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RESEARCH

The initiation and incrementation of sound change: Community-oriented momentum-sensitive learning

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This article presents a theory of the initiation and incrementation mechanisms whereby individual phonetic innovations become community-wide sound changes. The theory asserts that language learners are community-oriented and momentum-sensitive: they are community-oriented in that they acquire and obey a mental representation of the collective linguistic norm of their speech community, rejecting individual idiosyncrasies; they are momentum-sensitive in that their mental representation of the community norm includes an age vector encoding linguistic differences between age groups. The theory is shown to fulfil four critical desiderata: (i) it accounts for the sporadic and localized occurrence of community-wide sound change, (ii) it incorporates Ohala's prediction of a lawful relationship between the strength of the phonetic biases driving individual innovation and the typological frequency of the corresponding sound changes, (iii) it explains how community-wide sound change advances by intergenerational incrementation producing adolescent peaks in apparent time, and (iv) it reliably generates monotonic—including sigmoid—diachronic trajectories. Moreover, the hypotheses of community orientation and sensitivity to momentum, combined with the mechanical effects of density of contact, suffice to explain several macroscopic phenomena in the propagation of sound change, including class stratification, the curvilinear pattern in change from below, and the existence of change reversals. During propagation, linguistic variants do acquire indexical value, and so social meaning, but this produces only small-scale attitudinal effects; it is not the force that drives the intergenerational incrementation of sound change.

Keywords: sound change; actuation; intergenerational incrementation; adolescent peak; community orientation; momentum

1 Introduction

The individual innovations that eventually become population-wide sound changes are widely held to be caused by phonetic biases (Garrett & Johnson 2013; Sóskuthy 2013) through mechanisms partly elucidated by theories such as those of Ohala (1981; 1989). These phonetic biases, insofar as they stem from physical law and from universal properties of human physiology and cognition, apply everywhere permanently. Why, then, do sound changes occur only in particular places at particular times? This is *the problem of sporadic localized change*.

Linguists have long been aware of this puzzle. Labov (2001: 22), for example, quotes passages to this effect from Saussure (1916: Third Part, Chapter II, §4.IV) and Bloomfield (1933: 386). The latter states the difficulty pithily: "No permanent factor […] can account for specific changes which occur at one time and place and not at another." Bloomfield's words directly anticipate Weinreich et al.'s (1968: 102) formulation of *the actuation problem*: "Why do changes in a structural feature take place in a particular language at a given time, but not in other languages with the same feature, or in the same language at other times?” It is under this heading of actuation that much recent work (e.g. Baker et al. 2011; Sóskuthy 2013; 2015) discusses the sporadic and localized incidence of change. In a strong reading, however, Weinreich et al.’s question ultimately evokes a demand to produce deductive-nomological explanations of particular instances of sound change (Lass 1980; after Hempel & Oppenheim 1948)—something which is, by their own admission, impossible (cf. Weinreich et al. 1968: 99). The challenge, then, is to clarify not only why sound change in general is sporadic and localized, but also why specific instances are strictly unpredictable.

In this article I pursue these issues by developing the long-standing hypothesis that population-wide change is initiated, incremented, and propagated by different mechanisms from those that trigger individual phonetic innovations in the first place: in particular, the processes of initiation and incrementation depend crucially on the social embedding of innovative variants. Labov (2001: 22–23), following Weinreich et al. (1968: 176), traces this idea back to Meillet (1906), and similar proposals are articulated in Milroy & Milroy’s (1985) research into social networks, in Croft’s (2000) evolutionary approach to language change, and in Janda & Joseph’s (2003) “big bang” theory (see also Sóskuthy 2013: §2.5). In the evolutionary terminology favoured by Croft, the basic insight is that individual *mutations* are caused by functional phonetic factors, whilst population-wide change is driven by *social selection*.

The social selection mechanism proposed in this article as driving the initiation and incrementation of population-wide sound change is *community-oriented momentum-sensitive learning*. Following Labov (2014a; b) I assume, first, that the language learner is *community-oriented* in that she internalizes and follows a mental representation of the collective linguistic norm of her speech community, rejecting individual idiosyncrasies. Following Labov (2001; 2010), Mitchener (2011), and Stadler et al. (2016) I further assume that the language learner is crucially *momentum-sensitive* in that her mental representation of the community norm incorporates an *age vector* encoding differences in variable use between age groups. In this view, individual innovations (or “mutations” in evolutionary terminology) occur continually at a basic rate determined by the strength of the relevant phonetic biases and their interactions; however, community-oriented learners perceive the vast majority of such innovations as randomly scattered idiosyncratic deviations from the community norm, which are therefore rejected. Population-wide change is initiated only when, by accident, learners experience an inverse correlation between the frequency of a mutation and speaker age: if this accidental skew is sufficiently strong, learners acquire an age vector and incrementation begins (Mitchener 2011: 395; Stadler et al. 2016: 188). Enforcing the age vector, each new cohort of learners now increases its use of the innovative variant until, by late adolescence, it exceeds the level reached by the previous generation, at which point a relative decline in linguistic plasticity supervenes. This mechanism of momentum-driven intergenerational incrementation reliably produces *well-behaved* (Kauhanen 2017: §4) monotonic trajectories of change in real time, exhibiting the familiar *adolescent peak* at each point in apparent time (Labov 2001: Chapter 14; Tagliamonte & D’Arcy 2009).

Community-oriented momentum-sensitive learning belongs in a long line of theories that seek to explain general macroscopic facts of language change by reference to infra- and supra-individual factors, ignoring differences among individual speakers beyond those defined by broad demographic categories such as age, gender, and class. In this respect, it may be usefully contrasted with two recent proposals which, in different ways, ascribe a crucial role to *individual differences*.

First, Baker et al. (2011) suggest that sound change occurs only sporadically because, in general, listeners are extremely good at compensating for coarticulatory effects. The probability of compensation failure may however increase in certain circumstances. Using data from /s/-retraction near /ɹ/ in present-day English, Baker et al. highlight a scenario in which acoustically covert individual differences in articulation are accompanied by overt coarticulatory effects. In this article, however, I show that this proposal is insufficiently general, in that it fails to account for the sporadic and localized character of *all* types of linguistic change. In addition, more recent studies (notably Bailey et al. 2019) challenge the hypothesis that covert differences in /ɹ/-articulation are involved in the actuation of English /s/-retraction. I conclude that covert articulatory variation does not solve the problem of sporadic localized change, although the possibility remains that it may facilitate some types of innovation.

Secondly, Eckert (2019), developing ideas that can be traced back to Labov (1963), proposes a different account of how the social embedding of innovations leads to the incrementation and propagation of sound change. In this view, variants acquire indexical value through differential use by social groups (Silverstein 2003; Eckert 2008), and as a result are endowed with *social meaning* (Eckert 2012); once an innovation has become socially meaningful, it can be deployed by individual speakers to signal their attitudes and stances; this stylistic activity in turn causes the use of the variant to increase and spread. Thus, individuals may not control the social meaning assigned to a linguistic variant, but, according to Eckert, it is their stylistic agency that drives incrementation and propagation.

A number of observations, however, point towards intergenerational momentum, rather than social meaning, as the true incrementation mechanism in ongoing sound change. First, the granularity of social evaluation is poorly matched to that of incrementation, in that social meaning is often found to attach to linguistic units that are markedly more concrete or more abstract than those actually undergoing change: here I shall discuss the cases of the Northern Cities Shift in the USA (Labov 2002: 281–283) and of Velar Nasal Plus in Northern England (Bailey 2019a). Secondly, Eckert's theory highlights the oppositional character of social meaning and portrays speakers as engaged in "lifelong projects of self-construction and differentiation" (2012: 98). It consequently predicts that intra- and inter-speaker variance will increase as a change takes off, and will decrease as it decelerates towards completion; but this prediction is not borne out by the available evidence (Fruehwald 2017b).

These arguments suggest that, although attitudinal factors exert an undeniable effect upon sociolinguistic variation, they operate on a different scale, and are causally independent, from momentum-driven intergenerational incrementation. More generally, I will show that community-oriented momentum-sensitive learning, coupled with the purely mechanical effects of *density of communication* (Bloomfield 1933: 46ff; Labov 2001: 19–20; Trudgill 2008; 2014), suffices to account for major macroscopic patterns of propagation such as *class stratification* (Labov 2006: 397), the *curvilinear pattern* (Labov 1972: 294–295; 2001: 31–33, 171–172), and even some instances of *change reversal*.

The argument proceeds as follows. Section 2 sets out the problem of sporadic localized change. I first show that Ohalian theories of individual innovation do not specify mechanisms for the initiation, incrementation, and propagation of community-wide sound change. Simple *accumulation of error* makes wildly incorrect predictions (Baker et al. 2011: 361–364; Sóskuthy 2013: Chapter 2; Kirby & Sonderegger 2015: 2), which are mitigated, but not adequately solved, by *competing-motivations models* (Croft 2000: 81–82). I conclude that, whilst individual innovations are caused by phonetic biases, the initiation and incrementation of population-wide change crucially involves the social embedding of variants. This idea is then fleshed out in Section 3: after surveying the findings of apparent-time studies of ongoing sound change, I introduce the hypotheses of community orientation and momentum-sensitive learning, and show how these correctly predict that sound change is *self-actuating* (Mitchener 2011: 395; Stadler et al. 2016: 188), that it is sporadic and localized, and that it advances monotonically through intergenerational incrementation producing an adolescent peak in apparent time. Section 4 discusses Baker et al.'s (2011) proposals on acoustically covert articulatory variation. Section 5 lays out the argument against social meaning as the engine of intergenerational incrementation and propagation: after some preliminary considerations, Section 5.2 discusses granularity and variance; Section 5.3, class stratification; Section 5.4, the curvilinear pattern; and Section 5.5, change reversals. Using an analogy from physics, Section 6 concludes by drawing out a methodological lesson concerning the indispensable role of abstraction in the study of sound change, whilst acknowledging that research into individual differences may yet illuminate a broad range of important questions.

2 The problem of sporadic localized change

Most accounts of community-wide sound change trace its origins to individual phonetic innovations, which are analogous to genetic mutations in models of biological evolution. These individual innovations are generally understood to be caused by articulatory, acoustic, and auditory factors, often collectively designated as *phonetic biases* (Garrett & Johnson 2013; Sóskuthy 2013). A well-known instance is the aerodynamic voicing constraint, whereby the transglottal airflow required for vocal fold vibration ceases unless air pressure below the glottis exceeds supraglottal pressure by a minimum amount (Westbury & Keating 1986): this phonetic bias is responsible for a broad range of innovations that lead to historical changes affecting voiced obstruents (Ohala 1983; 2018). Similarly, aerodynamic factors lie at the origin of widely attested changes involving the affrication of velar plosives before high vowels (e.g. /ki/ > /tʃi/): coarticulation with the vowel causes the stop to be released into a narrowed channel, resulting in higher air velocity and increased noise (Ohala 1989: 185–186; 1992: 319–321).

