Modelling an ongoing sound change in the East Franconian dialect by means of an agent-based model (ABM)

The vowel-to-stop ratio, also called voicing ratio (V / (V + C)), is an important perceptual cue to the distinction between voiced and voiceless postvocalic obstruents in Standard German (Kohler 1979). That is, the postvocalic stop in the word *leiten* (to lead) has a longer closure duration and a slightly shorter vowel duration than the voiced stop in *leiden* (to suffer), which results in a lower voicing ratio for /t/ than for /d/. Speakers of the East Franconian dialect, however, are known to phonologically neutralise this contrast in favour of the voiced stop (see upper left panel of Figure 1; Harrington et al. 2012). Furthermore, several synchronic studies have found that there is a sound change in progress whereby the differentiation between voiced and voiceless stops in the Franconian dialect is gradually becoming greater, both acoustically and perceptually (Müller et al. 2011, Harrington et al. 2012).

The aim of the study at hand is to simulate this sound change using an agent-based model. Such models can be one innovative way of building towards a holistic model of sound change that unifies the essential questions of which conditions can give rise to a sound change in the first place (e.g. Ohala 1981, 2012, Lindblom 1990, Beddor 2009) and how it is then spread among the members of a speech community (e.g. Labov 1963, Trudgill 2008). In our ABM, speakers are represented by agents who store natural speech data in their memories and can communicate with each other. More specifically, the ABM was developed on the empirical basis provided by studies on Exemplar Theory (Pierrehumbert 2001, 2003), perceptual learning (e.g. Norris et al. 2003), and phonetic imitation (e.g. Babel 2012, Pardo 2006). Firstly, lexical and phonological categories are statistical generalisations over the associated phonetic signals, i.e. fine phonetic details are stored in the agents' memories (Goldinger 1996). Secondly, when an agent repeatedly perceives phonetic signals at the margins of a phonological category, this category will slowly shift towards these marginalised tokens, which in turn will influence the agent's speech production. And thirdly, agents can 'forget', i.e. remove, tokens that have been stored a long time ago (time decay, Pierrehumbert 2001).

In the set of simulations presented here, the agents were instantiated with data from either older Franconian (OF) or Standard German (SG) speakers from the study by Müller et al. (2011). It is hypothesised that, if the sound change is progressing in the proposed direction, OF agents will slowly develop a contrast between voiced and voiceless stops as a consequence of interactions with SG agents. It is also predicted that the OF agents will reach and eventually surpass a state where their distributions of /d/ and /t/ are very similar to those of the younger Franconian speakers. Figure 1 shows that after 4000 interactions, the OF agents have converged with the SG agents, meaning that they have indeed de-neutralised the formerly lost contrast between /d/ and /t/. It can also be seen that the categories of both groups have suffered from a reduction around the mean, which is caused by the sampling of new tokens from a Gaussian distribution during the production process of the interactions. Figure 2 confirms that the voicing ratio in /d/ and /t/ for SG agents remains fairly stable over the course of the interactions, while the OF agents change the voicing ratios in these stops quite drastically and end up at similar values as the SG agents. Our analysis furthermore showed that after only 600 interactions, the OF agents reach a state very close to that of younger Franconian speakers. We discuss the results with respect to the interactive-phonetic model of sound change (Harrington et al. 2018).

References

Babel, M. (2012): Evidence for Phonetic and Social Selectivity in Spontaneous Phonetic Imitation. *Journal of Phonetics* 40, 177–189.

Beddor, P. S. (2009): A Coarticulatory Path to Sound Change. *Language* 85: 4, 785–821.

Goldinger, S. D. (1996): Words and Voices: Episodic Traces in Spoken Word Identification and Recognition Memory. *Journal of Experimental Psychology* 22, 1166–1183.

Harrington, J./F. Kleber/U. Reubold (2012): The Production and Perception of Coarticulation in Two Types of Sound Changes in Progress. In: S. Fuchs/M. Weirich/D. Pape/P. Perrier (eds.): *Speech Planning and Dynamics*. Frankfurt am Main: Peter Lang, 33–55.

Harrington, J./F. Kleber/U. Reubold/F. Schiel/M. Stevens (2018): Linking Cognitive and Social Aspects of Sound Change Using Agent-Based Modeling. *Topics in Cognitive Science*, 1-22.

