LSA 511: Computational Models of Sound Change

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27 June 2013

Why are we here?

Frequency effects and their relation to lenition (weakening)

- Frequency often correlated with synchronic reduction (Hooper, 1976; Bybee, 2000; Jurafsky et al., 2002; Munson and Solomon, 2004...)
  - *memory* $>$ [mɛmɹi], but *mammary* $\not>$ [mæmɹi] (Hooper, 1976)
  - *told* $>$ [tol] but never *meant* $>$ [men] (Bybee, 2000)

- Frequency also correlated with rates of diachronic change (e.g. Philips, 1984)
  - (low-frequency) *nude* */njud/ $>$ [nuːd], not [njuːd], while
  - (high-frequency) *new* */nju/ $>$ [njuː], not [nuː]

Why are we here?

- Goal: an existence proof by constructing ‘a formal architecture which is capable of capturing these regularities’
- Should also predict that ‘some outcomes are possible and others are not’

Pierrehumbert (2001)

‘By examining the consequences of the perception-production loop over time, we provide a formal framework for thinking about the quantitative predictions of usage-based phonology, as proposed by Bybee. We derive the finding that leniting historical changes are more advanced in frequent words than in rarer ones. Calculations are presented which reveal the interaction of production noise, lenition and entrenchment. A realistic treatment is also provided for the time course of a phonological merger which originates from lenition of a marked category.’

Pierrehumbert (2001)

Other (tacit/explicit) claims made by/attributed to this paper:

- Under certain conditions, **category variance will stabilize**
- **Frequency** plays a role in neutralization

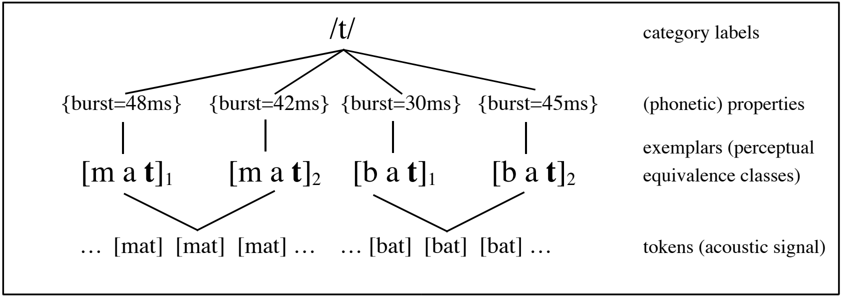
Things to keep in mind

1. Knowledge state of individuals
2. Network/social structure
3. Assumptions about communication
4. Learning algorithm

Exemplar ‘theory’

- Like ‘sound change’, a potentially ambiguous term
- Memory is episodic, highly detailed
- System is a map from points in multidimensional phonetic space to category labels...
- ...independent of where those labels might come from

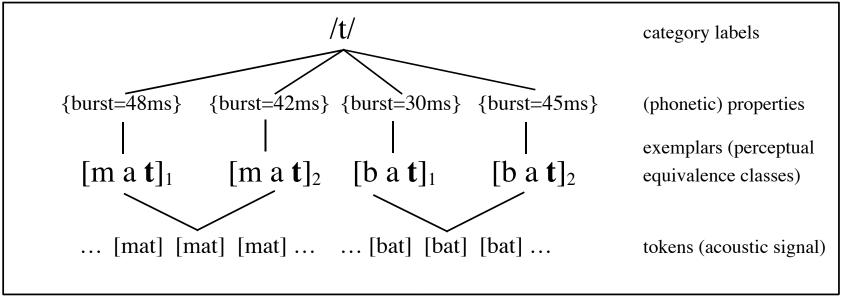
Exemplar storage: Units (knowledge state)



- An exemplar list $E(L)$ is a list of exemplars associated with label L:

$$E(L) = e_1^L, \ldots, e_n^L$$

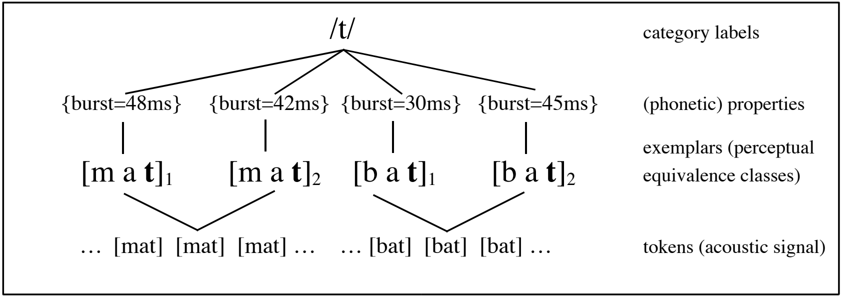
Exemplar storage: Units (knowledge state)



