EVIDENCE OF DESCENT WITH MODIFICATION AND SELECTION IN ITERATED LEARNING EXPERIMENTS

MÓNICA TAMARIZ
Language Evolution and Computation, PPLS, The University of Edinburgh, UK.
monica@ling.ed.ac.uk.

JOLEANA SHURLEY
Dept. of Linguistics, UC Santa Barbara, USA. jshurley_12@live.com.

Iterated learning experiments claim to model the evolution of languages. We report a study that tests to what extent the languages in these experiments actually follow evolutionary dynamics. Specifically, we look for the signature of (1) descent with modification, leading to diversity, and (2) selection, or adaptation to environmental factors, as languages change over generations.
We ran a modified design of the classic study by Kirby et al. 2008 (experiment 2). In that experiment, individuals organized in diffusion chains were trained on 50% of a language (excluding homonyms) and then had to produce labels for 100% of the meanings. The languages showed a gradual decrease in learning error and an increase in systematic structure over generations. The relevant novelty in our design was the tree-like structure of the chains (Fig. 1), designed to allow us to obtain a set of related languages with a known phylogeny. Like Kirby et al. (2008), we also used a 3x3x3 meaning space, but each of our meanings was a scene where a *subject* gives a *direct object* to an *indirect object*.

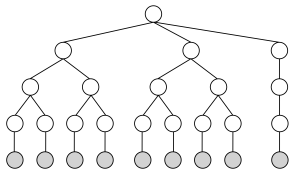

Figure 1. The tree-like design of our iterated learning experiment. Starting with a singe random language (top circle), we ran diffusion chains to obtain a family of languages. Each circle represents a language, and each line, a participant.

1. Phyogenetic analysis finds evidence of descent with modification

In order to check whether the changes in the languages are consistent with descent with modification, we constructed phylogenetic trees based on the pairwise edit-distances between languages. Phylogenetic tree building works on the assumption that change is the result of descent with modification, so if our constructed trees are similar to the veridical phylogenetic tree, the hypothesis that the languages have changed through these mechanisms is supported. We

reconstructed two trees: tree A, based on the distances between final-generation language only (the shaded circles in Fig. 1), and tree B, based on distances between all languages. Monte Carlo analyses found that the constructed trees were significantly more similar to the veridical tree than expected by chance (z-score$_A$=2.50; p_A<0.01; z-score$_B$=8.60; p_B<0.001), strongly indicating that change in our language family is, indeed, the outcome of descent with modification.

2. Mantel tests and spectral analysis find evidence of selection

We also found three quantitative signatures of selection in the languages. First, Mantel tests on the languages revealed a consistent, directional increase in systematic structure over generations, indicative of adaptation of the languages to being easy to learn and expressive (Kirby et al. 2008). Second, partial Mantel tests looking separately at the initial and final bigrams of the signals quantitatively confirmed the emergence of division of labour in some of the languages. In one case, for instance, word beginnings expressed the subject, and word endings, the indirect object. This hints at a process of adaptation of the structure of signals to the structure of meanings. Third, in order to explore further the selective pressures of meaning on signals we used Monte Carlo tests and spectral analysis (Tamariz 2011). This analysis tests whether the frequencies of elements of the signals evolve randomly over generations, following neutral evolutionary (or drift) dynamics, or come to resemble the frequencies of meanings, consistent with selection. The spectra of the ngrams that formed the signals of early languages were indistinguishable from spectra of randomly produced languages; however, the spectra of the languages produced at later generations showed significant drops in low frequencies and peaks of high frequencies that mirrored the (nonrandom) frequency structure of the meanings compared to randomly produced languages. These are significant departures from the predictions of the drift model, which are strongly indicative of the adaptation of the language structure under selective pressure originating in the structure of the meanings.

These analyses together show that iterated learning experiments are appropriate models of evolution by descent with modification and selection.

References

Kirby S, Cornish H & Smith K. 2008. Cumulative cultural evolution in the lab: An experimental approach to the origins of structure in human language. *PNAS*, 105 (31): 10681–10686.

Tamariz M. 2011. Linguistic structure evolves to match meaning structure. In Carlson L, Hölscher C, Shipley T (eds), *Proceedings of the 33rd Annual Conference of the Cognitive Science Society*. Austin, TX: Cognitive Science Society.