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Modeling phonology in time

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1. Introduction

The aim of theoretical linguistics is to construct models that help us understand language in some meaningful sense. In this regard, linguistic theory is much like the other branches of social science in seeking to achieve explicit, falsifiable, predictive, and complete theories by implementing those theories in mathematical models of the systems we seek to understand.

Examples of linguistic models include the formal descriptions of generative linguistics (e.g. Chomsky, 1965), psycholinguistic simulations of language processing (e.g. Frazier & Fodor, 1978), and sociolinguistic models of factors relating to linguistic variation (e.g. Labov, 1972). The key decisions in linguistic modeling (and models in the social sciences more generally) concern **what** to model and **how** to model it. Where generative linguistics focussed on modeling linguistic *structure*, psycholinguistics seeks to model the aspects of human *cognition* that are involved in using language, and sociolinguistic models seek to account for choices among linguistic variables in *communities* of speakers. One key point here is that different choices of what to model are interrelated. The speaker's selection of one linguistic variable versus another is influenced by cognitive processing, and the set of all sociolinguistic choices ultimately determines linguistic structure. The question of how to model language is also answered in different ways by different theoreticians. Where generative linguistics uses methods from formal *logic* and finite mathematics, psycholinguists model behavior with *simulations* of cognitive processes, and sociolinguists use *regression* models to identify causally-linked factors in language change.

2. Sound change and explanatory phonology

This paper seeks to make a contribution toward an explanatory theory of phonological structure by modeling sound change. My approach assumes that phonological structure is shaped by the phonetic, cognitive, and social forces that impinge upon human speech communication. An explanatory theory of phonological structure is thus dependent upon a workable model of sound change (see Hume & Johnson, 2001). In passing, I would note that the structure of optimality theory (McCarthy & Prince, 1993) lends itself to an interpretation as a theory of sound change; with GEN as a source of phonetic variation and EVAL as a set of constraints on the inclusion of phonetic variants in a subsequent stage of the language.

The key to success in modeling sound change, is to incorporate as many explanatory factors as needed. From before there was a difference between phoneticians and phonologists, scholars have espoused the idea that phonetic factors influence phonology (see e.g. Baudouin de Courtenay,

1894). The main problem has been to say how this influence works, which to my way of thinking means that we have to model communities of speakers. This paper reports work that I have done with my colleague Andrew Garrett (Garrett & Johnson, 2011) following on the general schema that I developed with Beth Hume (Hume & Johnson, 2001). The innovation of the more recent research is that we developed computerized simulations of various types of sound change.

The Hume & Johnson (2001) proposal is schematically represented in figure 1. This schema includes the traditional view that phonetic factors influence phonology – our “low level effects” - and we also envisioned a role for cognitive category formation processes and social factors. The external factors that we saw shaping the phonetic/phonology interaction included much more than just “articulatory drift”. However, like other authors we didn't really have a model, but only a collection of data that made us think that something like the schema in figure 1 must be true.