According to Ohala's (1981; 1989) influential proposals, phonetic biases give rise to individual innovations through mechanisms of *perceptual hypo- and hyper-correction*. In this view, speech perception requires the listener to compensate for phonetic biases. This task is equivalent to correcting for noise in the information-theoretic sense. From time to time, correction errors occur, and those errors that are retained in the listener's own productions (Beddor et al. 2018; Strickler 2019) constitute individual innovations. In an attractive implementation of Ohala's programme, correction failure induces *cue reweighting*: the listener-learner internalizes a mapping from phonological categories to probability distributions over continuous phonetic parameters that differs from the mappings of the speakers in her community (Hamann 2009; Bang et al. 2018; Coetzee et al. 2018; see also Bermúdez-Otero & Trousdale 2012: 694).

This approach to individual innovation makes it possible to provide satisfying quantitative explanations for numerous typological facts. For example, Ohala (1989: 182–185) observes that, in the languages of the world, dorsal plosives become coronal before /i/ or /j/ more often than they become labial before /u/ or /w/. This observation makes good sense in the light of laboratory data, which show that the probability of [ki] being misperceived as [ti] is higher than the probability of [ku] being misperceived as [pu]: see Figure 1.

Ohala's theory, however, is explicitly intended to account only for individual innovation; it does not specify the initiation and incrementation mechanisms whereby individual mutations become population-wide changes (Ohala 1981: 184; see also Croft 1995: note 28). Crucially, an adequate account of these mechanisms must explain the prevalence of what I shall call *sporadic localized bifurcation*. To understand the significance of this explanatory challenge, it is helpful to start from the observation that, at any point in time, most of the properties of a language are either invariant or subject to stable variation (Stadler et al. 2016: 172). Occasionally, however, the use of an innovative variant starts to undergo incrementation. Typically, this results in a monotonic (often sigmoid or S-shaped) trajectory of change that persists over several generations. This trajectory manifests itself in apparent time as an inverse correlation between speaker age and the use of the innovative variant (see e.g. Figure 2).

Thus, the initiation and incrementation of community-wide language change occurs only sporadically. In the normal run of events, moreover, it is also spatially circumscribed: i.e. it is confined to a subregion of the geographical space in which the relevant linguistic variety (dialect or language) is spoken. Through this means, localized bifurcation gives rise to the characteristic pattern of evolutionary branching encoded in phylogenetic treess (Figure 3).

Of course, to say that sporadic localized bifurcation is normal in the course of language change by no means entails that all types of change are equiprobable or that their frequency is arbitrary; on the contrary, we have just seen that the crosslinguistic prevalence of a type of change exhibits a lawful dependence on the probability of the misperception

More probable misperception	[ki] heard as [ti]	p = 0.47
Less probable misperception	[ku] heard as [pu]	p = 0.24

⬇

More frequent change	/ki/ > /tʃi/	e.g.	West Germanic		Old English	
			*/kiːðɑn/	>	/tʃiːdɑn/	‘chide’
Less frequent change	/ku/ > /pfu/	e.g.	Proto-Bantu		West Teke	
			*/kumu/	>	/pfumu/	‘chief’

Figure 1: Phonetic bias strength predicts the relative frequency of change types (Ohala 1989; misperception probabilities from a confusion matrix in Winitz et al. 1972).

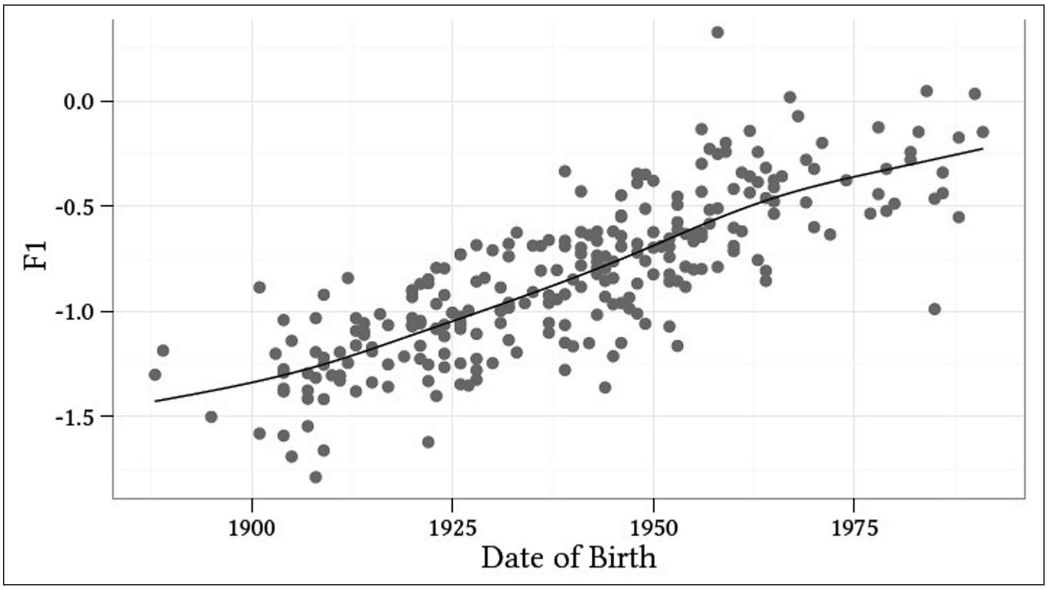

Figure 2: Intergenerational incrementation of Philadelphia /aɪ/-raising (Fruehwald 2013: 34): data from the Philadelphia Neighborhood Corpus (Labov & Rosenfelder 2013); dots represent individual speakers’ mean F1 for the nucleus of /aɪ/ in raising environments.

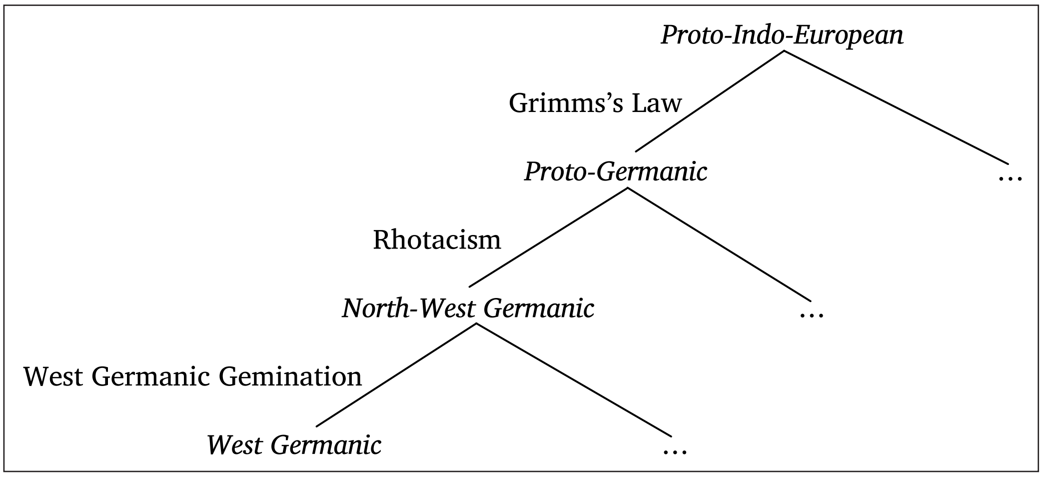

Figure 3: Evolutionary branching by localized bifurcation in Germanic (after Lass 1994).

events that cause the relevant individual mutations (Figure 1). It means, rather, that we do not know of any circumstances in which population-wide change is inevitable; instead, changes are observed to occur at a given time in a particular place, and yet not at times and in places where the known relevant circumstances seem the same. This assertion is consistent with the existence of instances of *convergent evolution* in which genetically related language varieties undergo similar changes independently at different times in geographically separate areas (Sapir 1921: Chapter 7; Lass 1997: 120–121): in the recent history of English, for example, processes of change involving /aɪ/-raising (Moreton 2016: 17) and /s/-retraction in /stɹ/ clusters (Baker et al. 2011: 348) have been initiated independently in several dialects. Yet this phenomenon merely shows that those dialects must share certain properties which raise the probability of the relevant innovations; it falls far short of entailing that the community-level changes are inevitable. This interpretation receives empirical support from the obverse of convergent evolution: the existence of *hold-out areas*, which resist a change that has otherwise permeated a whole language or family. Using English again as an example, the North West of England constitutes a hold-out area by retaining coda [ɡ] after [ŋ] (so-called Velar Nasal Plus: Bailey 2018), and Glain (2014: 23) suggests that the North East may be a hold-out area in respect of /s/-retraction. In fact, hold-out areas exist for all types of linguistic change: in syntax, for example, Persian holds out as a prepositional OV language, resisting the switch to VO that has affected other Indo-European branches such as Baltic, Germanic, and Romance (Hawkins 1990: 121; based on Friedrich 1975).

At this point, the challenge posed by sporadic localized bifurcation comes into focus. We have seen that community-wide changes originate in individual innovations caused by phonetic biases. Yet those phonetic biases are driven by physical law and by universal properties of human physiology and cognition. In consequence, the biases are in force everywhere at all times. If so, how can permanent universal biases produce sporadic localized change? As we saw in Section 1, clear statements of this problem are already found in the work of Saussure (1916: Third Part, Chapter II, §4.IV) and Bloomfield (1933: 386), among others. More recently, the insight has been expressed through the assertion that incrementation and propagation cannot take place by simple *accumulation of error*: see e.g. Baker et al. (2011: 361–4), Sóskuthy (2013: Chapter 2), and Kirby & Sonderegger (2015: 2).

In the terminology of dynamical systems theory, allowing error to accumulate has the effect that even very gentle biases create attractors in linguistic phase space: for example, a slight bias against a property will sooner or later drive all languages into regions of phase space in which that property is absent. Admittedly, more complex dynamics give rise to attractors that are not fixed points: notably, Boersma (1998: Chapter 17) shows how interacting biases can keep languages moving eternally in closed cycles. Developing this line of reasoning, many linguists (e.g. Sóskuthy 2015) have sought the explanation for the sporadic incidence of sound change in *competing-motivations models* (Croft 2000: 81–82): in such models, one bias may be held in check by another, and the complex interactions of multiple biases give rise to the variety of linguistic systems that we actually observe. However, although such competing-motivations models do play an indispensable role in the explanation of typological facts, they fall short of accounting for sporadic localized bifurcation. In particular, any explicit competing-motivations model encounters a problem whenever variation in respect of the biasing factors included in the model is uniform across a geographical space and yet change occurs within a limited subregion of that space. Appeals to undetectable variation or to biases yet to be identified are always possible, of course, but, when repeated, they reduce the overall programme to unfalsifiability. Alternatively, the model may assume a measure of stochasticity and allow one subregion to surge ahead, while the other is predicted to follow suit with a high probability. As we have seen, this sort of convergent evolution does occur, but evolutionary divergence, as illustrated in Figure 3, is even more common.

