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Towards computational models of animal cognition, an introduction for computer scientists

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Abstract

The last few years of the twentieth century witnessed the emerging convergence of biology and computer science and this trend has been accelerating since then. The study of animal behavior or behavior biology has been one of the major contributors for this convergence. Behavior is fascinating because it is the response of an organism to internal and external signals and it is controlled by complex interactions among nerves, the sensory and the motor systems. To some extent, behavior is similar to the output (or *response*) of a computer system or a network node if we consider an animal brain as a computer node. This paper is the first in a two-part series in which I review the state-of-the-art research in behavior biology inspired computing and communication, with the first part focusing on animal cognition and the second part on animal communication (Ma, 2014). The present article also assumes the task of presenting a general introduction on behavior biology literature, which sets a foundation for synthesizing both parts of the series but the synthesis will be performed in the second part of the series. I sets three objectives in this 'cognition' part: (i) to present a brief overview on the literature of behavior biology for computer scientists; (ii) to summarize the state-of-the-art studies in several cognitive aspects of animal behavior: focusing on emerging research in *cognitive ecology*, *social learning* and *innovation*, as well as *animal logics*; (iii) to review some important existing studies inspired by animal behavior and further present a perspective on the future research. These cognition-related topics offer insights for research fields such as machine learning, human computer interactions (HCI), brain computer interfaces (BCIs), evolutionary computing, pervasive computing, etc. In perspective, I suggest that the interaction between behavioral biology and computer science should be bidirectional, and a new subject, *behavioral informatics,* or more general *computational behavior biology,* should be developed by the cooperative efforts between biologists and computer scientists.

Keywords: Animal cognition; Cognitive ecology; Social learning; Bioinspired computing and communication; Behavioral informatics; Computational behavior biology

1. Introduction

The recognition of the significance of biology for computing can be traced back much earlier, from Alan Turing's definition of *machine intelligence* in the 1930s, von Neumann's research in *automata theory* in the 1950s, *genetic algorithms* and *evolutionary computing* pioneered in the 1970s, to more recent *swarm intelligence* inspired by social insects in the 1990s. These are just a few in a growing long list, among which, swarm intelligence is one of the latest examples.

Animals were traditionally characterized as mindless-inflexible and machine-like creatures with simple instincts.

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The foundation for this kind of "*prejudiced*" characterization was based on the anthropocentric human cognition and judged by capabilities such as reasoning, problem-solving and symbolization. Although whether or not animals are as dumb as they were characterized (most likely not) is still in debates, more and more scientists realize that the anthropocentric standard is not helpful to understand the animal cognition and behavior. More "*objective*" and less or non-anthropocentric definitions for animal cognition have been adopted, e.g., "*cognition is evolved to enable organisms to control their own behavior, allowing them to cope with environmental complexity*" by Godfrey-Smith (2001). Obviously, a non-anthropocentric approach is at least better suited for studying animal behavior and it is also consistent with the gradually converging consensus that the transition from animal cognition to the more complex human cognition is gradual. For example, the basic apparatus for *logical reasoning*, the *abstraction* process, also exists in animals, even though it is simpler than the human equivalent. Even the notion that logic and language are inseparable is being questioned, which indicates that animals may indeed be able to reason logically.

Animal cognition is a very broad and active discipline covering some of the hottest research fields such as animal learning and memory. In this paper, I only focus on five emerging fields (topics): *cognitive ecology*, *animal logics*, *social learning*, *innovation* and *teaching*, which have received relatively little attention in computer science, but may have important inspirations to fields such as pervasive computing, machine learning, brain computer interfaces (BCIs) and human computer interactions (HCIs). *Cognitive ecology* emphasizes the so-called *phenotypic plasticity* that contributes to *adaptability* and it studies the interface between the nerve system and behavior from the evolutionary and ecological perspective. *Animal logics* may be simpler than human logics due to the lack of complex linguistic interactions, and yet both types are adequate for their respective life forms. Thus, animal logics may be easier to implement but still adequate for a given functionality. Social learning and innovation are just two of the repertoire of animal behavior. The reason I choose to cover them is because they are emerging fields in behavioral biology and have received little attention in computer science. Nevertheless, they may offer important insights for research in machine learning, evolutionary computation, etc.

Animal cognition is primarily studied in the discipline of behavior biology, or the study of animal behavior. Behavior biology formally started with *ethology*, which was "*taken over*" by *behavioral ecology* in the middle of 1970s. Since then, behavioral ecology has been the dominant field in behavioral biology, and the dominance is so overwhelming that it probably does not make much difference to treat them as 'synonyms'. *Cognitive ecology* is probably better termed as *Cognitive behavioral ecology*, which shows its importance given the dominance of behavioral ecology in the study of animal behavior. Since reviewing the whole behavioral biology is beyond the reach of this article, I only choose to accomplish two tasks in this article: (i) present a very brief overview of the discipline with a focus on identifying the core literature sources of the discipline for interested computer scientists; (ii) review several cognitive aspects of animal behavior that are particularly inspirational to computing and communication. As a side note, the present paper is the first of a two-part series in which I review the state-of-the-art research in behavior biology inspired computing. The part two of the series is focused on animal communication and animal communication networks (Ma, Yang, Neilson, Hess, & Millar, 2014). In addition, a synthetic discussion on cognition and communication with respect to computing is postponed to the part two.

The remainder of this article is organized as five sections. Section 2 is an overview of behavioral biology, and it is intended to summarize the scope and major literature sources of the subject. Section 3 surveys emerging research topics of animal cognition, focusing on cognitive ecology, social learning and innovation, as well as animal logics. In Section 3, I also summarized a case study by Ma (2009a), which modified Gadanho's (2003) ALEC (Asynchronous Learning by Emotion and Cognition) architecture, by drawing on the principles from animal *social learning* and *cognitive ecology*. Section 4 reviews some existing computing and communication studies inspired by behavioral biology, particularly studies related to Section 3 topics. Section 5 is a perspective discussion.

2. An overview of behavioral biology/ecology

The terminology for behavioral biology and its related disciplines could be confusing even for the students of biology due to both the breadth of the subject as well as historical reasons (*e.g.*, transformation from *ethology* to *behavioral biology*). As pointed out by Dugatkin (2001), the simplicity is particularly important when it comes to illustrate the position of behavioral ecology in relation to other disciplines. I take the liberty to "*approximate*" behavioral biology with behavioral ecology, and the difference

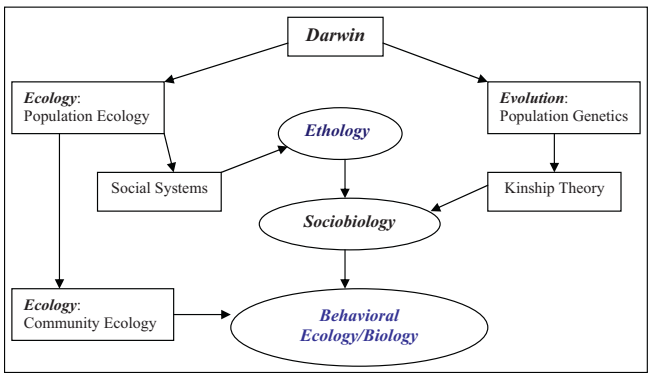

Fig. 1. Brown's (1975) diagram of behavioral ecology's position in Biology, cited in Dugatkin (2001).