- Individual exemplars represented as (property, label) pairs

$$e_1^L = \{burst, 48ms\}, e_2^L = \{burst, 42ms\}, \ldots$$

Exemplar storage: Constraints

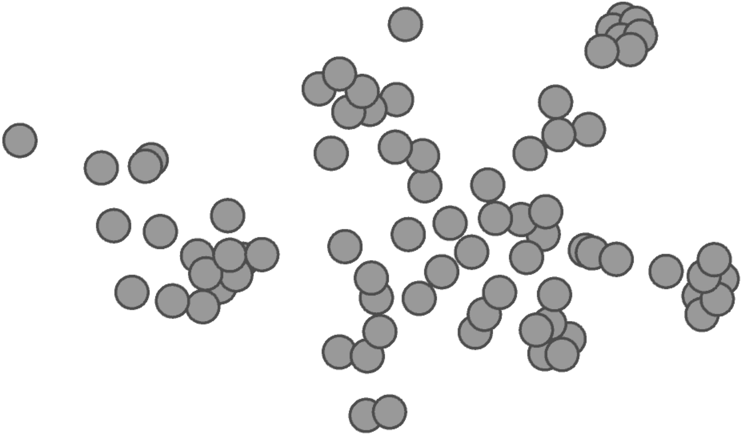


- Memory limitations → memories decay
- Perceptual limitations → granular representations

Model 1: Single category

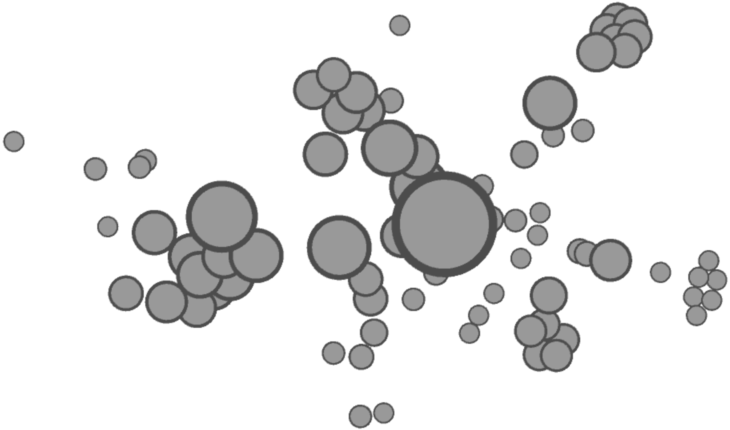
- Single speaker/hearer, talking to themself
- Entails simple(st) network structure
- Knowledge state as detailed above
- What are the assumptions about communication and learning?

Model 1: Production



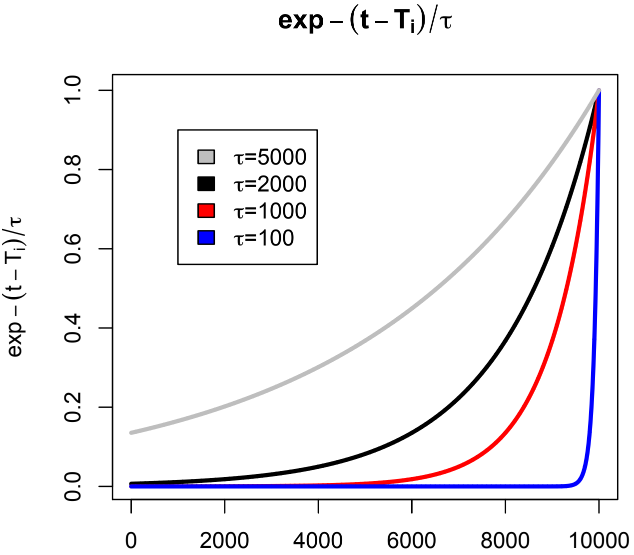
...if target were selected with uniform probability

Model 1: Production

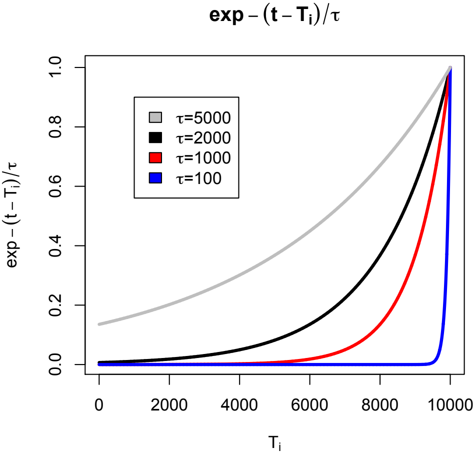


...target selected weighted by recency: $\exp(-\frac{t-T_i}{\tau})$

Model 1: Production



Model 1: Production



- Resting activation level a function of time and τ:

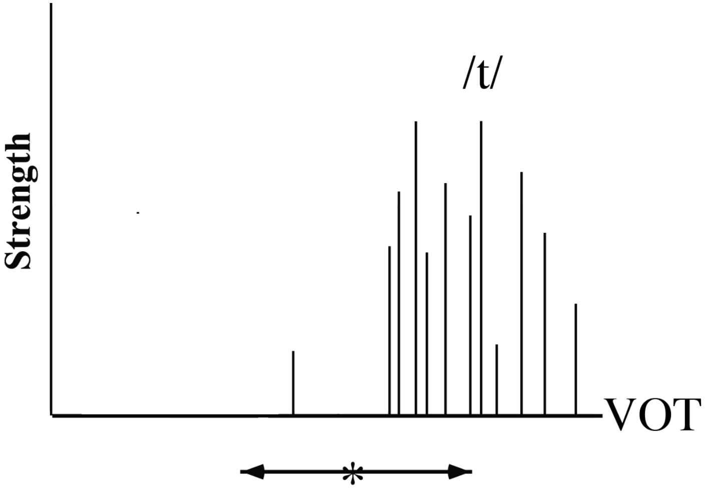
$$\exp(-\frac{t - T_i}{\tau})$$

- Bounded between 0 and 1
- As numerator gets bigger, weight gets smaller

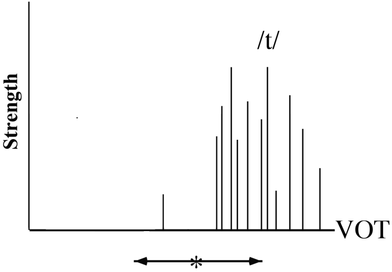
Model 1: Production

- Noise: 'random deviations from the phonetic target due to noise in the motor control and execution'
- Modify production target $x = x_{target} + \epsilon$
- ϵ : random number chosen from a uniform distribution over some fixed range (e.g., from $-.1$ to $.1$)

Model 1: Perception



Model 1: Perception

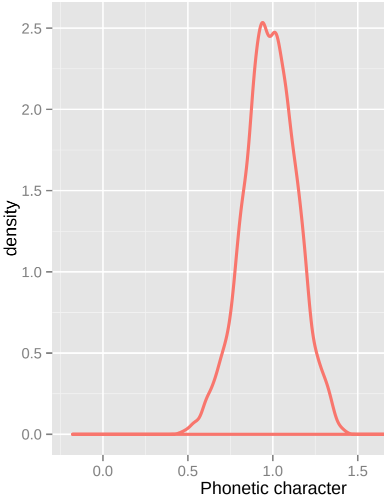


$$W(x - e_i^L) = \begin{cases} 1 & \text{if } |x - e_i^L| < 0.05 \\ 0 & \text{otherwise} \end{cases}$$

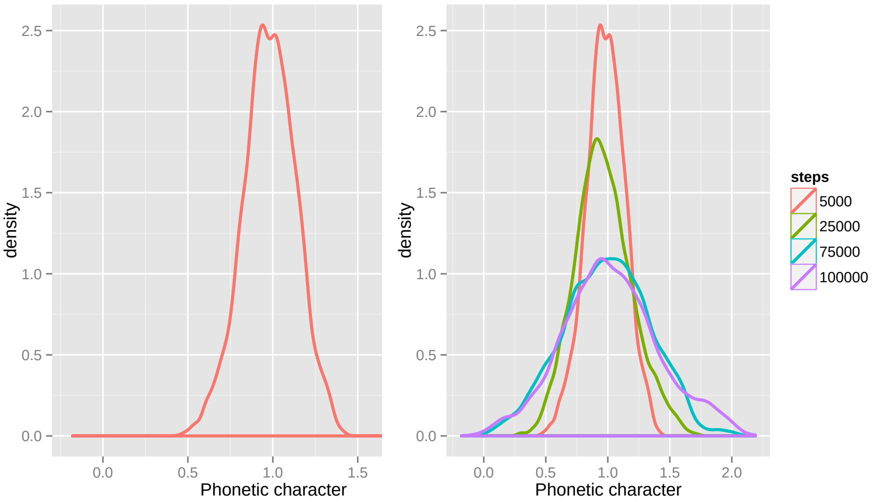
$$score(L, x) = \sum_{i=1}^{n} W(x - e_i^L)$$

If score $\neq 0$, x is retained. (learning!)