I conclude that the problem of sporadic localized change calls for a more powerful solution than can be provided by competing-motivations models. The alternative is to decouple the processes that give rise to individual innovations from those that drive the initiation and incrementation of population-wide change. In this view, new variants come into being through correction failures caused by phonetic biases, but causal factors of a different sort are responsible for controlling the level of use of the new variants within a speech community, so that error does not accumulate, and incrementation takes place only in a sporadic and localized fashion.

What factors, then, drive the initiation and incrementation of community-wide sound change? As adumbrated in Section 1, an old idea, going back at least to Meillet (1906), holds that such factors are crucially related to the social embedding of new variants: in Croft's (1995: 524) crisp formulation, "Innovation will occur as the result of functional factors […] Propagation of innovations is determined by social factors." The following section fleshes this hypothesis out through the proposal of community-oriented momentum-sensitive learning.

3 The initiation and incrementation of community-wide sound change

3.1 Incrementation close up: the adolescent peak

Section 2 showed that an adequate model of the initiation and incrementation of community-wide sound change must predict sporadic localized bifurcation (Figure 3), while at the same time preserving the lawful relationship between the strength of the phonetic biases that cause individual innovations and the typological frequency of the corresponding changes (Figure 1). In addition, the model must explain how, once initiated, community-wide sound change advances by intergenerational incrementation (Figure 2), with each successive cohort of speakers using the innovative variant more than the preceding cohort (Labov 1994: 83–84, 112; 2001: Chapter 14). Finally, the model must account for the fact that incrementation is typically monotonic (although, as we will see in Section 5.5, change reversals can and do occur). As part of this, it is generally agreed that the model should be able to produce sigmoid curves, although a number of studies have observed largely linear trajectories of sound change (e.g. Labov et al. 2013).

Thanks to work in Labovian sociolinguistics, the empirical facts of incrementation are known in considerable detail. In general, preadolescent children are conservative: they use the innovative variant less than contemporary teenagers and younger adults. During adolescence, however, speakers rapidly increase their use of the innovative variant, so that, around the age of 17, they reach a level exceeding that of all contemporary age-groups: this is known as the *adolescent peak* (Labov 2001: Chapter 14; Tagliamonte & D'Arcy 2009). After adolescence, the speaker's mean use of the variable remains largely stable.

In consequence, apparent-time studies of ongoing sound change typically find the pattern illustrated in Figure 4, which plots the degree of /oʊ/-fronting by age-group in Charleston, South Carolina, at the end of the 20th century (Baranowski 2007). Among adults, /oʊ/-fronting is inversely correlated with age: each age-group exhibits the amount of fronting that they reached by late adolescence, which was higher than that of the immediately preceding cohort. Preadolescent children are conservative, producing realizations of /oʊ/ within the adult range. In contrast, adolescents have the highest level of fronting, giving rise to the expected peak.

Several quantitative correlations confirm that the adolescent peak is intimately bound with the mechanism of intergenerational incrementation (Labov 2001: Chapter 14; Tagliamonte & D'Arcy 2009). First, the prominence of the adolescent peak at a given point in real time *t* is directly proportional to the speed (instantaneous velocity) of the change at *t*. In changes following a logistic trajectory, therefore, the adolescent peak is sharpest at the mid point, when incrementation is fastest. Near floor or ceiling, in contrast, velocity is lower, and so apparent-time curves look flatter. Similarly, if change *a* advances faster than change *b*, then *a* will show a more prominent adolescent peak.[1]

The fact that speakers cease to increment their use of innovative variants around age 17 can plausibly be imputed to a general decline in linguistic plasticity. In this respect, it is highly suggestive that the age at which the adolescent peak is reached coincides with the critical period for second language acquisition identified by Hartshorne et al. (2018). We know, however, that this decline in linguistic plasticity is not absolute and affects some

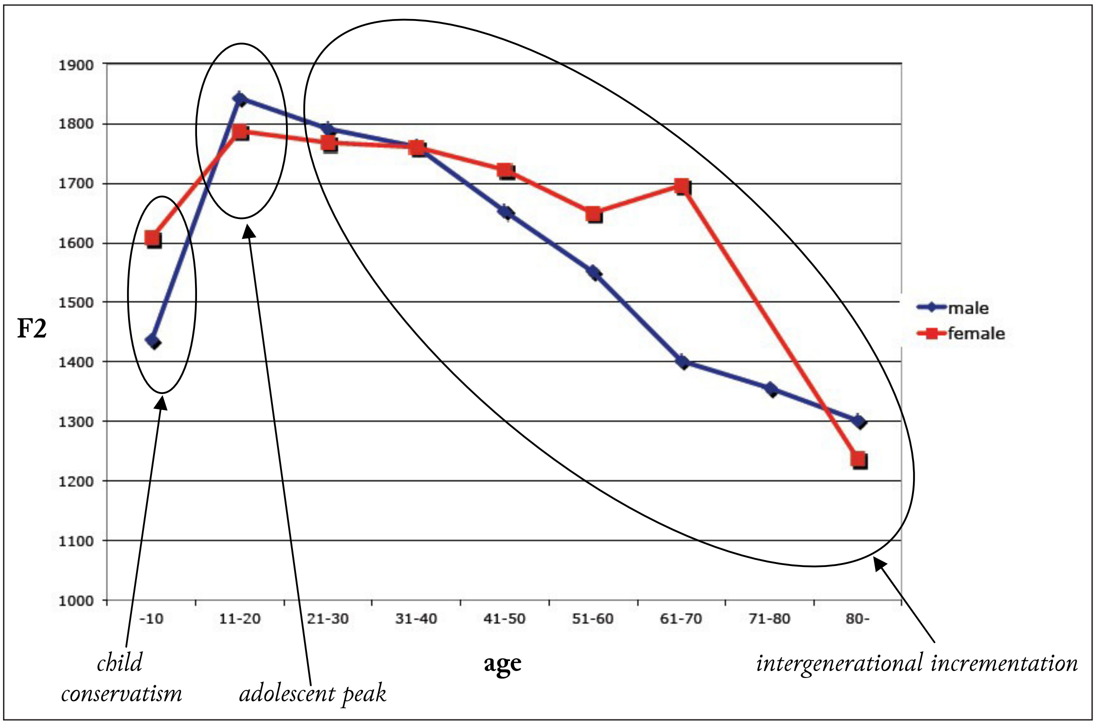

Figure 4: /oʊ/-fronting in Charleston (courtesy of Maciej Baranowski; data from 100 speakers).

[1] The interaction of the adolescent peak with gender is a complex issue. Current evidence suggests that adolescent peaks are present in both genders, whether the change is led by females or by males (Holmes-Elliott 2016).

parts of the grammar less severely than others: in particular, adults appear to perform gradient phonetic adjustments (Harrington 2006) more easily than they learn new categories (Nahkola & Saanilahti 2004) or large-scale patterns such as chain-shifts (Labov 2007). By the same token, the account of intergenerational incrementation presented above is not invalidated by the observation that some individuals exhibit life-span changes, i.e. shifts in variable use after adolescence (e.g. Sankoff & Blondeau 2007; Wagner & Sankoff 2011; Sankoff 2019). The empirical record confirms that, despite the existence of life-span change, generational change is the main mechanism of incrementation: in a study of five variables using data from the Philadelphia Neighborhood Corpus (Labov & Rosenfelder 2013), for example, Fruehwald (2017a) found relatively weak evidence for effects of life-span change, while generational effects proved extremely robust.

3.2 Incrementation under community-oriented momentum-sensitive learning

I now proceed to show how the desiderata listed in the first paragraph of Section 3.1 are met by a model of initiation and incrementation based on the hypothesis that learners are *community-oriented* (i.e. they reject individual idiosyncrasies) and *momentum-sensitive* (i.e. they respond to differences in the use of linguistic variables across age-groups).

This model implements the key insight of Janda & Joseph's (2003) "big bang" theory: the mechanism that brings new variants into being is not the same as the mechanism that initiates and sustains the incrementation of their use within the community. In particular, I assume that new sound patterns are created by *phonologization* through Ohalian correction failure; later developments in the life cycle of those patterns (*stabilization*, *domain narrowing*, and *morphologization* or *lexicalization* in Figure 5) involve input restructuring

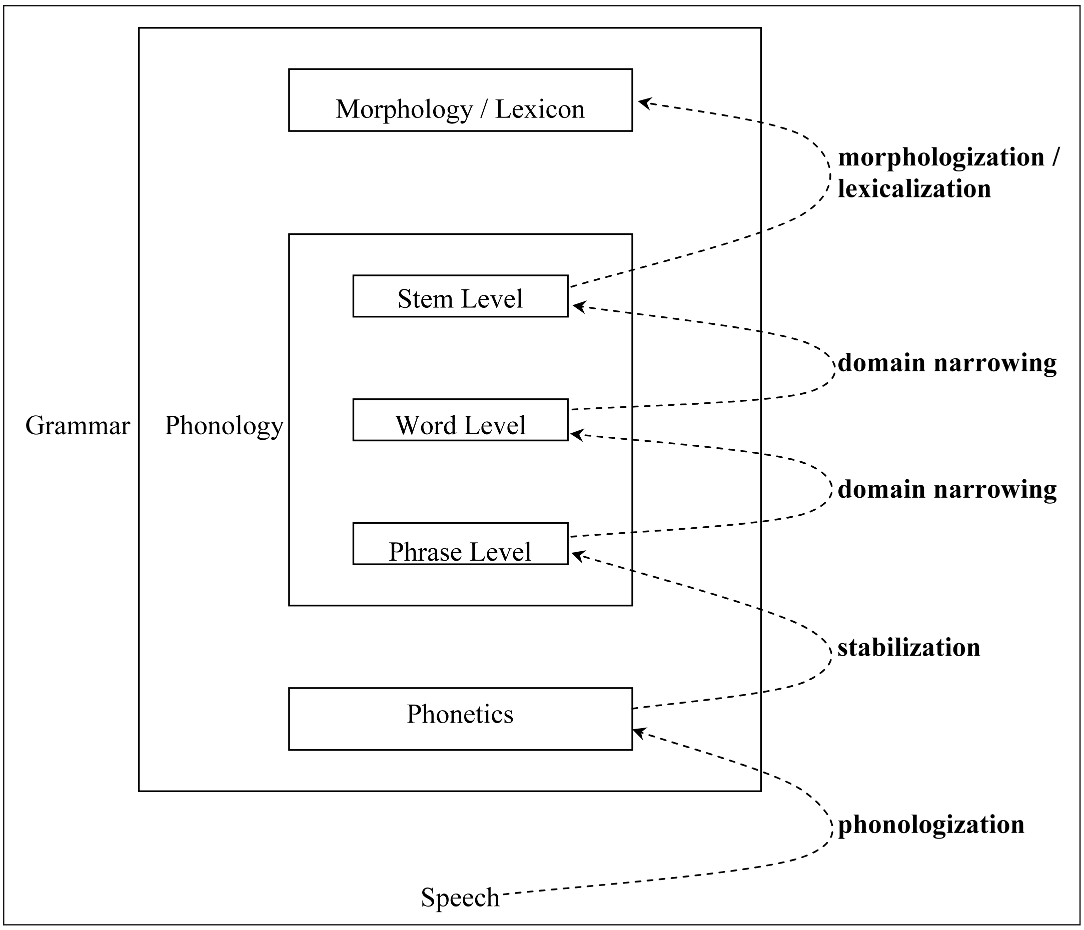

Figure 5: The life cycle of phonological processes (Bermúdez-Otero & Trousdale 2012: 700).