Kohler, K. J. (1979): Dimensions in the Perception of Fortis and Lenis Plosives. *Phonetica* 36, 332-343.

Labov, W. (1963): The Social Motivation of a Sound Change. *Word* 19, 273–309.

Lindblom, B. (1990): Explaining Phonetic Variation: A Sketch of the H&H Theory. In: W. J. Hardcastle/A. Marchal (eds.): *Speech Production and Speech Modelling*. Dordrecht: Springer Netherlands.

Müller, V./J. Harrington/F. Kleber/U. Reubold (2011): Age-Dependent Differences in the Neutralization of the Intervocalic Voicing Contrast: Evidence from an Apparent-Time Study on East Franconian. In: *Proceedings of the 12th Interspeech*. Florence, 633–636.

Norris, D./J. M. McQueen/A. Cutler (2003): Perceptual Learning in Speech. *Cognitive Psychology* 47, 204–238.

Ohala, J. J. (1981): The Listener as a Source of Sound Change. In: C. S. Masek/R. A. Hendrick/M. F. Miller (eds.): *Papers from the Parasession on Language and Behavior*. Chicago: Chicago Linguistic Society, 178–203.

Ohala, J. J. (2012): The Listener as a Source of Sound Change: An Update. In: M.-J. Solé/D. Recasens (eds.): *The Initiation of Sound Change: Perception, Production, and Social Factors*. Amsterdam: John Benjamins, 21–36.

Pardo, J. S. (2006): On Phonetic Convergence during Conversational Interaction. *The Journal of the Acoustical Society of America* 119, 2382–2393.

Pierrehumbert, J. B. (2001): Exemplar Dynamics: Word Frequency, Lenition and Contrast. In: J. Bybee/P. J. Hopper (eds.): *Frequency Effects and the Emergence of Linguistic Structure*. Amsterdam: John Benjamins, 137–155.

Pierrehumbert, J. B. (2003): Phonetic Diversity, Statistical Learning, and Acquisition of Phonology. *Language and Speech* 46: 2-3, 115–154.

Trudgill, P. (2008): Colonial Dialect Contact in the History of European Languages: On the Irrelevance of Identity to New-Dialect Formation. *Language in Society* 37, 241–280.

Figures

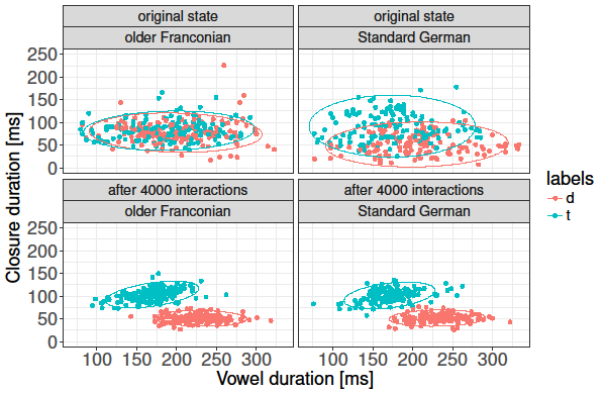

Figure 1: Result of interactions between older Franconian and Standard German speakers: Closure duration plotted against vowel duration for postvocalic /d/ and /t/ in their original state and after 4000 interactions.

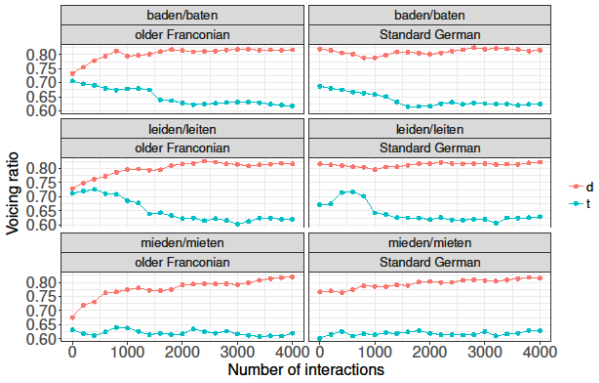

Figure 2: Voicing ratio in /d/ and /t/ as a function of number of interactions for the older Franconian and Standard German agents, separated by word pairs.