Model 1: Results



Model 1: Results

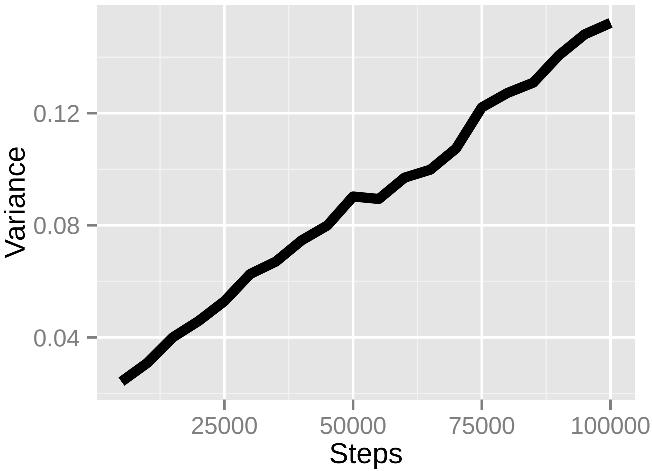


Model 1: Results

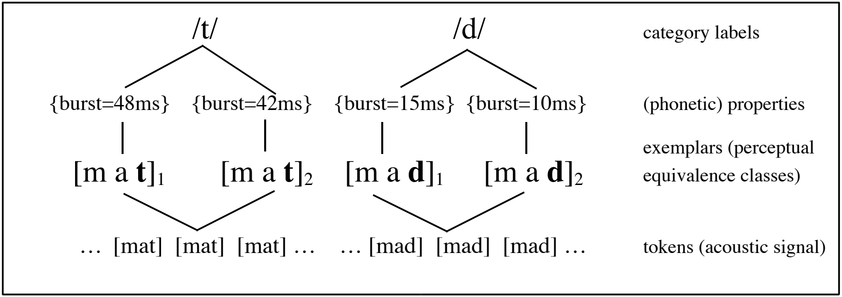
What does P conclude from this?

- ‘The total representation of the category is strengthened as more and more memories are stored’
- ‘the variance of the distribution ... increases with usage’

Model 1: Results



Model 1a: Two categories

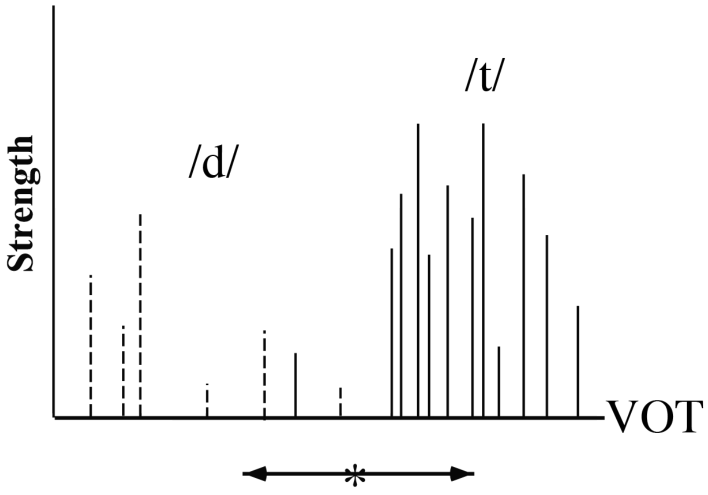


- How do we extend this model to more than one category?

Model 1a: Production

- Now that there are two categories A and B, which one does the speaker utter an instance of at any given timestep?
- Each list seeded w/ a single value; then randomly produce a token x of A or B with probability p and $1 - p$, respectively
- p is fixed/static: e.g. phrase-final voiced obstruents (B) are *a priori* less likely than phrase-final voiceless obstruents (A)

Model 1a: Perception



Model 1a: Perception

- New exemplars are given a score for each list (category) L:

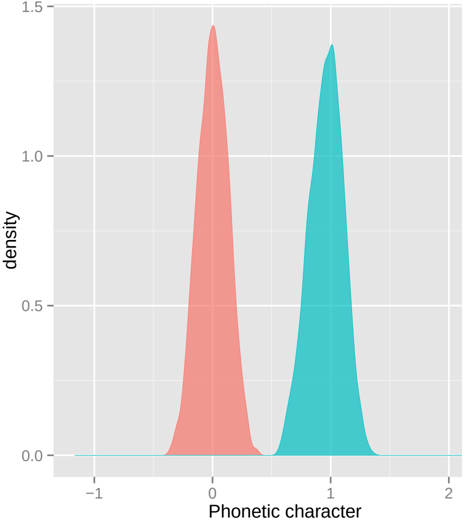
$$score(L,x) = \sum_{i}^{n} \underbrace{W(x - e_i^L)}_{\text{distance}} \overbrace{\exp(-\frac{t - T_i}{\tau})}^{\text{activation level}} \tag{1}$$

- Assign input x to list with the highest score:

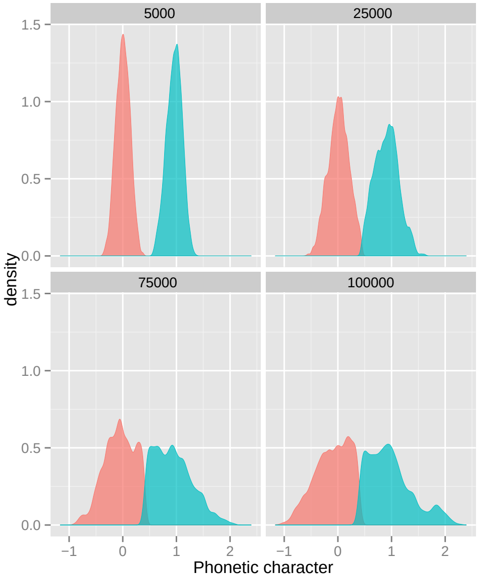
$$\arg\max_L score(L_n, x), L \in \{L_1, \ldots, L_n\} \tag{2}$$

- If $L_i = L_j$ for all i, j, discard x.