(Bermúdez-Otero 2015: 382–388). However, whilst correction failure and input restructuring create new variants, they are not responsible for incrementing their level of use; as we shall see presently, that task is performed by momentum-sensitive learning. This division of labour explains why error fails to accumulate under the effect of the permanent biases that cause innovation.

I follow Labov (2014a; b) in assuming that language acquisition is community-oriented. This means that, on the basis of her experience of linguistic behaviour in the speech community, the learner internalizes and then follows a mental representation of the collective linguistic norm. Adhering to this internal representation of the community norm leads the learner to reject variants that she perceives as individually idiosyncratic. The most dramatic example of this suppression of individual deviation is found in children's rejection of features of parental speech that fail to match the local dialect. Labov adduces many instances of this phenomenon: for example, children in new towns like King of Prussia just outside Philadelphia (Payne 1976) and Milton Keynes in England (Williams & Kerswill 1999) abandon their parents' diverse dialects and converge upon the local norm; similarly, Labov (2006) found no significant differences in variable use between second-generation and third-generation New Yorkers on the Lower East Side, even though the former had non-native parents. Interestingly, there is good evidence that convergence upon the community norm starts very early and that it operates subpersonally and automatically. Nardy et al. (2014), for example, documented the homogenization of variable use in a group of French-speaking kindergarteners: they found that the similarity in usage between any two children was directly proportional to the frequency with which those children interacted, showing no effect of attitudinal parameters such as reported interpersonal attraction or awareness of prescriptive standards.

Community-oriented learning is consistent with the fact that preadolescent children are conservative in their use of variables (Figure 4). This simply reflects the fact that, early in life, their linguistic experience is limited and dominated by the speech of their immediate caregivers, who are mostly adults. In later childhood and adolescence, however, learners gain much wider exposure to the speech community: in the urban areas of developed countries, in particular, this is often facilitated by attendance at large schools. This wider socialization into the community enables learners to build more detailed mental representations of the community norm.

A related assumption of the model is that the learner's knowledge of the community norm comes to include an *age vector*: in other words, children and adolescents acquire a mental representation of the differences in variable use between age-groups in their community (Labov 2001: Chapter 14; 2010: 195–195, 344, 369). Until approximately 17 years of age, moreover, the learner crucially retains sufficient linguistic plasticity for the age vector to be enforced in her own speech. This means that the learner undergoes incrementation of her use of innovative variants to the level that is appropriate according to her mentally represented age vector.

To understand how this happens, consider a speech community subject to an ongoing sound change that increases the use of a variant *v*. Let us now follow the developmental trajectory of a young learner *L* as she is socialized into this speech community. While *L* is small, she remains conservative, using *v* at a relatively low rate like her adult caregivers. As she grows up, however, *L* is socialized into the wider community, partly through schooling. She is now exposed to the differences in variable use between late adolescents, young adults, and older adults. In consequence, an age vector encoding these intergenerational differences is added to *L*'s mental representation of the community norm: crucially, this age vector reflects the fact that younger speakers use *v* more than older speakers. At this point, *L*'s learning faculty detects a disparity between *L*'s own usage and the collective norm: *L*'s use of *v* matches adult rates but falls below adolescent levels, thus failing to comply with the inverse correlation between speaker age and use of *v* that holds across the community. Therefore, since the learning faculty is community-oriented, it increments *L*'s use of *v* in the direction of the older cohort of adolescents. When the members of that older cohort reach adulthood, however, their linguistic plasticity declines, and so their use of *v* levels out. Meanwhile, *L* herself remains plastic, and the incrementation in her use of *v* continues during her own adolescence. The process is sustained by the orientation of the learning faculty towards the community norm: the older cohort are now adults, and the norm encoded in the age vector is for adolescents to use *v* more than adults. The result is that, by age 17, *L* and the other members of her age cohort have reached a peak of *v* use beyond the level of the immediately preceding generation—only then to undergo a decline in their own linguistic plasticity.[2]

Figure 6 provides a schematic representation of the age vector in action. Successive cohorts are represented by numbered circles; their dates of birth are shown in the left-hand side column. The apparent-time diagrams in the middle and on the right-hand side provide snapshots of the community at two points in real time separated by a ten-year interval. In the year 2000, the members of cohort 5 are ten years old: they internalize an age vector *m* (for *momentum*), encoding the community pattern whereby late adolescents (cohort 4) use the relevant variant more than adults (cohorts 3 and 2). By 2010, the members of cohort 5 are twenty years old: the use of the variant by cohort 4 has not changed in adulthood, while cohort 5 have undergone incrementation during adolescence, so that their distance from older adults (cohorts 4 and 3) complies with *m*.

It should be clear that, if this account of the adolescent peak is correct, the incrementation of sound change in progress does not involve agency on the learner's part (cf. Section 5). Acquiring a mental representation of the community norm, incrementing the use of innovative variants in line with the age vectors contained in that mental representation, and ceasing incrementation as linguistic plasticity declines is not something that learners do; it is something that happens to them. Since these cognitive processes are not the actions of agents, they do not have motivations or reasons; they only have causes (Schlosser 2019). In much the same way, when human beings with normal vision perform binocular

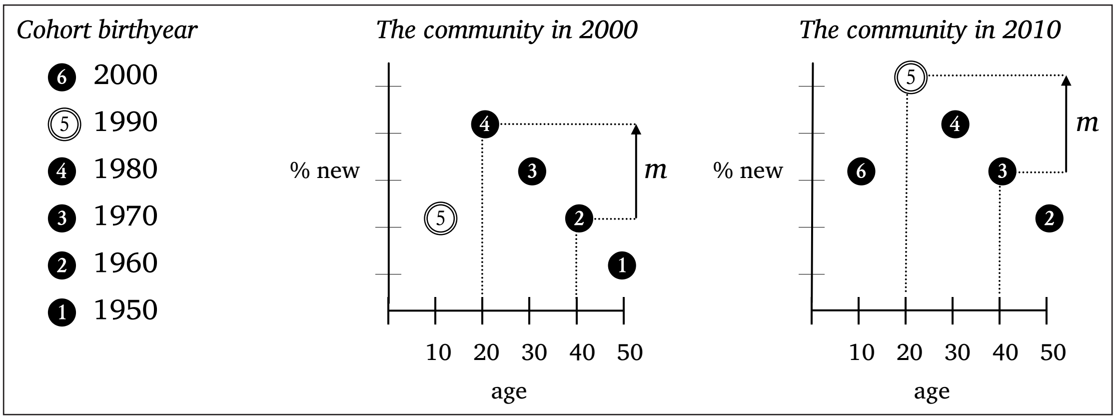

Figure 6: Cohort 5 enforces the age vector during adolescence, causing incrementation.

[2] A decline in linguistic plasticity during adulthood is also crucial for Baxter & Croft (2016), but their account of the adolescent peak is otherwise very different. Baxter and Croft assume that incrementation is driven by the "differential social valuation of variants by speakers" (2016: 133). The precise nature of this valuation is not specified, but various forms of social meaning would fit the bill: see Blythe & Croft (2012: 272–273); cf. Section 5 below. In this sense, Baxter and Croft interpret the adolescent peak as an *effect* of the incrementation mechanism, whereas, in an account driven by the age vector, the adolescent peak is the *cause* of incrementation.

stereopsis, we do not inquire into their reasons or motives, for binocular stereopsis is not an action: it is a subpersonal automatic cognitive process. As in the case of binocular stereopsis, however, we may legitimately wonder why momentum-sensitive learning is part of human nature. This question admits of both narrow and wide answers. Taking a narrow viewpoint, one would simply say that momentum-sensitive learning is just one aspect of the learner's community orientation: as we have seen, language learning involves discovering and following the community norm, and differences in variable use across age groups are just part of that norm. Taking a wider view of the problem, however, one may ask why learners are community-oriented in the first place. I shall not tackle this larger question here, but will merely suggest that answers are probably to be sought in the evolutionary history of sociality in primates in general and *Homo sapiens* in particular.

More generally, this account of the incrementation of sound change belongs in the general class of momentum-based selection models. The term *momentum* is due to Gureckis & Goldstone (2009), who use a model of this type to explain the historical evolution of parental choices for children's first names (see also Lieberson 2000; discussed in Labov 2010: 194–195). Mitchener (2011) and Stadler et al. (2016) conduct mathematical and computational explorations of momentum-based selection in language change: Mitchener's model is driven by apparent-time momentum, like the account proposed here, whereas Stadler et al.'s model relies on real-time input, but both produce qualitatively similar dynamics. Stadler (2016) provides further discussion, assessing the evidence for speakers' knowledge of the momentum of sociolinguistic variables. One of Stadler et al.'s (2016) most important results is that momentum-sensitive learning produces monotonic incrementation and S-shaped curves reliably. The emergence of sigmoid trajectories is due to the fact that a variable's momentum, reflected in the size of the age vector acquired by the learner, does not remain the same as the change advances in real time: in consequence, incrementation need not be linear. Indeed, Stadler et al. (2016) demonstrate that momentum-sensitive learning gives rise to S-shaped changes under a very broad range of conditions: their model includes a parameter b which modulates the effects of the variable's momentum on the learner's acquired level of use; when $b \geq 1$, sigmoid trajectories occur systematically.

3.3 Initiation under community-oriented momentum-sensitive learning

The most appealing property of community-oriented momentum-sensitive learning is that it predicts the existence of sporadic localized bifurcation.

Recall that the factors that drive mutation are permanently active (Section 2). In consequence, individual innovations occur continually at a basic rate determined by the strength of the relevant biases and their interactions. Community-oriented learners, however, reject individual idiosyncrasies. For this reason, the vast majority of innovations fail to undergo incrementation and propagate: a learner will reject a mutation, even when carried by more than one individual in her social circle, as long as she experiences it as a randomly scattered deviation from the community norm.