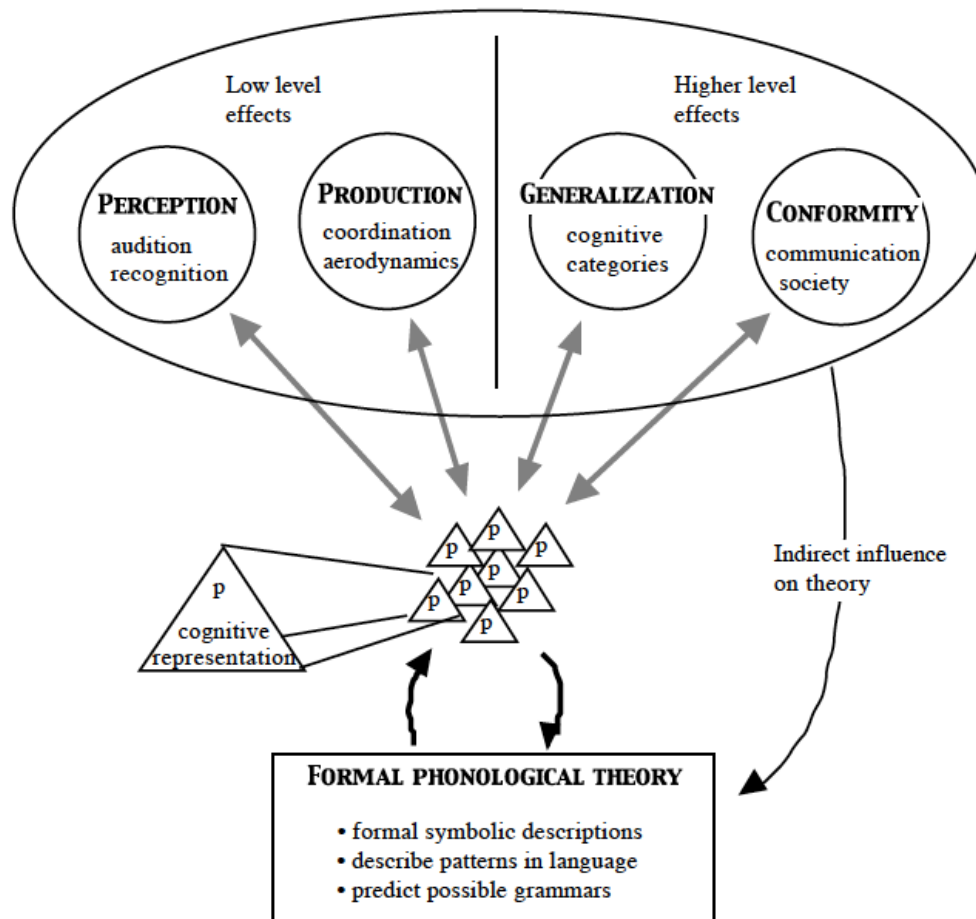


Figure 1. A model of the factors that shape phonology (Hume & Johnson, 2001).

A second innovation of our schema, is that we pulled formal phonological theory out of the picture. Of course, there is as a “formal phonological theory” box in figure 1, but our emphasis was that the generative theory is best seen as a symbolic description of the cognitive representation of

linguistic/phonological knowledge possessed by people, (symbolized by triangles in figure 1). What a linguist writes in his/her grammar only has a secondary influence on cognitive phonology, if at all – it is a report about the phonology but not a causal factor in determining it. Although there may be serious omissions or conceptual flaws in the Hume & Johnson (2001) “model”, one key problem is that it wasn't an implemented model, and thus the ideas involved in our schematic view of “external factors” could not be rigorously investigated. Garrett & Johnson (2011) addressed this deficiency, in a preliminary way, in our multi-agent simulations of sound change.

3. Simulating sound change with multi-agent simulation

Multi-agent simulation is a strategy for modeling the aggregate behavior of a community of independent actors that simulates the individuals as autonomous computational “objects” whose behavior is governed by simple decision rules chosen by the modeler. This style of model simulation has been used to study social phenomena like traffic patterns, epidemics, and fashion. The simulations of sound change that are reported here trace the development of phonological units in a population of speakers as a function of social interaction, receptivity to change, and phonetic bias. The models are extremely simple, aiming to highlight the importance of a social factor in the actuation of sound change. Simulating the behavior of a collection of autonomous agents, has been used by previous researchers studying language change (Klein 1966, Pierrehumbert 2001, Culicover and Nowak 2003, Galantucci 2005, Wedel 2006). Common to these and other models of phonological systems is the assumption that speakers are generally faithful in their reproductions of the phonetic forms of language, and most also assume phonetic bias factors influence the development of phonological categories. The simulations presented here add social identity to this type of model.

Phonetic Bias factors

Phonetic bias factors are sources of variance in linguistic performance. Garrett & Johnson (2011) identified four general categories of phonetic bias factors, and discussed a number of sound changes that can be attributed to these biases. The phonetic biases we identified are from (1) motor planning, (2) gestural mechanics, (3) speech aerodynamics, and (4) speech perception. Ordinarily, in the course of speaking and hearing, the phonetic distortions introduced by these factors (whether in speech production or perception) do not result in sound change. This is because listeners usually disregard the phonetic variants introduced by bias factors. However, we suggested that in an exemplar memory system of representation, bias variants are not filtered out, and consequently they are available for reanalysis in sound change. We further suggested that social factors interact with bias variation in ways that lead to sound change. Our theory linking bias factors to sound change was based on the assumption that linguistic categories are represented by clouds of exemplars, and

that speech production is based on such constellations of remembered instances. Exemplar-based phonological categories make it possible for speakers to represent social phonetic variation which can then be imitated for social effect (Babel, 2009).

