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

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Abstract

Animals communicate with each other via varieties of signal modalities such as visual, acoustic, semiochemicals, gestural, or communication behavior. Although animal communication has been studied as a signaler-receiver dyadic system until recently, it is actually a complex network due to the ubiquitous existence of third-party receivers in their signaling space, such as eavesdroppers, bystanders, and audiences. A question of fundamental importance in both science and humanity is whether or not animal signals are honest or deceitful (i.e., communication reliability) since it may shed light on the study of trust and altruism in human beings. The objective of this paper is twofold. First, the state-of-the-art research in *animal communication* (dyadic paradigm) and *animal communication networks* (network paradigm) and their potential inspiration for secure, resilient and pervasive computing are reviewed. Secondly, by arguing that competition, cooperation and communication are the three fundamental elements that natural selection acts upon in the evolution of organisms, and by comparing the study of *cooperation* (such as formulated as the Prisoner's Dilemma (PD) game), with the study of *animal communication* (such as formulated with Sir Philip Sydney (SPS) game), it is suggested that the latter field may spawn important cross-disciplinary research with the potential influence similar to or beyond that generated by the PD game research. The paper also summarizes the recent extension to evolutionary game theory (EGT) with *survival analysis* and *dynamic hybrid fault models* by the author. Finally, seven open questions, with regard to animal communication inspired computing and communication, primarily from the interdisciplinary perspective are posed. As a side note, this is the second article of a two-part series in which I review the state-of-the-art research in *behavior biology* inspired computing and communication. Given the extensive scope of behavior biology, I only focus on two fields most relevant to computing and communication *animal cognition* (part one, Ma, 2014) and *communication* (this article). The previous part one reviewed animal-cognition inspired computing; part one also presented an overview of the behavior biology inspired computing. This part two is focused on animal communication; the relationship between cognition and communication is mainly discussed in this part also.

Keywords: Reliability of animal communication; Animal communication network; Handicap principle; Eavesdropping; Extended evolutionary game theory; Signal honesty

1. Introduction

"*The biological world is full of the smells, sounds, movements, and electric signals by which animals communicate*".

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Bradbury and Vehrencamp (1998), *Principles of Animal Communication*. p1.

"*Lord, lord, how this world is given to lying.*" *(Falstaff in Henry IV, Part I, Act V, Scene iv)*".

Cited in Searcy and Nowicki (2005), *The Evolution of Animal Communications.* p218.

The animal brain is a complex computing machine. The communication between animals, whether visual, acoustic, chemical, motor, or just communication behavior in general, conveys information. Animals behave according to complex computational and communicational processes that involve their interactions with the environment and other animals. The basic paradigm of animal communication has been treated as dyadic, signaler-receiver, until recently. However, third-party receivers such as eavesdroppers, bystanders or audience exist almost ubiquitously; therefore, a network perspective is more appropriate for understanding animal communication. A fundamental question is whether or not animal signals are honest or deceitful. The answer to this question also bears upon the question of whether human beings stand out as a separate group in terms of the truthfulness of their communication. If animals can lie, do they have sufficiently powerful cognitive capability to support the mental states (such as intention and belief)? If the communication is generally honest, what are the mechanisms that enforce the honesty? The question is also relevant to the evolution of often puzzling altruism.

Communication is a fundamental function of life, and it exists in almost all living things: from single-cell bacteria to human beings. A recent study has discovered that the genome of ancient single cell choanoflagellates carries the markers of three types of molecules that cells use to achieve phospho-tyrosine signaling proteins, which are responsible for intercellular chemical communications in multi-cellular organisms like human beings (NSF (National Science Foundation), 2008). This clearly shows the evolutionary continuity and universality of communication. Therefore, one should not be surprised that engineering communications have been expanded to more and more ubiquitous paradigms.

Communication in plants is well documented, and some scientists even advocate for the establishment of a research discipline (Baluska, Mancuko, & Volkmann, 2006). For example, the action potentials, the very characteristic and fastest way of neuronal communication, were discovered in plants as early as 1873 (Baluska et al., 2006; Davies, 2004). It has been found that plant cells not only express diverse neuronal molecules but also communicate together via plant synapses (Baluska et al., 2006). This is one of the major foundations for the emerging field of plant neurobiology.

Behavior is often the response to signals (Silverton & Gordon, 1989; Trewavas, 2006). Social behavior generally depends on communication; without communication, social behavior is hardly possible. One core foundation for both cognition and intelligence is the processing of information. Signals are the carrier of information, and communication enables the transmissions of information via signals.

Intelligence is often defined anthropocentrically or brain chauvinistically (Trewavas, 2006; Vertosick, 2002). A biological definition is attempted by Stenhouse (1974) who considers intelligence as *adaptively variable behavior* during the lifetime of an individual. In contrast of intelligence, there is simple, *automatic and unvarying* response or behavior. From this definition, intelligence is simply adaptive and variable behavior. Obviously, there are two additional components for intelligence: one is adaptive to what and the other is why being adaptive. For biological intelligence, the intelligent behavior of an individual is adaptive to *environment* to increase *fitness* for survival. These fundamental concepts indicate the critical importance of signals and communications to behavior, cognition and intelligence. It also shows the inner connections between the major topics we choose to discuss in this article, behavior, cognition, social learning, intelligence, and innovation. The justification for treating cognitive ecology as an important research field is also obvious because the study of adaptive behavior to *environment* is not complete without ecological and evolutionary perspectives.

In this article, I set the following four objectives. First, I briefly introduce the essentials of animal communication with focusing on the recent advances in network paradigm—animal communication networks. Secondly, I review state-of-the-art research in the honesty (reliability) of animal communication as well as its inspiration for secure and resilient computing. Thirdly, since evolutionary game theory (EGT) was initially developed with the study of animal communication (aggression display) and has become one of the cornerstones for mathematical modeling of animal behavior, its crucial role in computing and communication will also be discussed. Specifically, by comparing the study of *cooperation*, which was inspired by the altruistic behavior and often formulated as the Prisoner's Dilemma (PD) game, with the study of *animal communication*, I argue that the latter field may spawn important cross-disciplinary research with the potential influence similar to or beyond that generated by the PD game research. Given the critical important of EGT, as a case study, I summarize the extension to evolutionary game theory (EGT) with *survival analysis* and *dynamic hybrid fault models* by Ma (2008, 2009b), Ma and Krings (2008d) or the paradigm of "*Byzantine Generals Playing Evolutionary Games*." The advantages of the extended evolutionary game theory (EEGT) modeling are discussed within the context of *network survivability* and *strategic information warfare* research (Ma, Krings, & Sheldon, 2009).

Finally, I pose seven open questions primarily from the interdisciplinary perspective. The first two questions are concerned with the possibility to develop animal