Model 1a: Results



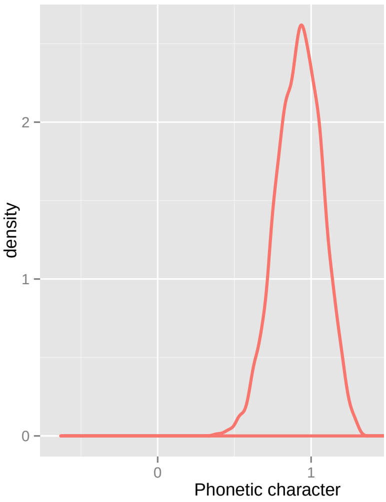
Model 1a: Results



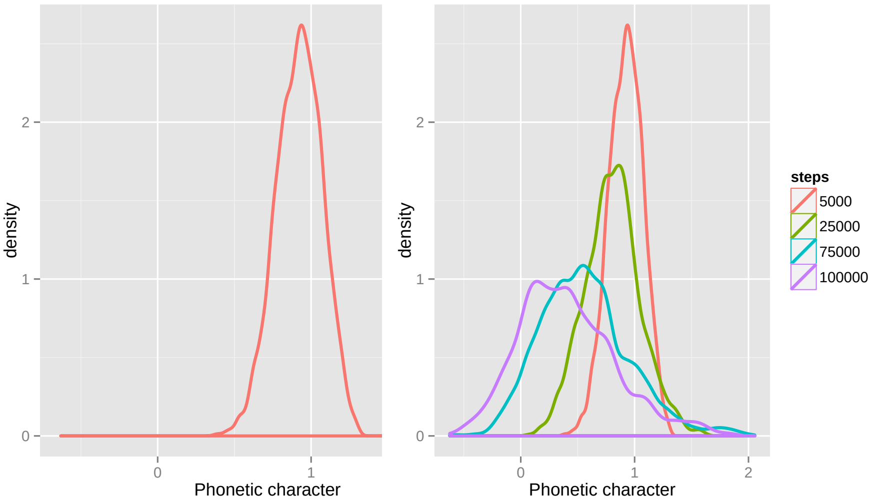
Model 2: Bias

- Motivation: ‘tendency to undershoot ... in order to save effort and speed up communication’ (Lindblom, 1984)
- Drives leniting changes like schwa reduction and /t/-deletion?
- Production target is now $x + \epsilon + \lambda$
- λ is a constant (i.e. fixed) parameter (e.g., -0.1)

Model 2: Results



Model 2: Results



Model 2: Discussion

- ‘We derive the finding that leniting historical changes are more advanced in frequent words than in rarer ones....’
- In what sense does this model derive this?
- Synchronic interpretation?

Model 3: Lenition + Entrenchment

- **Problem**: variance appears to increase without bound
- Aggravated by lenition bias, but...
- Phonetic variability *decreases* with practice (Lee et al 1999)
- ‘There is no combination of parameter settings for the model which allows a category to fill out after being seeded by a single example, without simultaneously predicting that the spreading out will go on indefinitely’

Model 3: Lenition + Entrenchment

- **Solution**: entrenchment
- Production involves **averaging over multiple exemplars**
- Pick n_{trench} closest exemplars to target, where 'close' is the inverse of the weighted distance used in perceptual scoring:

$$d_i = |x_{target} - e_i^L| \exp(\frac{t - T_i}{\tau}) \quad (3)$$

$$\omega(T_i, t) = \exp(\frac{t - T_i}{\tau}) \quad (4)$$

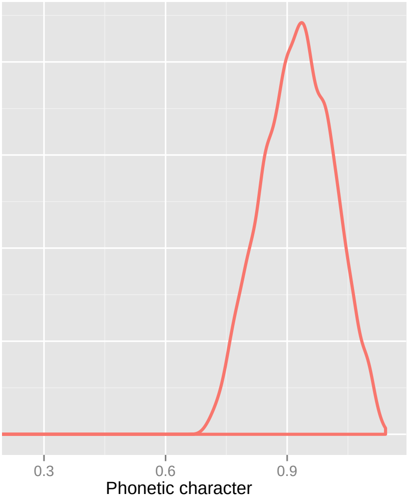
Model 3: Lenition + Entrenchment

- **Solution**: entrenchment
- Production involves **averaging over multiple exemplars**
- Pick n_{trench} closest exemplars to target, where ‘close’ is the inverse of the weighted distance used in perceptual scoring:

