LANGUAGE-BIOLOGY COEVOLUTION FIXATION TIMES

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In order to understand language evolution, we need to understand the interaction between biological and cultural evolution (e. g. Deacon, 1997). This paper presents a modification of a standard approach from theoretical biology (the Moran process, Moran, 1958, explained below) for calculating how quickly biological specializations to culturally transmitted traits can evolve: the fixation time. This addresses two issues that thwart the analysis of language-biology coevolution. The first issue is that of the speed of biological and cultural evolution. Although it is often assumed that languages change much faster than biological evolution, (cultural) language change may be very slow in some cases (Pagel, Atkinson, & Meade, 2007, although see Greenhill, Atkinson, Meade and Gray 2010 for a different perspective on the speed of language change) while biological evolution can operate rapidly in small populations. The second issue is that evolution operates in finite populations, so randomness plays a role. This means that one cannot just look for fitness advantages, but must calculate the probabilities of the spread of a trait.

The Moran process is used to mathematically model evolution in finite populations. It describes the change in the number of mutants in an otherwise uniform population of fixed size. The state of a population can then be fully described by a single number. The Moran process only allows for an increase or decrease by one of the number of mutants. Thus evolution can be modeled as a simple Markov process, consisting of a single sequence of states, allowing the calculation of the probability that a mutant will spread and the time it will take to spread.

By allowing multiple (instead of one) sequences of states – each sequence modeling a different type of culture – and new transitions between states with different culture, this paper extends the Moran process to cases where biology coevolves with culture. This is applied to an example (modeled after Chater, Reali, & Christiansen, 2009) in which there are two cultural states (neither with an intrinsic fitness advantage) and two biological types of agents: generalists and specialists. Generalists learn both types of culture equally well, whereas specialists learn one type better than the generalists (giving a fitness advantage) and

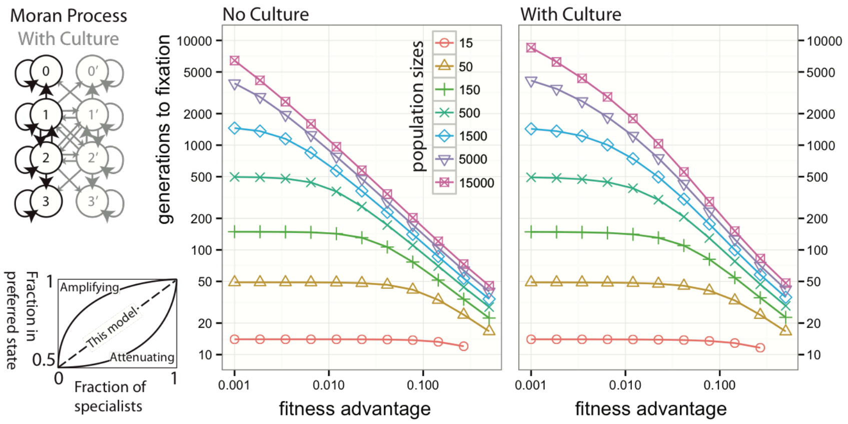

Figure 1: Top left Panel: Moran process with extra states and transitions needed for incorporating culture indicated in grey. Numbers indicate the number of mutants in a population state, arrows indicate possible transitions. Bottom left panel: graphs illustrating amplifying and attenuating culture. In amplifying culture, a small proportion of specialists causes the culture to spend a large fraction of time in the preferred state. Middle and right panels: fixation times in generations for systems without culture (middle) and systems with culture (right). The x-axis shows the effect of the fitness advantage associated with being a specialist in the preferred culture. Different line markers indicate different population sizes. Culture is neither amplifying nor attenuating. Note that fixation times in the presence of culture are somewhat longer, but not extremely so.

one type worse. At the same time, the number of specialists determines the fraction of time the culture spends in the state preferred by the specialists. This is illustrated in the lower left panel of figure 1. If the fraction of specialists is 0, one can expect the population to spend half of the time in each cultural state (when both states are truly equivalent). If the fraction of specialists increases, one expects the fraction the population spends in the preferred state to increase as well. The relation between the two fractions can have different forms, but here only the linear relation is explored.

Using a mathematical technique developed by Antal en Scheuring (2006) the time it takes for a mutation for specialization to a specific cultural variant to reach fixation was calculated. It turns out that for a range of fitness advantages and a range of population sizes, fixation times in the presence of culture are not much longer than when there is no culture. This indicates that it is possible for biological adaptations for arbitrary culture to evolve whenever the number of possible cultural states is low, and when the number of specialists for a certain type of culture determines the fraction of time a population spends in that type of culture. Also, it does not necessarily mean that such adaptations will be strong (i.e. individuals can only learn their preferred type of language) or easily observable, as work by Thompson, Smith & Kirby (2012) shows that whenever a weak bias evolves, the amplifying effect of culture causes any advantage of stronger biases to disappear. However, my results do show that we should not a priori give up hope of finding cognitive mechanisms that evolved for language.

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