Grammar change through cultural transmission

Juan Guerrero Montero[*1], Richard A. Blythe[1], Simon Kirby[2], Dan Lassiter[2], and Robert Truswell[2]

[*]Corresponding Author: j.a.guerrero-montero@sms.ed.ac.uk
[1]School of Physics and Astronomy, University of Edinburgh, Edinburgh, United Kingdom
[2] School of Philosophy, Psychology, and Language Sciences, University of Edinburgh, Edinburgh, United Kingdom

The inter-generational transmission of language, which underpins language evolution, has long been modelled as a process of Iterated Bayesian Learning (IBL; Griffiths and Kalish, 2007). These models involve agents producing linguistic data in the form of utterances that agents in the next generation use to learn the language. This learning process involves combining this linguistic input with a prior distribution representing their inductive biases. The IBL paradigm has been proven equivalent to the Wright-Fisher (WF) model from population genetics (Reali & Griffiths, 2010), which in turn provides access to quantitative tools for analysing language change in corpus data (Newberry et al., 2017).

Nevertheless, IBL has qualities that do not reflect those of natural languages. First, its emerging stationary distribution over languages depends only on the inductive biases contained in the prior and not on the communication process, assuming that speakers sample from their posterior. Secondly, this stationary distribution respects detailed balance, implying that evolution processes are equally likely to happen in the forward and backwards directions. However, language change is directional, as evidenced by e.g. the irreversibility of grammaticalisation (Haspelmath, 1999). While certain extensions of IBL avoid these issues, e.g. by allowing learning from several agents (Smith, 2009) or changing the production strategy (Kirby, Dowman, & Griffiths, 2007), their mathematical complexity usually weakens the equivalence of the model to WF. This hinders application to corpus analysis, as the WF model is efficient, well-studied, and can be customised to include a wide variety of evolutionary effects.

Here, we introduce a model of grammar change where F linguistic functions represented by E expressions co-evolve following an IBL paradigm. In it, grammars are composed of probabilities g_{fe} representing speakers' expectation that expression e is used to express function f. While the model can include effects like production errors and biases, its key component is the inclusion of imperfect understanding, implemented as a probability that the learner infers function f' when f was meant. Figure 1, top, represents the model schematically.

We show that imperfect understanding breaks convergence to the prior and detailed balance, thus accounting for the directionality of language change as well as communicative effects on the statistical properties of language, while remaining equivalent to a set of F co-evolving WF processes (one per function). This feature allows us to quantify and discriminate between effects like drift, understanding and production errors, analogy and social selection, which are all parametrised differently in the WF paradigm. This enables a full analysis of grammar change in corpus data.

We apply the model to data on the diachronic use of relativisers in Middle and Modern English from the PPCHE corpus (Kroch, 2020) and the PCMEP corpus (Zimmermann, 2015), as seen in Figure 1, bottom. The connection to WF enables a model comparison capable of discriminating between the effects of multiple evolutionary forces. Results show that a model with error in understanding and in production provides a better fit than the null hypothesis of pure drift ($p < 0.001$) and models with selection ($\mathrm{BIC}_{\mathrm{sel}} - \mathrm{BIC}_{\mathrm{err}} \gg 10$).

In summary, we find that this model provides both a framework for grammar change through cultural transmission that reproduces features like the directionality of change and a robust quantitative method for testing causal hypotheses in historical change. Taken together, we gain insights into the components of cultural evolution that were responsible for real-world diachronic phenomena.

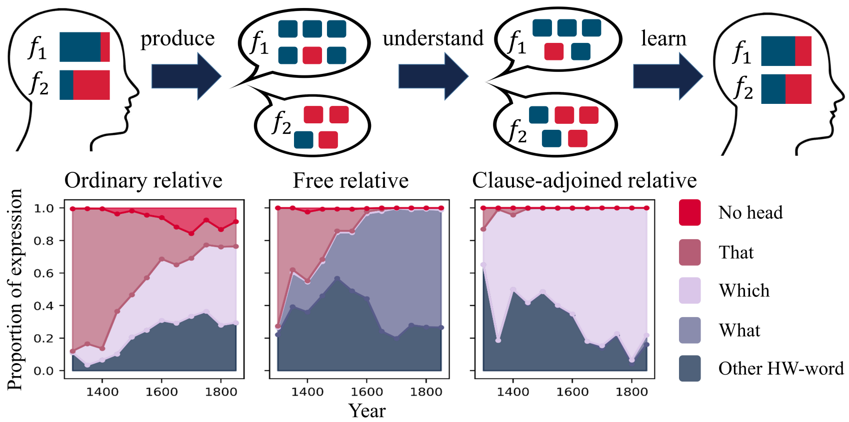

Figure 1. **Top:** Schematic representation of the model for a language with two functions ($F = 2$, f_1 and f_2) and two expressions ($E = 2$, red and blue). A speaker produces utterances for both functions using either expression with a probability dictated by their grammar. The learner then understands those utterances imperfectly, which may lead to some of them being assigned to the wrong function. They then use the utterances to infer the grammar. **Bottom:** Time series of the usage of five different phrases ($E = 5$) as heads of three types relative clauses ($F = 3$) in PPCHE and PCMEP between the years 1300 and 1850. Our model shows that mutation due to error in production (with a yearly rate of $\epsilon = 0.0009$) and in understanding (with a yearly rate of $\eta = 0.00015$) explain the behaviour of the data better than pure drift ($p < 0.001$) or selection ($\mathrm{BIC}_{\mathrm{sel}} - \mathrm{BIC}_{\mathrm{err}} \gg 10$).

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