Simulations

The simulations shown in figures 2 and 3, which are presented in more detail in Garrett & Johnson (2011), test the idea that individuals may differ in how they assign social meaning to phonetic variation. On this view, some individuals in a language community, may attend to linguistic variation while others do not. If the attentive individuals become aware of a particular phonetic variant in their social group, they may interpret the variant as a group identity marker, and then use it more often. One social/psychological parameter that may give rise to such a pattern of behavior is *empowerment*; Galinsky et al. (2006:1071) suggest that empowerment may ‘inhibit the ability to pay attention to and comprehend others’ emotional states.’ To this we add a converse linguistic principle: lack of power sharpens one’s attention to linguistic variation (Dimov 2010).

Figure 2 shows the results of a simulated sound change in response to a gradient phonetic bias factor such as the shift from voiced fricative to approximant (motivated by an aerodynamic bias factor). The starting phonetic and social identity distributions are shown in the histograms. The results of a bivariate random selection from these distributions is shown in the top right panel. Social group differences are indicated on the vertical axis, which measures an arbitrary ‘social identity’ parameter. Phonetic output is shown on the horizontal axis, where a value of zero indicates a voiced fricative production, and a value of four indicates a voiced approximant production. The bottom panels show the gradual phonetic drift, from iteration 0 to iteration 50 of the simulation, as approximated variants are adopted by one social group, and not by the other. The main social factor in this simulation is that members of one social group attend to and incorporate the phonetic variation in their future speech plans, so for them the bias factor seeds a sound change, while members of the other social group do not allow the approximated variants to influence their production targets. The main point of the simulation is that the phonetic bias factor is present for both groups of speakers, and provides the raw material for a sound change (and in this sense determines the directionality of the change), however, actuation – the fact that a change occurs for some speakers – is due entirely to social factors. In particular, we hypothesize that social empowerment modulates attention to phonetic variation so that speakers introduce new material (and hypothetically also new phonological patterns) into the language.

Figure 3 shows the results of a simulation that differs from this only in that the phonetic bias factor (a motor planning error) leads to discontinuous phonetic variation. The change in this case is more structure preserving, though the model of change is exactly the same as in the previous simulation.