From time to time, however, it so happens that, quite by accident, a learner encounters an innovative variant more often in the speech of younger than older speakers: in other words, an accidental skew causes the learner to experience an inverse correlation between the frequency of the mutation and speaker age. If this accidental skew is sufficiently clear and strong, the learner acquires an age vector and incrementation begins. As Mitchener (2011: 395) puts it, "the mechanism of these spontaneous changes is that[,] every so often, children pick up on an accidental correlation between age and speech." Similarly, Stadler et al. (2016: 188) describe change in a momentum-based model as "self-actuating". This explains sporadic localized bifurcation: isolated and randomly distributed innovations are actively repressed; innovations that accidentally cluster in a pattern inversely correlated with age are not only adopted, but also actively incremented by the learner.

Crucially, if a mutation occurs at a relatively high rate, its distribution in the speech community has a greater chance of accidentally exhibiting an age skew that is clear and strong enough to trigger the acquisition of an age vector. In consequence, the probability with which innovative variants are selected for incrementation is directly proportional to the basic rate of mutation. Stadler (2016: Chapter 6) establishes this result with the tools of dynamical systems science: he expresses the key insight by saying that momentum-sensitive learning is a "symmetric" (i.e. *neutral*) selection mechanism operating upon the output of an "asymmetric" (i.e. *biased*) source of mutations (the same idea appears in Croft 1995: 524). This property enables community-oriented momentum-sensitive learning to preserve Ohala's explanation of the relative crosslinguistic frequencies of different types of sound change (Figure 1). Similarly, the theory has no difficulty incorporating the insights of competing-motivations models of phonological typology (Section 2).

Let us now take stock. We have fulfilled all the desiderata stated in Section 3.1: community-oriented momentum-sensitive learning

(i) accounts for the sporadic and localized occurrence of population-wide sound change,
(ii) preserves the lawful relationship between the strength of phonetic biases and the typological frequency of sound changes predicted by Ohala's theory of individual innovation,
(iii) explains how sound changes advance by intergenerational incrementation producing adolescent peaks in apparent time, and
(iv) reliably generates monotonic—including sigmoid—trajectories of change.

We may further observe that the theory of sound change outlined in Sections 2 and 3 operates at a relatively high level of abstraction. The account of individual innovation adopted in Section 2 relies on phonetic biases arising from physical law and from universal properties of human physiology and cognition; individual differences in language processing styles play no role (cf. Yu 2013). Similarly, the model of the initiation and incrementation of community-wide sound change proposed in Section 3 ignores all differences between speakers beyond those associated with broad demographic categories like age; personal identity and individual agency are not involved (cf. Eckert 2012). We may therefore wonder whether we might make further explanatory gains by adopting a less abstract approach, incorporating individual differences into the theory. In the following sections I argue against such a move. Section 4 shows that the solution to the problem of sporadic localized change is not to be sought in individual patterns of articulation, *pace* Baker et al. (2011). Section 5 provides evidence that, even if individual speakers use socially meaningful variables to signal their identities and construct personae, it is not their stylistic agency that drives the intergenerational incrementation of sound change, *pace* Eckert (2019). The broad methodological point is stated in Section 6 by means of an analogy from physics: the explanatory success of macroscopic models of sound change can be gauged in part by the extent to which they incorporate only those microscopic facts that are truly relevant and causally efficient.

4 Covert articulatory variation

Baker et al. (2011) propose an account of English /s/-retraction driven by acoustically covert individual differences in articulation, and they suggest that this account instantiates a general solution to the problem of sporadic sound change. Here, */s/-retraction* denotes an [ʃ]-like realization of /s/ in the vicinity of a following /ɹ/. Word-initial /stɹ/-clusters provide the most favourable environment: e.g. [ʃ]*treet*. The change has been independently observed in many varieties of present-day English: see Baker et al. (2011: 348) for references.

Drawing upon observations by Mielke et al. (2010), Baker et al. (2011) claim that the influence of /ɹ/ upon a preceding /s/ depends in part on the speaker's /ɹ/-production strategy. English exhibits wide individual differences in /ɹ/-articulation; these differences are covert in that it is virtually impossible to detect them acoustically (Delattre & Freeman 1968). In general, the phoneme has two discrete allophones: one bunched, the other retroflex. These two allophones appear in a wide variety of distributional patterns, often highly complex and speaker-specific (Mielke et al. 2016). In addition, there is continuous articulatory variation within each allophonic category: in particular, a speaker's lingual configuration for bunched [ɹ] may be more or less similar to her tongue shape for /s/ (Mielke et al. 2010). Crucially, Mielke et al. (2010) report that, among speakers exhibiting merely gradient /s/-retraction, /s/ sounds more [ʃ]-like in /stɹ/-clusters if the speaker's tongue shape for bunched [ɹ] is relatively similar to her /s/-posture.

Given this, Baker et al. (2011) propose an actuation mechanism for the change from gradient to categorical /s/-retraction, which corresponds to the *stabilization* phase in the life cycle of the pattern: see Figure 5 and Bermúdez-Otero (2007: 504–506; 2015: 383, 386–388). The hypothesis is that the potential for stabilization arises in relatively rare encounters between two types of interlocutor: a speaker exhibiting a high degree of gradient /s/-retraction by virtue of having relatively similar /s/- and /ɹ/-postures, and a listener displaying a low degree of gradient /s/-retraction in consequence of having relatively different /s/- and /ɹ/-articulations. In such circumstances, Baker et al. suggest, the listener will perceive the speaker's pronunciation of /s/ in /stɹ/-clusters as retracted, but will not have access to the coarticulatory cause of this retraction: in the listener's own speech, /ɹ/ exerts less coarticulatory influence upon /s/, and the acoustic signal provides no clue to the fact that the speaker articulates /ɹ/ with a different tongue shape. As a result, the listener may end up misparsing gradiently retracted tokens of /s/ as categorically retracted, i.e. as realizing [ʃ] in the surface phonological representation.

As Baker et al. emphasize, their proposal predicts that, in general, stabilization will occur infrequently. Listeners are ordinarily very good at compensating for coarticulatory effects (Mann 1980; Mann & Repp 1980). Baker et al.'s account of English /s/-retraction names conditions under which the probability of compensation failure may be expected to increase, but these conditions are met only rarely. On this basis, Baker et al. suggest that covert individual differences in articulation may hold the key to the sporadic incidence of sound change.

Several considerations indicate, however, that Baker et al.'s proposal is insufficiently general. First, sporadic incidence is a hallmark of *all* types of language change, including changes in syntax. Even if we limit our discussion to phonetic and phonological change, sporadic localized bifurcation characterizes all stages in the life cycle of sound patterns, not just stabilization (Figure 5). For example, Turton (2014) and Ramsammy (2015) describe several cases of dialectal variation involving a categorical phonological process whose morphosyntactic domain has undergone narrowing in one location but not another.

There are, moreover, many documented instances of the stabilization of a coarticulatory pattern whose known triggers are all acoustically overt. For example, Turton (2014; 2017) demonstrates that /l/-darkening is categorical in some English dialects and merely gradient in others. Her analysis thus demonstrates that the stabilization of English /l/-darkening involves localized bifurcation: for example, stabilization has taken place in British Received Pronunciation, but not in Manchester working-class speech. Yet, to date, the continuous phonetic factors known to exert a gradient effect upon /l/-darkness are all acoustically overt: the main ones are surrounding vowel quality and rhyme duration (Sproat & Fujimura 1993). It thus appears that English /l/-darkening offers a case of localized stabilization unmediated by covert articulatory variation.

Finally, Baker et al.'s proposal has little to say about the localized character of sound change. By their very nature, covert individual differences in articulation are not expected to exhibit an orderly distribution in geographical space. In consequence, changes whose actuation allegedly depends on such differences have no greater probability of occurring in one place than in another. Smith et al. (2019: 8) concede this point by assuming that, even for innovations putatively caused by covert articulatory differences, the transition from individual mutation to community-wide sound change requires an initiation mechanism like the one outlined above in Section 3.3: "If the different acoustic coarticulatory patterns that result from covert articulatory differences *cluster in a younger age group in a particular place at a particular time, to a greater degree than the preceding generation*, it could spark a sound change [emphasis mine]." In this scenario, the real work of explaining sporadic localized bifurcation is done by the entirely general mechanism of community-oriented momentum-sensitive learning; stabilization caused by covert articulatory differences has been downgraded to the status of a specific type of individual innovation. Nothing is left of Baker et al.'s claims of relevance to the problem of sporadic localized change.

The possibility remains that covert articulatory variation may indeed be involved in some types of individual innovation, as argued by Baker et al. and Smith et al. English /s/-retraction, however, appears not to be an instance of this type of innovation. Bailey et al. (2019) show that, in Manchester English, /s/-retraction affects /stɹ/- and /stj/-clusters simultaneously and is undergoing intergenerational incrementation at the same rate. This finding is consistent with the hypothesis that the change from [s] and [ʃ] does not depend on the fine detail of /ɹ/-articulation, but is rather mediated by the affrication of the following /t/, which is triggered by both /ɹ/ and /j/.

5 Social meaning

5.1 General considerations

I have asserted that the intergenerational incrementation of sound change in progress is caused by a subpersonal automatic cognitive mechanism of momentum-sensitive learning which does not involve speaker agency (Section 3.2). Eckert (2019) proposes a different hypothesis, according to which incrementation is driven by speakers' stylistic activity. In her theory, variants acquire indexical value through differential use by social groups (Silverstein 2003; Eckert 2008), and as a result are endowed with *social meaning* (Eckert 2012); once an innovation possesses social meaning, it can be deployed by individual speakers to signal their stances and to construct personae; this stylistic activity in turn causes the use of the variant to increase and spread. Individuals do not control the social meaning assigned to a linguistic variant, but their stylistic agency drives incrementation and propagation. This section argues against these claims. I provide evidence indicating that intergenerational incrementation cannot be propelled by the social evaluation of variants. I further show that community-oriented momentum-sensitive learning, coupled with the purely mechanical effects of *density of communication* (Bloomfield 1933: 46ff; Labov 2001: 19–20; Trudgill 2008; 2014), suffices to account for major macroscopic patterns of propagation such as *class stratification* (Labov 2006: 397), the *curvilinear pattern* (Labov 1972: 294–295; 2001: 31–33, 171–172), and even some instances of *change reversal*.

This debate does not concern the undeniable fact that individual speakers' personal attitudes may affect their use of linguistic variants: see Eckert & Labov (2017: 5–14) for a review of the evidence from production. Similarly, the fact that some linguistic variables acquire social meaning is not in dispute: social meaning can be directly observed in perceptual studies, notably by means of the matched guise technique (Lambert et al. 1960; see e.g. Campbell-Kibler 2006). I take these to be established empirical facts. The question, rather, is how far their consequences reach. In particular, to what extent should we incorporate social meaning into models seeking to explain general macroscopic facts about the initiation, incrementation, and propagation of sound change?

