Identifying Selective Pressures in Language Evolution: Polya Urns and the Price Equation

IDENTIFYING SELECTIVE PRESSURES IN LANGUAGE EVOLUTION: PÓLYA URNS AND THE PRICE EQUATION

MÓNICA TAMARIZ

Language Evolution and Computation, PPLS, The University of Edinburgh, 3 Charles Street, Edinburgh EH8, UK. monica@ling.ed.ac.uk.

Different models of language change and evolution place emphasis on different factors driving evolution. Croft (2000), for instance, highlights the effects of social prestige as a selective pressure behind language change. This paper outlines a new methodology to quantitatively assess whether a proposed factor exerts selective pressure on the evolution of linguistic variants, or whether evolution is neutral with respect to that factor. The method involves running simulations of the spread of linguistic variants (using Pólya urn dynamics, see below) and then applying the Price equation, a tool from evolutionary biology (Price, 1970) recently applied to models of language evolution (Jaeger, 2008), to the simulation outcomes. A Pólya urn contains a number of tokens of different variant types. At each time step a token is *drawn* at random and then it is returned to the urn and *n* tokens of the same type are *added* to the urn. Urns represent agents and the tokens are exemplars of cultural variants. Drawing a token stands for production of an exemplar and addition of new tokens represents storage of perceived exemplars. The variant population evolves as the relative proportions of the types change.

The price equation (Eqn. 1) quantifies the respective contribution of selection (the covariance term in Eqn. 1) and transmission error (the expectation term in Eqn. 1) to change in a quantifiable feature z of the tokens (Δz in Eqn. 1). In this paper we focus on selection: if we find that the covariance term is different from zero, we can infer that the feature constitutes a selective pressure. The proposed methodology is illustrated by examining whether the factor "variant prestige" exerts selective pressure on variant evolution in the Pólya urn simulations or not. In a simulation with variant prestige in place, when a high-prestige variant is selected, three tokens of that type are added to the urn (modeling production of a high-prestige variant having a high impact on hearers); conversely, when a low-prestige variant is drawn, only one token of that type is added to the urn. In the "no prestige" condition, one token is added regardless of which type is drawn.

$$(1)\quad \Delta\bar{z} = Cov\left(\frac{w_i}{\bar{w}}, z_i\right) + E\left(\frac{w_i}{\bar{w}}\Delta z_i\right)$$

The Price equation is applied at every timestep in the simulation by comparing the state of the urn at the current and the previous timestep. Fig. 1 shows the average covariance values with and without prestige. Positive covariance on the right-hand plot indicates that prestige level covaries with fitness, therefore prestige poses positive selective pressure on variant evolution.

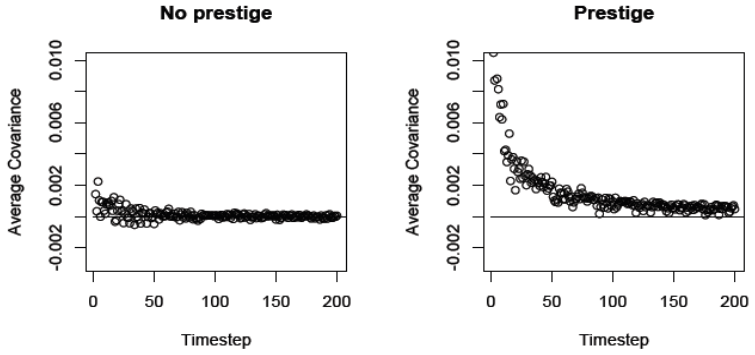

Figure 1. Covariance term of the Price equation calculated at each timestep of a Pólya urn simulation (values averaged for each timestep over 1000 simulation runs). Decreasing values over time reflect the fact that adding one or two tokens has diminishing impact on the increasing population of tokens that accumulates in the urn.

This is a simple illustration of a methodology that can be extended in multiple ways: by examining the second term of the Price equation, transmission error can be investigated; the Pólya urn simulation can be extended to include social network structure, learning algorithms, generation turnover, random or directed mutation, etc.; the feature of interest can be not only social prestige, but also novelty value, resilience to noise, ease of production etc.

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