*(1), 1-15.

Gong, T., Shuai, L., & Comrie, B. (2014). Evolutionary linguistics: theory of language in an interdisciplinary space. *Language Sciences*, *41*, 243-253.

Hauser, M. D., Yang, C., Berwick, R. C., Tattersall, I., Ryan, M. J., Watumull, J., ... & Lewontin, R. C. (2014). The mystery of language evolution. *Frontiers in psychology*, *5*, 401.

King, S. L., & Janik, V. M. (2013). Bottlenose dolphins can use learned vocal labels to address each other. *Proceedings of the National Academy of Sciences*, *110*(32), 13216-1322

Kohl, P. L., Thulasi, N., Rutschmann, B., George, E. A., Steffan-Dewenter, I., & Brockmann, A. (2020). Adaptive evolution of honeybee dance dialects. *Proceedings of the Royal Society B*, *287*(1922), 20200190.

Kolmogorov, A. N. (1965). Three approaches to the quantitative definition of information. *Problems of information transmission*, *1*(1), 1-7.

Kolodny, O., Edelman, S., & Lotem, A. (2015). Evolution of protolinguistic abilities as a by-product of learning to forage in structured environments. *Proceedings of the Royal Society B: Biological Sciences*, *282*(1811), 20150353.

Reznikova, Z., & Ryabko, B. (2011). Numerical competence in animals, with an insight from ants. *Behaviour*, *148*(4), 405-434.

Reznikova, Z. (2021). Ants' Personality and Its Dependence on Foraging Styles: Research Perspectives. *Frontiers in Ecology and Evolution*, *9*, 269.

Ryabko, B., Reznikova, Z. (2009). The use of ideas of information theory for studying "language" and intelligence in ants. *Entropy*, *11*(4), 836-853.

Shannon, C. E. (1948). A mathematical theory of communication. *The Bell System Technical Journal*, *27*(3), 379-423.

Tomasello, M. (2008). *Origins of Human Communication*. Cambridge, MA: MIT Press.

Wacewicz, S., & Żywiczyński, P. (2015). Language evolution: Why Hockett's design features are a non-starter. *Biosemiotics*, *8*(1), 29-46.