In tackling this question, the first problem we encounter is methodological. Assuming that we can somehow control for automatic accommodation, we can estimate the relative effect of style on production by comparing an individual's usage across different social settings (e.g. Eckert & Labov 2017: 5–10). It is far more difficult, however, to determine the extent to which an individual's (or a social group's) overall mean level of use of a variant depends on the social meaning of the latter. This is in part because an individual's position in the community's spectrum of variation will reflect the combined effects of both attitudes and exposure, but the two are hard to disentangle, as people with different attitudes socialize in different ways, and vice versa (Pierrehumbert 2016: §3.3): a high-schooler's stance in respect of higher education, for example, will affect her stylistic practice (Roberts 2016: 56–57), but also the composition of her social network. In consequence, it should not come as a surprise that, in statistical analyses of variation at the community level, attitudinal variables can exhibit a strong linear relationship with demographic variables like class (Baranowski 2017: 328–329). This collinearity is further explored in Section 5.3 below, which also discusses the case of sociolinguistically exceptional individuals (Eckert & Labov 2017: 12–14).

The second problem is both methodological and substantive. It arises over the fact that, as noted above, social meaning can be detected directly in perception (e.g. by means of matched guise experiments) and indirectly in production (e.g. by analyses of style-shifting). It turns out, however, that these two procedures do not necessarily converge on the same result. Notably, Haddican et al. (2013) relied on production data to infer the indexical values associated with the fronting and diphthongization of /uː/ and /oː/ in York, but Lawrence (2017) found a poor match between these indexical values and the social meaning that York listeners assigned to the variables in a perceptual task. One possible account of this mismatch (Hall-Lew 2017) is that it reflects the personal stylistic agency of the participants in Lawrence's experiment: the hallmark of indexical value would be its "mutability" because individuals are constantly "reinterpreting variables […] in a continual process of bricolage" (Eckert 2012: 94). Adopting this account, however, is tantamount to conceding the argument of this section: if personal stylistic agency causes social evaluation to diverge from community-level production patterns, it can hardly be the main cause of those patterns.

Setting these issues aside, the next section identifies two major empirical problems for the claim that the intergenerational incrementation of ongoing sound change depends on the social meaning of variants.

5.2 Granularity, variance

First, the social evaluation of variants is often either too fine-grained or too coarse to serve as the engine of incrementation of ongoing change. For example, Labov (2002: 281–283) and Eckert & Labov (2017: 22–23) cite the case of the Northern Cities Shift, a large-scale pattern that involves a set of five vowel phonemes rotating in phonetic space. Observations of speakers' stylistic practice indicate that social meaning attaches to the realizations of single phonemes or, at most, of pairs of adjacent phonemes. This is consistent with the fact that, in areas where the shift is propagated mainly by contact between adult speakers, such as the St. Louis corridor, the pattern spreads only in a fragmentary fashion (Labov 2007: §4). In the Inland North, however, where the shift advances by intergenerational incrementation in the course of language acquisition (Section 3.1), the integrity of the pattern is highly preserved (Labov 2007: 372, 375, 378). This would come as a surprise if intergenerational incrementation itself were propelled by social meaning, rather than by momentum-based learning (Section 3.2).

Just as the granularity of social meaning is too fine to drive the incrementation of the Northern Cities Shift in the Inland North, it is too coarse to account for ongoing shifts in the use of Velar Nasal Plus in North West England. This phenomenon consists of the conservative realization of etymological *ŋg* as [ŋg] rather than [ŋ] in positions where it is not followed by a vowel belonging to the same stem-level domain, so that *si*[ŋg]-*er* rhymes with *fi*[ŋg]*er* (Bermúdez-Otero 2011: 2020–2025; Bermúdez-Otero & Trousdale 2012: 697–699). In a recent matched-guise experiment, Bailey (2019a) found that Velar Nasal Plus is becoming available to carry social meaning: older speakers exhibit identical responses to [ŋg] and [ŋ] guises, but younger speakers show an incipient evaluative distinction. At the same time, sociolinguistic interviews show an increase in the use of [ŋg] in apparent time. It transpires, however, that the ongoing incrementation of Velar Nasal Plus is not driven by its incipient indexicality: natural and laboratory data reveal that this incrementation is strictly confined to prepausal position (Bailey 2019b), whereas social evaluation attaches to the [ŋg] variant in all contexts, including those in which the variable remains stable (Bailey 2019a).

Finally, sociolinguistic and ethnographic studies of the social meaning of linguistic variants often highlight their oppositional value: e.g. Labov (1963) reports that the inhabitants of Martha's Vineyard use centralized diphthongs to signal a commitment to the island's traditional way of life and a rejection of the influence of newcomers from the mainland, while Zhang (2005) finds that the replacement of neutral tones with full tones by Beijing yuppies indexes their positive stance towards the cosmopolitan culture of Hong Kong in contrast with the perceived insularity of state managers. Thus, Eckert (2012: 98) emphasizes how the personal stylistic agency of speakers manifests itself in "lifelong projects of self-construction and differentiation". However, the predominantly oppositional character of social meaning suggests that indexicality cannot be the primary driver of incrementation in the case of ordinary sound changes advancing monotonically towards completion, for in such situations the lagging groups end up converging with the leading groups.[3] If oppositional indexicality drove propagation, one would at least have to ask why we do not see more cases of arrested incrementation ushering in stable linguistic polarization.

Let us suppose that this problem can be circumvented by positing an additional mechanism that depolarizes the social evaluation of the variable and brings the lagging groups up to the level of use of the leading groups: perhaps the indexical value of variables is diluted as their use spreads. Such a scenario still predicts that interspeaker variation will increase in magnitude during the initial phase of the change, as propagation gathers momentum under the effect of oppositional indexicality. This prediction, however, is in direct conflict with the empirical evidence currently available. The relevant information is not abundant: as Fruehwald (2017b) notes, many studies of ongoing sound change follow the variable's central tendency over time, but few track the evolution of its dispersion. Using data from the Philadelphia Neighborhood Corpus, however, Fruehwald (2017b)

[3] Blythe and Croft (2012) argue that changes will not normally follow S-shaped trajectories unless variants are subject to differential social valuation (see note 2 above). As we saw in Section 3.2, however, momentum-based learning suffices to generate S-curves reliably (Stadler et al. 2016). See also Kauhanen (2017) for germane discussion.

monitored intra- and inter-speaker variance during the incrementation of prefortis /aɪ/-raising and preconsonantal /eɪ/-raising in Philadelphia from the late 19th to the late 20th century. Crucially, he found that, for both variables, intra- and inter-speaker variance remained stable during this period: see the schematic representation in Figure 7. This observation rules out oppositional indexicality as the main incrementation engine for sound change.

The situation may be illuminated by an analogy, somewhat similar to a comparison proposed by Labov (2002: 283). An ordinary sound change undergoing monotonic incrementation to completion may be likened to a large swell wave coursing through the open sea: its origin, amplification, and propagation from a distant fetch of ocean are like the initiation and incrementation of sound change driven by community-oriented momentum-based learning. In contrast, the short-wave roughness on the surface of the swell is caused by local winds; this is like the effect of personal identity and agency on the ongoing change. Both phenomena are real, interesting, and important,[4] but they operate at measurably different scales and are to a significant extent causally independent from each other.

In agreement with this conclusion, Holmes-Elliott's (2020) panel study of children and adolescents in Hastings shows parallel trajectories of steady incrementation for GOOSE-fronting, which is socially unmarked, whereas incrementation is less consistent and robust precisely for those variables that are subject to strong social evaluation.

Pursuing these arguments, the following sections provide empirical evidence of macroscopic patterns of propagation that are best explained mechanically by the principle of density of communication, rather than in terms of social meaning.

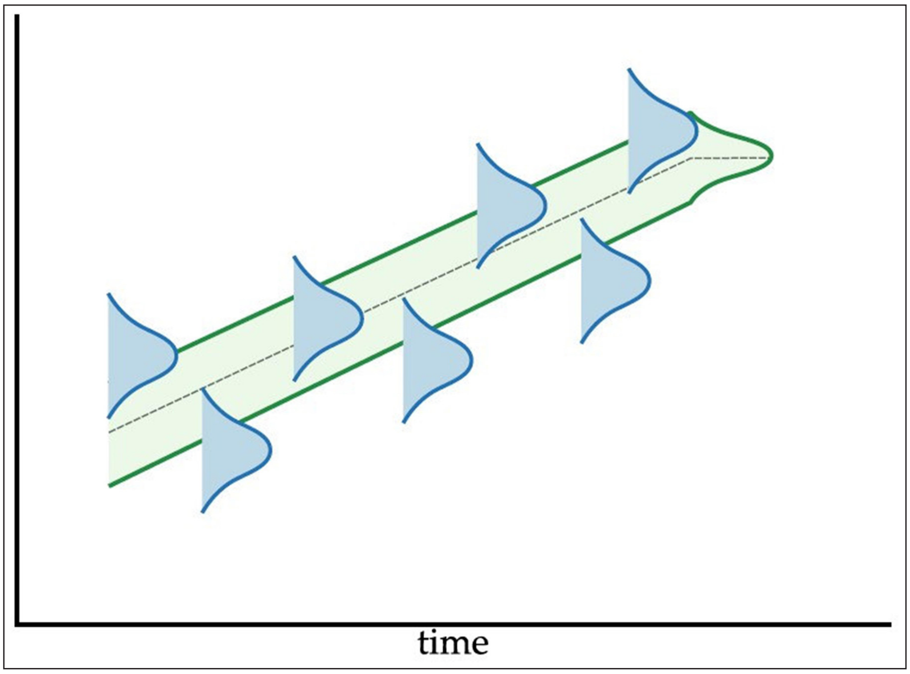

Figure 7: Intra-speaker variance (blue Gaussians) and inter-speaker variance (green Gaussian) remain stable during the incrementation of sound change; the dashed line represents the variable's central tendency at the community level (Fruehwald 2017b).

[4] Sea waves of every length, from tides through swell down to capillary waves, as well as their interactions with one another and with atmospheric activity, are all flourishing fields of research in fluid dynamics, oceanography, meteorology, and related disciplines.

5.3 Class stratification

One of the most salient phenomena in the propagation of sound change is stratification by class: since Labov's seminal study of New York City in the early 1960s, this observation has been replicated time after time (Labov 2006: 397). But what causes class stratification: density of communication or social meaning? A number of conceptual arguments suggest that the role of density of communication is primary and dominant.