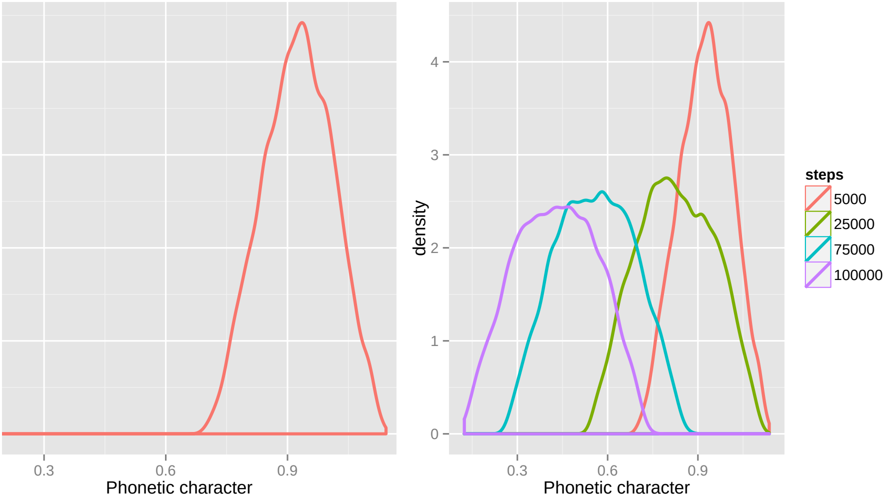
$$d_i = |x_{target} - e_i^L|\,\omega(T_i, t) \qquad (5)$$

$$x = \frac{\sum x_i \omega(T_i, t)}{\sum \omega(T_i, t)} \text{ for } n_{trench} \text{ closest exemplars} \qquad (6)$$

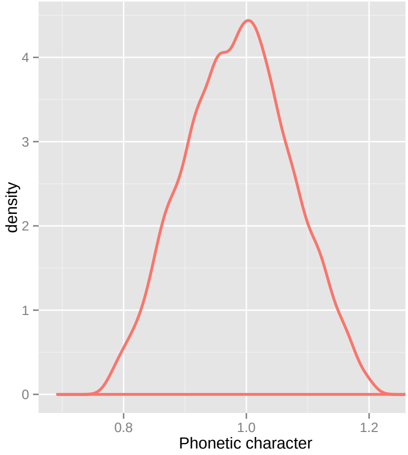
Model 3: Results



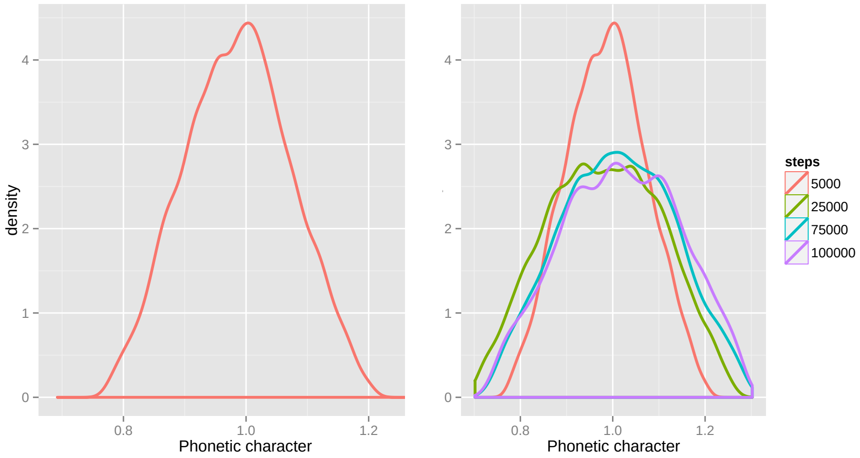
Model 3: Results



Model 3a: Entrenchment only



Model 3a: Entrenchment only

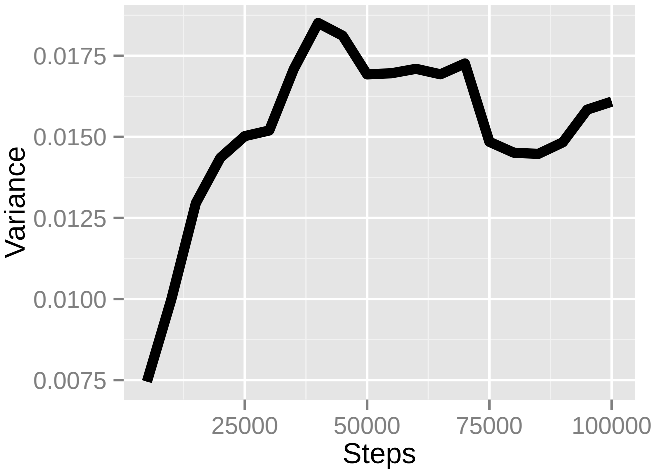


Models 3/3a: Conclusions

- ‘With the particular parameter settings selected here, the spreading effects arising from production noise and lenition and the anti-diffusive effect of entrenchment have essentially cancelled out in determining the variance.’

