The evolutionary language game: An orthogonal approach

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Abstract

Evolutionary game dynamics have been proposed as a mathematical framework for the cultural evolution of language and more specifically the evolution of vocabulary. This article discusses a model that is mutually exclusive in its underlying principals with some previously suggested models. The model describes how individuals in a population culturally acquire a vocabulary by actively participating in the acquisition process instead of passively observing and communicate through peer-to-peer interactions instead of vertical parent–offspring relations. Concretely, a notion of social/cultural learning called the naming game is first abstracted using learning theory. This abstraction defines the required cultural transmission mechanism for an evolutionary process. Second, the derived transmission system is expressed in terms of the well-known selection–mutation model defined in the context of evolutionary dynamics. In this way, the analogy between social learning and evolution at the level of meaning–word associations is made explicit. Although only horizontal and oblique transmission structures will be considered, extensions to vertical structures over different genetic generations can easily be incorporated. We provide a number of simplified experiments to clarify our reasoning.
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1. Introduction

Words form the basic unit of a language. Humans use these words to identify things or actions in their environment. Using a word implies that the user also associates a particular meaning with that word. Wrong associations between words and meanings leads to misinterpretations which require corrections. These associations do not stand on their own. Vocabulary and more generally language are population-level phenomena which spread through cultural transmission systems. Questions concerning the minimal requirements of these transmission schemes in order to acquire

a language are pertinent to the better understanding of the actual dynamics. In order to answer these, and other, questions, we need well-founded models which examine the cultural evolution of language.

It is established that social learning plays a crucial role in the acquisition of language. Although, there is not a real consensus on the actual social learning mechanisms. Boyd and Richerson (1985) generally define social learning as the transmission of stable dispositions by teaching or imitation. Yet, the actual mechanics of the latter processes can differ. Two well-known models are the observational learning model and the operant conditioning model (Rosenthal and Zimmerman, 1978). The first model assumes that learning occurs by pure observations and that properties are acquired through statistical sampling of these observations. The second stresses the importance of a stimulus and the response when acting upon this stimulus. In the

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context of language acquisition observational learning has been examined in numerous situations. Our view on language acquisition belongs to the second type of models. The primary motivation for choosing this perspective is that we consider language learning to be functional, i.e. directed toward the communication of meaning.

The social learning scheme defines the general layout of the cultural evolutionary system, yet different transmission structures exist. Three alternative forms are often cited: vertical , oblique (role-model) and horizontal transmission (Cavalli-Sforza and Feldman, 1981; Boyd and Richerson, 1985). The work here focuses on the latter and some small comments will be made about oblique transmission. Horizontal transmission refers to the transmission between peers instead of parents and children (as in vertical transmission). Hence, there is no primary role, individuals can be either antagonist or protagonist in the social interaction. In oblique transmission, the roles are explicitly defined. An individual is either teacher or student. Moreover, oblique transmission implicitly assumes that among the teachers their is some degree of coherence in the language. The major difference with vertical transmission is that in both horizontal and oblique structures, the transmission can occur within one 'genetic' generation. Hence, there is a difference between 'genetic' and 'cultural' time. Boyd and Richerson (1985) refer to this situation as an asymmetric inheritance system. This difference may lead to conflicts since cultural transmission may favor other trait variants than genetic transmission. We will not explicitly discuss such conflicts here.

The previous discussion provides a combination of two underlying principals which are orthogonal with those used for previously designed models (Hurford, 1989; Oliphant and Batali, 1997; Nowak et al., 1999; Nowak and Komarova, 2001; Kirby and Hurford, 2002). Yet, as far as we are aware, none of them actually considers the suggested perspective. Nevertheless, large amount of evidence exists that both cornerstones have played a crucial rule in the origin and evolution of language. To clarify the major differences, take for instance the mathematical framework discussed by Nowak et al. (1999). First, as indicated earlier, the vocabulary in their model is acquired through observational learning, i.e. learning how to associate a word and a meaning without experiencing it oneself (Rosenthal and Zimmerman, 1978; Boyd and Richerson, 1985). In this approach, imitation of observed behaviors between communicating population members forms the primary mechanism for the student/child to acquire the language. Hence, the role of cognitive processes is restricted to an almost literal imitation of the shared lexicon. Second, the authors apply a cultural evolutionary model with vertical transmission between 'genetic' generations. The dynamics describe how through a process of

blending inheritance the lexicon of the different population members converges toward a shared one. In their context, the communication between the (cultural or genetical) parents of the same genetic generation was examined. Our aim is to provide an alternative mathematical framework that incorporates those features of cultural evolutionary system which are orthogonal to their model.

In Section 2 we will outline the basic model. Afterward, in Section 3 the cultural transmission scheme which describes how the associations between words and meanings are transmitted between peers is discussed. The dynamics of the transmission scheme will be analysed in Section 4. In Section 5, the dynamics of the evolutionary language game will be outlined and discussed. In this section, it will be shown that the cultural transmission scheme is equivalent to selection–mutation models discussed in the context of evolutionary game dynamics. Finally, the paper will be concluded in Section 6.

2. The model

2.1. The complete picture

The complete model consists of a population of individuals which posses a number of capabilities to acquire and communicate meaning. Here, it is assumed that each individual can perform a number of tasks: direct the others attention toward some objects in an environment, perceive these objects and assign meaning to them (Steels, 1995, 1999; Tomasello, 2003). The most primitive way to perform this first task is by pointing or some other gesture to manipulate the attention of the individual with whom one wants to communicate. The second and third task require that an individual maintains a set of meanings which are associated with different objects in the environment and a lexicon which collects the associations between the different words and meanings. Hence, the functional process consists of a combination of individual learning to discriminate objects in the environment and cultural transmission to communicate this meaning towards others. The current discussion we will only consider the latter since it captures the elements of the evolutionary process which we want to investigate.

Two final assumptions are made. First, we will, at each step of the discussion, always consider the communicative effects between two individuals first. Second, all individuals have homogeneous language skills. The initial simplification is introduced to capture the actual social learning process before making any generalisations towards populations. Yet, the extension towards populations is crucial due to the population-level consequences of cultural transmission. The latter