At the birth of a variable, sociolinguistic differentiation must precede sociolinguistic evaluation both temporally and causally. If a variant were distributed uniformly across the speech community, it would have no indexical value and so could not acquire social meaning. Differences in the social distribution of variants must thus arise first by mechanical means (Labov 2006: 397). This is easily explained on a background of neutral propagation by probability matching (Labov 1994: 580–583; see also Kauhanen 2017: §2), consistent with the community orientation of the learner (Section 3.2). As proposed in Section 3.3, the locus of initiation, where incrementation begins, consists of a small set of learners who acquire an age vector upon exposure to an accidental pattern of age-skewed variation. Subsequently, other speakers in the larger community become exposed to the change in inverse proportion to their status distance from the locus of initiation, simply because average density of interaction decreases with distance on the status scale. This mechanical effect endows the innovative variant with first-order indexicality (Eckert 2008: 463; after Silverstein 2003), which can come to be cognitively represented in the minds of some members of the community. Once we have reached this stage, further developments become possible: knowledge of the variable's value as a first-order index may lead some speakers to endow it with additional social meanings, and those speaker's productions may accordingly start to display attitudinal effects.

Moreover, it seems reasonable to expect that, in a large proportion of cases, those attitudinal effects may at most amplify, but will not qualitatively alter, the pattern of class stratification created mechanically by density of contact. This is because attitudinal variables often exhibit strong linear relationships with status. This appears to be true, in particular, of two important individual variables: attitudes to local traditional life-styles and attitudes to education. In Eckert's (1989; 2000) study of Belten High, for example, jocks, characterized by their educational aspirations and cooperative relations with teachers, came mostly from the upper half of the local socioeconomic hierarchy, whilst burnouts came mostly from the lower half (Eckert 2012: 92).

In sum, class stratification is one of the most salient facts about the propagation of sound change. The arguments we have considered so far suggest that it emerges mechanically from the impact of socioeconomic distance on density of communication; the effects of personal identity and agency are causally secondary and smaller in scale.

Baranowski's (2017) study of GOOSE- and GOAT-fronting in Manchester provides strong empirical support for this conclusion. Unlike the majority of English dialects, Manchester shows advanced fronting of /uː/ before coda /l/, as in *school* and *pool*. The variable is stable in apparent time and exhibits strong stratification by class: the speakers' degree of /uː/-fronting before /l/ correlates inversely with their socioeconomic status (Figure 8).

Unusually, Baranowski's study directly compared the effects of socioeconomic status and those of attitudes to Manchester. Status was operationalized in terms of occupation (Baranowski 2017: 303). Attitudes to Manchester were operationalized in terms of the responses to questions such as "how Mancunian do you feel?" (Baranowski 2017: 326). As expected, attitudinal scores displayed a fairly large correlation with status, but not so strong as to prevent both variables from being entered into the same mixed-effects linear regression (Baranowski 2017: 328, 330–331). Baranowski ran three regressions with the

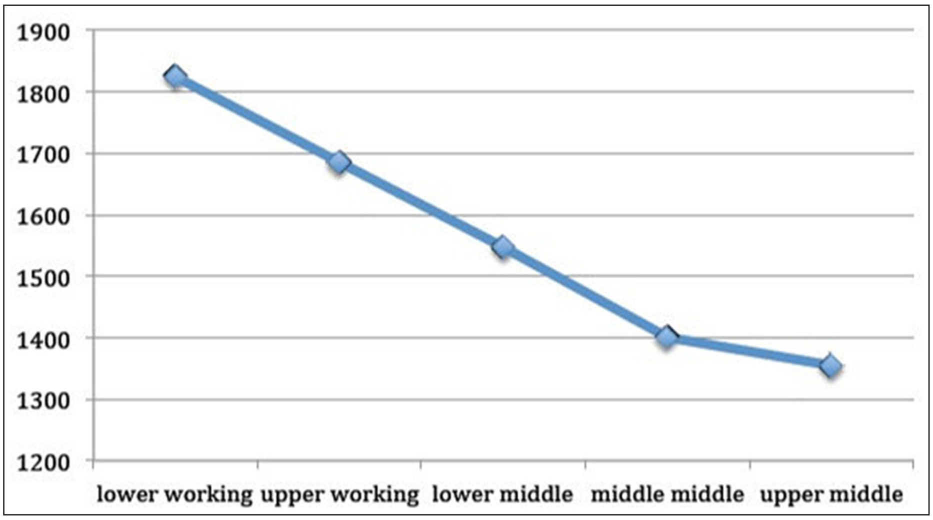

Figure 8: Class stratification of pre-/l/ /uː/-fronting in Manchester (courtesy of Maciej Baranowski): the *y*-axis indicates F2 in Hz.

F2 of GOOSE before /l/ as the the dependent variable: the first included status as a predictor, but not attitudes; the second included attitudes, but not status; and the third included both. The first model outperformed the second according to both the Akaike information criterion (AIC) and the Bayesian information criterion (BIC). Crucially, the third, more complex, model did not emerge as a clear winner over the first: it was favoured by AIC but not BIC. In this light, "we cannot confidently conclude that adding attitudes to social class improves the explanation of the variation" (Baranowski 2017: 331). In the case of GOAT-fronting, which also displayed strong class stratification, the results were even clearer: an ANOVA comparison showed that a model including both class and attitudes was not significantly different from one with class alone.

As Baranowski (2017: note 13) acknowledges, a critic might object that a different selection or operationalization of attitudinal variables might have resulted in a bigger effect of attitudes. Note, however, that this argument cuts both ways: the operational definition of class is itself not trivial, and so, had the effect of attitudes proved significant, an opponent might just as well have objected that this effect could disappear in a study using a better operationalization of class (Baranowski & Turton 2018). All one can conclude from such prudential considerations, well motivated though they are, is that it would be highly desirable for many more studies like Baranowski's to be conducted until the overall picture emerges clearly by simple preponderance of evidence.

In the meantime, it is useful and enlightening to pursue the implications of the hypothesis that many, perhaps most, sociolinguistic variables behave like GOOSE and GOAT in Manchester. This scenario invites us to consider in greater depth the following question: why is there such a strong correlation between status and attitudes, and why does status outperform attitudes as a predictor of variation? The conceptual considerations explored at the beginning of this section suggest a plausible answer. First, status exerts a causal effect upon attitudes: for example, parental occupation and income partially determine the chances of an American student becoming a jock or a burnout. In consequence, status shapes linguistic variation both primarily through the mechanical effects of interpersonal contact and secondarily through its effect on attitudes. Figure 9 represents a subset of the relevant causal relations.[5]

[5] Note that Figure 9 represents interpersonal contact and attitudes as mutually dependent. This is because, as we saw in Section 5.1, people with different attitudes socialize in different ways and, in turn, socialization patterns shape attitudes.

This depiction of the causal chain is fully compatible with the existence of sociolinguistically exceptional individuals and with the possibility that many of them owe their exceptionality to their personal stylistic agency (Eckert & Labov 2017: 12–14). Those exceptional speakers may be expected to exert a limited influence on the community pattern anyway. First, a few special cases contribute far less to the average than the mass of the ordinary. Secondly, and more importantly, the community-oriented learner, like a statistician suspicious of outliers, actively rejects individual idiosyncrasies (Labov 2014a; b; and see again Section 3.2 above).

5.4 The curvilinear pattern

A special case of class stratification is the curvilinear pattern (Labov 1972: 294–295; 2001: 31–33, 171–172), in which an ongoing sound change is led by the social classes that occupy the interior of the socioeconomic hierarchy, whilst the lowest- and highest-status groups lag behind. Figure 10 illustrates this phenomenon with data from the *cot-caught* merger in Charleston (Baranowski 2013): the loss of the contrast is led by the lower and middle segments of the middle class (LM and MM), whilst the working (WC), upper-middle (UM), and upper (UC) classes are relatively conservative, exhibiting higher distinction scores.

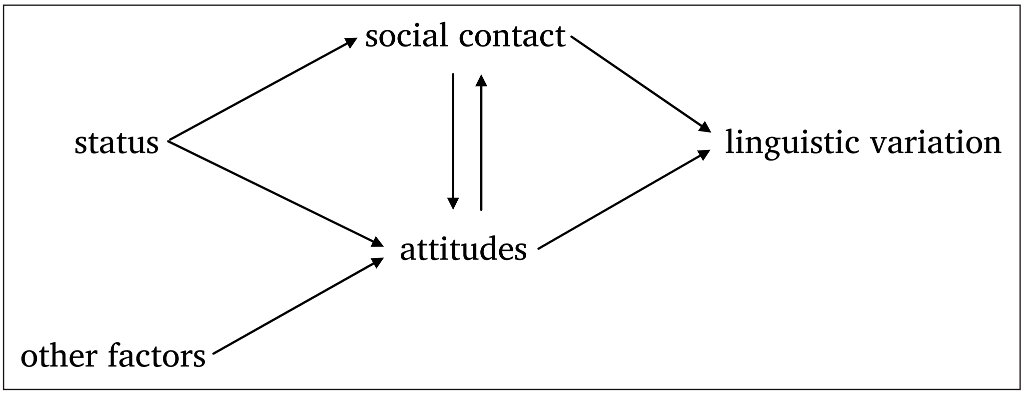

Figure 9: Status and attitudes in the chain of causation of linguistic variation.

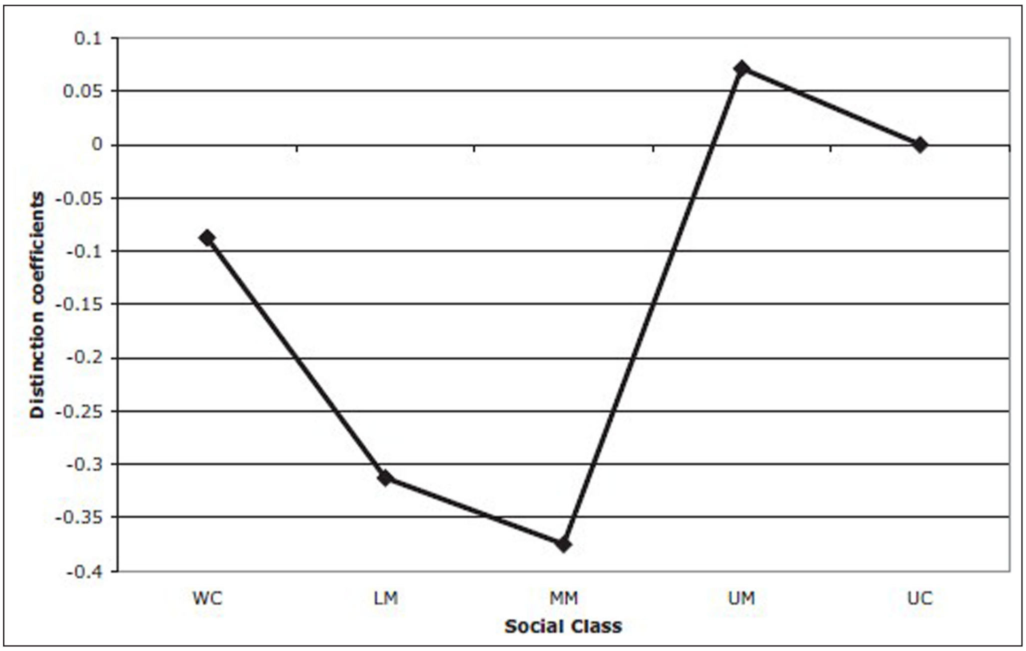

Figure 10: Curvilinear pattern of the *cot-caught* merger in Charleston (courtesy of Maciej Baranowski).