- In other words: variance stabilizes at some point

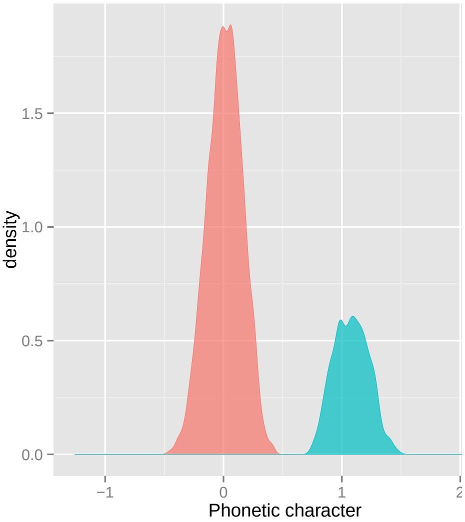
Models 3/3a: Entrenchment



Model 4: Neutralization

- **Intuition:** lenition bias in a region of phonetic space shared by multiple categories will eventually result in stable merger
- ‘We consider the case of a marked phonological category competing with an unmarked one....we take the unmarked category to be more frequent than the marked one...’
- P shows us lenition *plus* entrenchment *plus* unequal frequency
- What about just unequal frequencies, full stop?

No lenition, no entrenchment, unequal frequencies



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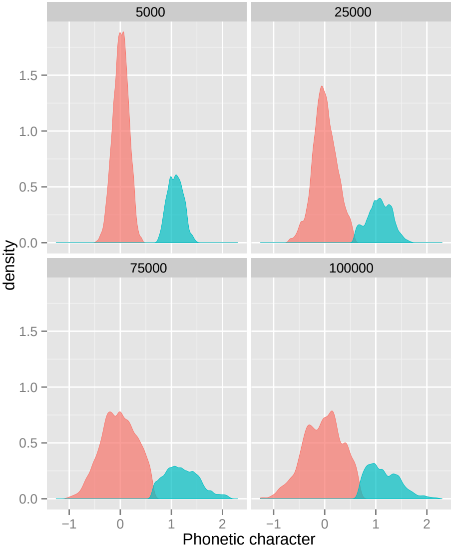
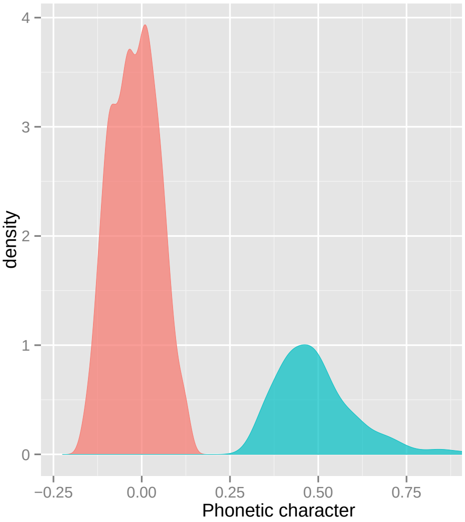
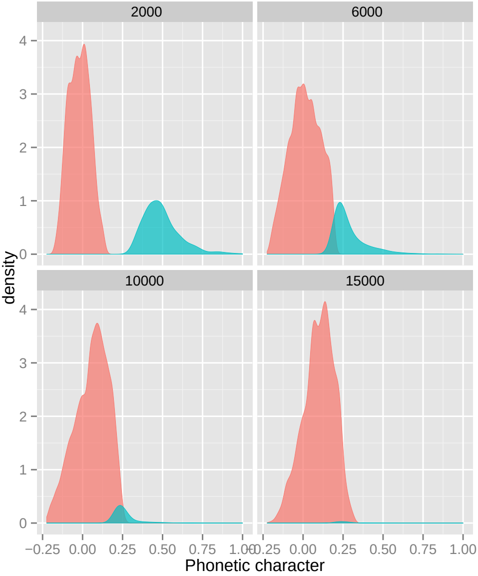


Model 4: Results



Model 4: Results



Model 4: Conclusions

- Is this a ‘realistic treatment of the time course of phonological merger’?
- If it is, what should the time course of change look like?