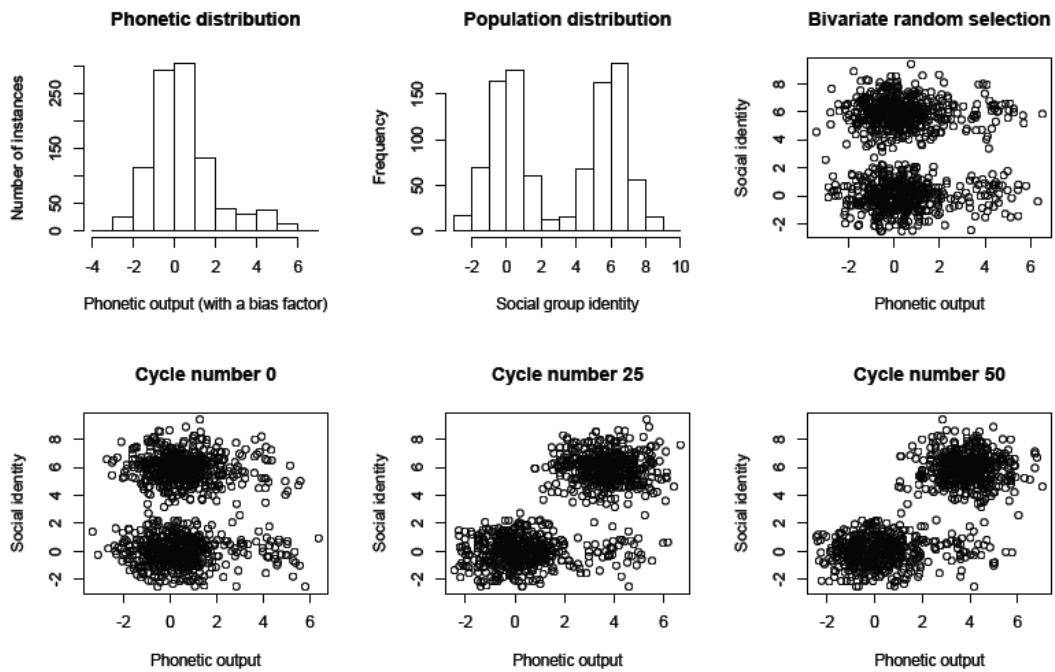


Figure 2. Simulation of a sound change from gradient phonetic bias, like the aerodynamic bias that tends to make voiced fricatives into voiced approximants (Garrett & Johnson, 2011).

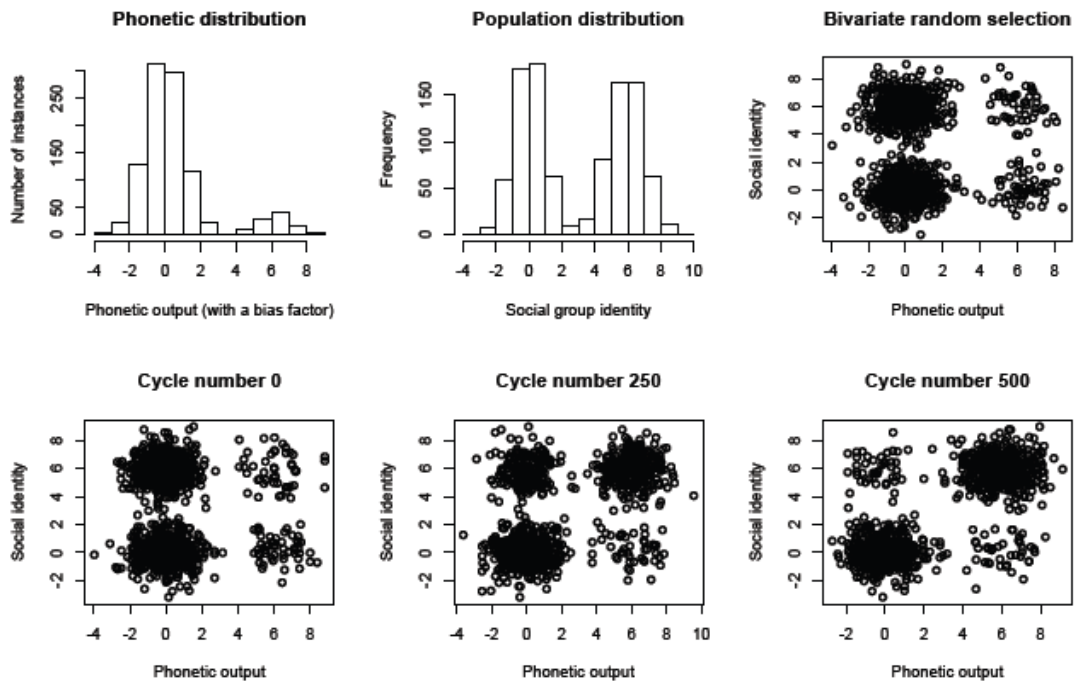


Figure 3. Simulation of a sound change from discontinuous phonetic bias, like the speech planning error that results in consonant harmony (Garrett & Johnson, 2011).

4. An expanded vision of theoretical linguistics

As I mentioned in the introduction, model-building in linguistics has encompassed a range of modeling strategies and linguistic phenomena. I am arguing in this paper for an approach that uses multi-agent simulation to study a key topic of linguistic theory – namely the development of synchronic phonological structure through historical sound change. Of the problems that have faced linguistic theory, perhaps the most pressing has been the problem of devising an evaluation metric (Chomsky & Halle, 1968). That is, of all the possible structural descriptions of grammar, how does the theorist choose an analysis? In practice, this is something of an aesthetic choice governed by the linguistic fashion of the day. To advance linguistic theory we must devise methods of combining the results of our research (on social interactions, cognitive processing, language acquisition, and so on) into a comprehensive model of language. I believe that multi-agent simulation is a promising way to get to that more comprehensive model.

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