The curvilinear pattern is very commonly observed in sound changes fulfilling two requirements: first, they operate below the level of social awareness; secondly, they are in progress, advancing rapidly by intergenerational incrementation. The *cot-caught* merger in Charleston fits this description exactly. It does not elicit overt comments (Baranowski 2013: 288, 291), and it displays the expected distribution in apparent time: distinction scores rise smoothly with age among speakers up to 50, and older speakers retain the contrast (Baranowski 2013: 275). In this respect, the *cot-caught* merger stands in stark contrast with a similar ongoing change in Charleston: the *pin-pen* merger. The latter also shows vigorous incrementation in apparent time, but it operates above the level of social awareness, prompting overt remarks from speakers (Baranowski 2013: 287). Significantly, the *pin-pen* merger fails to conform to the curvilinear pattern, instead displaying an inverse monotonic correlation with socioeconomic status (Baranowski 2013: 282–283, 291).

Why should it be the case that sound changes are likely to follow the curvilinear pattern while they are in progress if they operate from below? Labov (2001) contemplates two possibilites. One is purely mechanical: the curvilinear pattern is created by density of communication (Labov 2001: 191–192). The other involves covert social meaning: changes are led by members of the interior status groups because these are in the best position to "display the symbols of nonconformity in a larger pattern of upward social mobility" (Labov 2001: 516–517). A strong argument favours the first of these two answers: changes from below tend to exhibit curvilinear propagation because this is the pattern most likely to arise mechanically from the topology and dynamics of the social network.

Support for this assertion may be found in Kauhanen's (2017) mathematical and computational exploration of neutral change, i.e. change propagated by probability matching in the absence of social evaluation. Kauhanen demonstrates that neutral change exhibiting realistic patterns of incrementation and propagation occurs spontaneously in a network if the latter satisfies two properties, one topological, the other dynamic. First, the network must be strongly clusterized: some nodes occupy a relatively central position by virtue of having a large number of connections; other nodes have fewer connections and so count as more peripheral. Secondly, the network must undergo rewiring: periodically, some nodes are removed, and others are created. Crucially, neutral change in such a network will typically irradiate from the centre: over time, propagation is easy from the centre to the periphery, but hard in the opposite direction (Kauhanen 2017: 349–351).

Admittedly, Kauhanen conceives of the nodes in his model as individual speakers, but extrapolating his results to a coarser level of granularity leads to an interesting scenario. If nodes consist of groups of speakers of similar socioeconomic status, then middle-status nodes are more likely than high- or low-status nodes to occupy central positions in the network (in the technical sense). This is because, with density of communication falling in direct proportion to status distance, only intermediate-status nodes are likely to have strong connections with other nodes throughout the social scale. Accordingly, propagation is more likely to be successful precisely for those innovations that originate in the intermediate-status groups. If this extrapolation is correct, the curvilinear pattern is the hallmark of mechanical propagation in a social network clusterized by class.

5.5 Change reversal

I have argued that many macroscopic patterns of propagation submit to largely mechanical explanations. In such cases, attitudinal variables may have significant small-scale effects, but the large-scale evolution of the community depends mainly on supra-individual topological properties of the social network, notably density of communication as determined by demographic variables such as class. As highlighted in Hall-Lew (2017), however, the acid test for this approach to propagation lies in accounting for scenarios of change reversal, in which the use of a variant starts to decline after a period of consistent growth. Labov et al.'s (2013) survey of twentieth-century Philadelphia highlights two cases: /aʊ/-raising and /oʊ/-fronting, both led by women in the first half of the century, went into reversal in the second half.

Change reversal is problematic because, according to the model of momentum-based learning outlined in Section 3.2, intergenerational incrementation, once initiated, is self-sustaining. Crucially, however, the model also predicts that incrementation may cease and even go into reverse if, for any reason, a new cohort of adolescents comes to be exposed to a community pattern in which the use of the innovative variant by adults no longer decreases monotonically with speaker age. Such a situation can be brought about by population changes (e.g. migration) or changes in network topology (e.g. shifts in class segregation). In a simple scenario, for example, the arrival of a large contingent of young immigrants of working age lacking the local variant may invert the age vector acquired by the current adolescent cohort.

What role, if any, population changes or shifts in network topology may have had in the reversal of /aʊ/-raising and /oʊ/-fronting in Philadelphia is at present unclear (Labov et al. 2013: 51–52, 59–60; Tamminga 2019). However, an instance of reversal in which population change was demonstrably decisive, in combination with network topology, is the retreat from the Southern Vowel Shift in Raleigh, North Carolina. In this case, the reversal was triggered by an influx of white-collar workers from the North and was crucially facilitated by social segregation by status, as affluent local residents and their children interacted more frequently with affluent Northern immigrants than with the local working-class population (Dodsworth & Kohn 2012). This confirms that, as Hall-Lew (2017) argues, the reversal of sound change is impossible in the absence of social change. It is, however, quite feasible for the relevant social change to operate mechanically, while attitudinal variables add small-scale effects.

6 Conclusion: idealization and the explanation of sound change

Let me now return to an intuition expressed in the final paragraph of Section 3.3: surely, paying greater attention to individual differences between speakers can only lead to deeper and better explanations of the facts of sound change?

At first glance, the recent history of the field seems to support this intuition. Since the 1960s, Labovian sociolinguistics has significantly improved our understanding of sound change. This progress has been achieved largely by dispensing with idealizations which, however well-motivated and productive in the pursuit of different research questions, concealed the mechanisms whereby community-wide change is implemented, incremented, and propagated. Chomsky's (1965: 3) ideal speaker-hearer, for example, is a useful tool in research whose main goal is to ascertain the generative capacity of the human faculty for language and to solve Plato's Problem. One must give it up, however, if one's goal is to understand how sound change is implemented: the fundamental question of lexical regularity vs diffusion, for example, could not be put on a firm empirical footing until the arrival of quantitative variationist sociolinguistics (Labov 1981). Similarly, Andersen's (1973: 767) Z-model of change (Figure 11) is a reasonable and helpful idealization if one's purpose is to develop a model of reanalysis as a mechanism of innovation. The Z-model, however, treats the child's input as if it were produced by a single generation of adult speakers, and so it excludes the possibility of acquiring an age vector. It thus sets aside facts that are crucial to understanding incrementation, at least if the proposal of momentum-based learning outlined in Section 3.2 is broadly correct.

It would be wrong, however, to expect that, every time we roll back abstraction and idealization in the study of sound change, we will receive an immediate pay-off in the

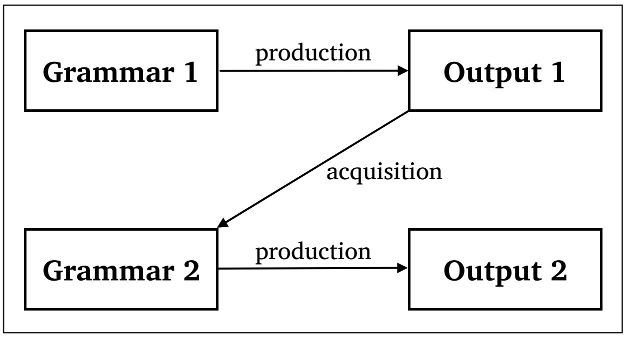

Figure 11: The Z-model of innovation (adapted from Andersen 1973: 767).

form of models of greater explanatory power. An example from physics will serve to make this point. The macroscopic behaviour of gases is described in terms of properties such as temperature, pressure, volume, and amount of substance. Under certain conditions (chiefly high temperature and low pressure), the relations between these variables are excellently approximated by the ideal gas law, which is in turn derived from the microscopic behaviour of molecules by the kinetic theory of gases. Crucially, the latter shows that the temperature of a gas depends on the speed distribution of its molecules, but not on their positions or directions of travel. Modern versions of the theory, moreover, explain the circumstances under which factors like molecular size cease to be negligible. Historically, the discovery of the gas laws predates their derivation from the kinetic theory, whose initial assumptions were in turn only relaxed in later formulations.

This analogy suggests a number of methodological lessons that are directly relevant to the study of sound change (see also Kauhanen 2018). Choosing the right idealization is often crucial to making progress towards solving a scientific problem. In particular, successful accounts of macroscopic facts typically ignore much of the available information about the corresponding micro-states, precisely because a key measure of their explanatory success is the extent to which they incorporate only causally efficient factors. By the same token, our macroscopic models improve by the addition of microscopic variables only insofar as we can correctly track the effects of those variables.

The moral is that our accounts of sound change should incorporate individual differences only when they are truly relevant. One area where they may turn out to be crucial is lifespan change (cf. Section 3.1). Whenever a speaker's observable linguistic behaviour shifts in adulthood, we may ask whether this reflects a change in grammar, in attitudes, or in the physiological and cognitive mechanisms of speech, corresponding to Tamminga et al.'s (2016) categories of *i*-, *s*-, and *p*-conditioning. In cases where an adult's performance shifts away from the community norm, the cause is probably socio- or psycholinguistic. For example, MacKenzie (2019) reports that, between his thirties and his eighties, the broadcaster Sir Richard Attenborough increased his use of tapped /r/ in word-final prevocalic position, in opposition to the general pattern in British English. Since the change was confined to frequently uttered collocations, MacKenzie suggests that it does not reflect an update to Attenborough's /r/-tapping rule, but rather the accumulated effect of life-time experience on the structure of the stored representations of the relevant linguistic chunks. A similar process is probably at work in the more general pattern of age-grading that Guy & Boyd (1990) observed in the application of /t,d/-deletion to irregular weak verbs like *kept* and *told*.

In sum, there is no shortage of good reasons to study individual differences. This does not entail, however, that individual variation should be incorporated into theoretical models seeking to explain such macroscopic properties of sound change as the occurrence of localized bifurcations, the adolescent peak, monotonic incrementation, class stratification, curvilinear propagation, or even the existence of change reversals. In this respect, the study of sound change is not different from any other domain of scientific enquiry: for each explanatory task there is an optimal level of abstraction.

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Competing Interests

The author has no competing interests to declare.

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