Silva (2006)

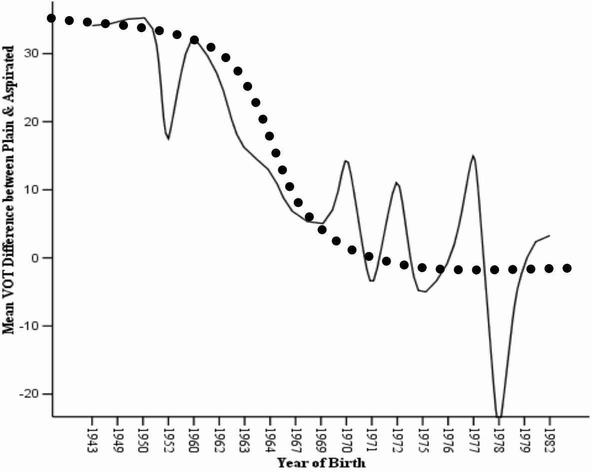
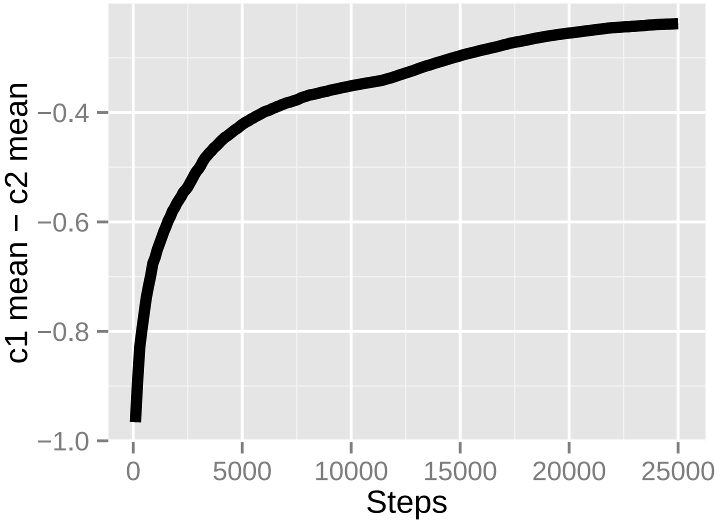


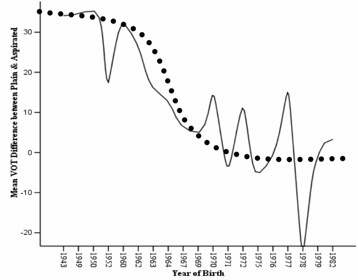
Figure 3. Age-related change for the VOT Gap (ms) (mean VOT_{asp} – mean VOT_{lax}).

Model 4



c1 mean − c2 mean
−0.4
−0.6
−0.8
−1.0
0
5000
10000
15000
20000
25000
Steps

Model 4



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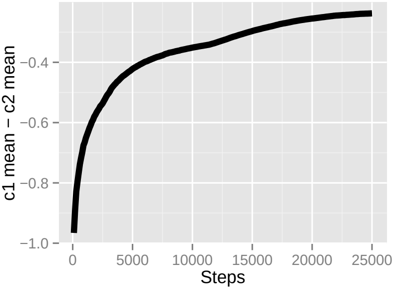

Assumptions/limitations

- **Category labels.** Here: given. Where do they come from?
- **Unidimensionality of phonetic character.** What would be required to move to a multidimensional representation?
- **Network/social structure.** Realism of modelling single speaker-hearer?
- ...

What have we learned?

- (Non-)existence proof(s)?
- Explicitness?
- Counterintuitive results?
- Qualitative predictions?
- Baseline?

Weekend: extensions and explorations

- **Frequency and lenition.** What is necessary for neutralization to obtain: differences in frequency (p), lenition, or both?
- **Entrenchment: one category.** Does the variance always stabilize with nonzero entrenchment? Evaluate the claim that stable variance decreases as n_{trench} increases.
- **Entrenchment: two categories.** Vary the amount of entrenchment in the neutralization simulation. What happens?
- **Window size.** How does changing the window size impact the evolution of categories in the two category cases?

Weekend: extensions and explorations

- **Changing τ.** How does changing τ effect the evolution of the mean and variance of a category over time?

- **Noise.** Is there an effect of increasing/decreasing the amount of noise (i.e., changing endpoints of the distribution from which noise (ϵ) is drawn)?

- **Lenition.** What happens in the neutralization scenario as the amount of lenition λ is varied?

- **Advanced topics.** 3 categories? Alternative scoring function?

Post guidelines

- What did you try?
- What did you find? (pictures optional)
- Can you give an intuitive explanation for why you got the result that you did?
- What empirical/linguistic prediction(s) does your finding make?

Post guidelines

- 1 member of each group: please **email us group list** ASAP
- Example Piazza post, code available tomorrow
- Posts due **5pm Monday 1 Jul**