LI 308: Computational Models of Sound Change

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Pierrehumbert (2001)

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] vs. *mammary* $\not>$ [mæmɹi] (Hooper, 1976)
  - *told* $>$ [tol] vs. *meant* $\not>$ [mɛn] (Hooper, 1976)

- Frequency also correlated with rates of diachronic change (e.g. Philips, 1984, 1986; Bybee, 2001, 2002; but cf. Labov, 1981, 1994)
  - (low-frequency) *nude* */njud/ $>$ [nuːd], not [njuːd], while
  - (high-frequency) *new* */nju/ $>$ [njuː], not [nuː]

Pierrehumbert (2001)

- 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.’

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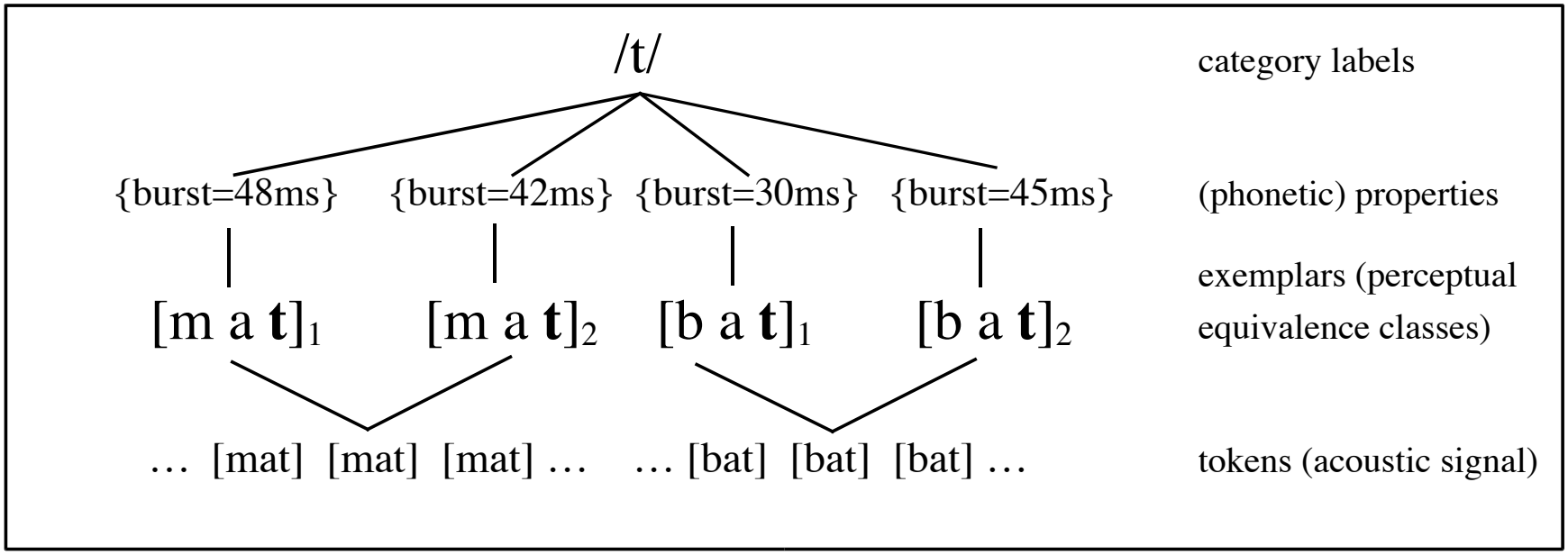
Elements of exemplar ‘theory’

- 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

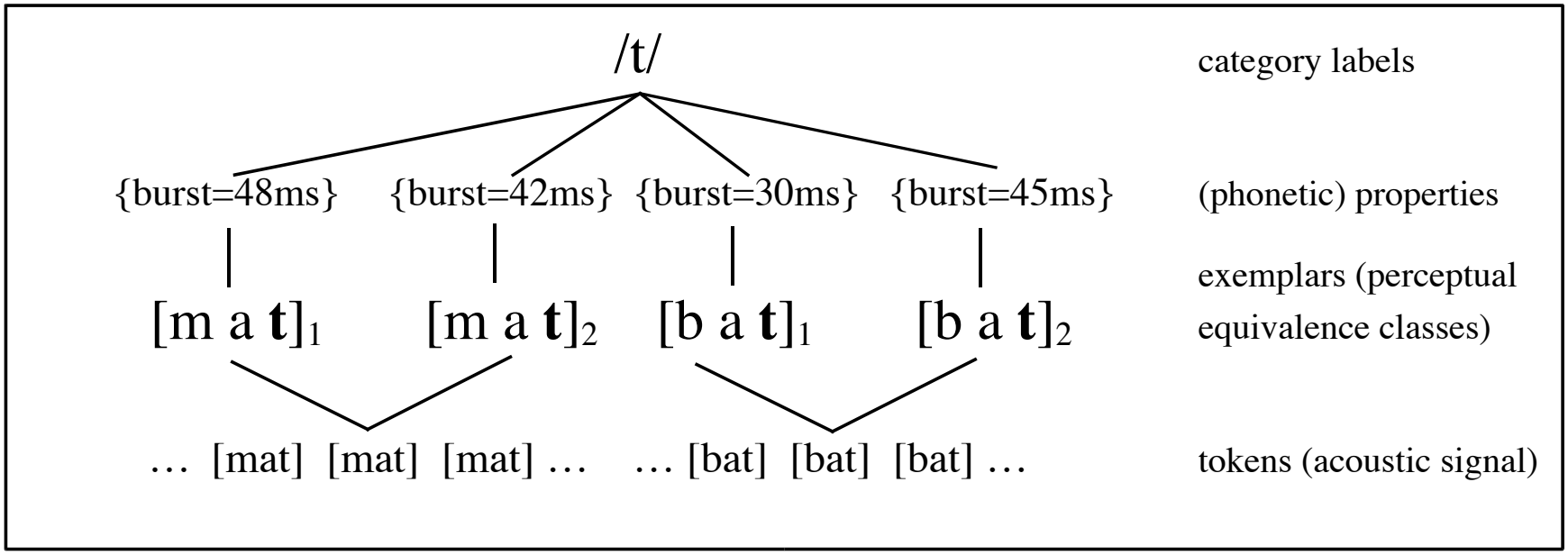
Exemplar storage: Units (knowledge state)



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

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

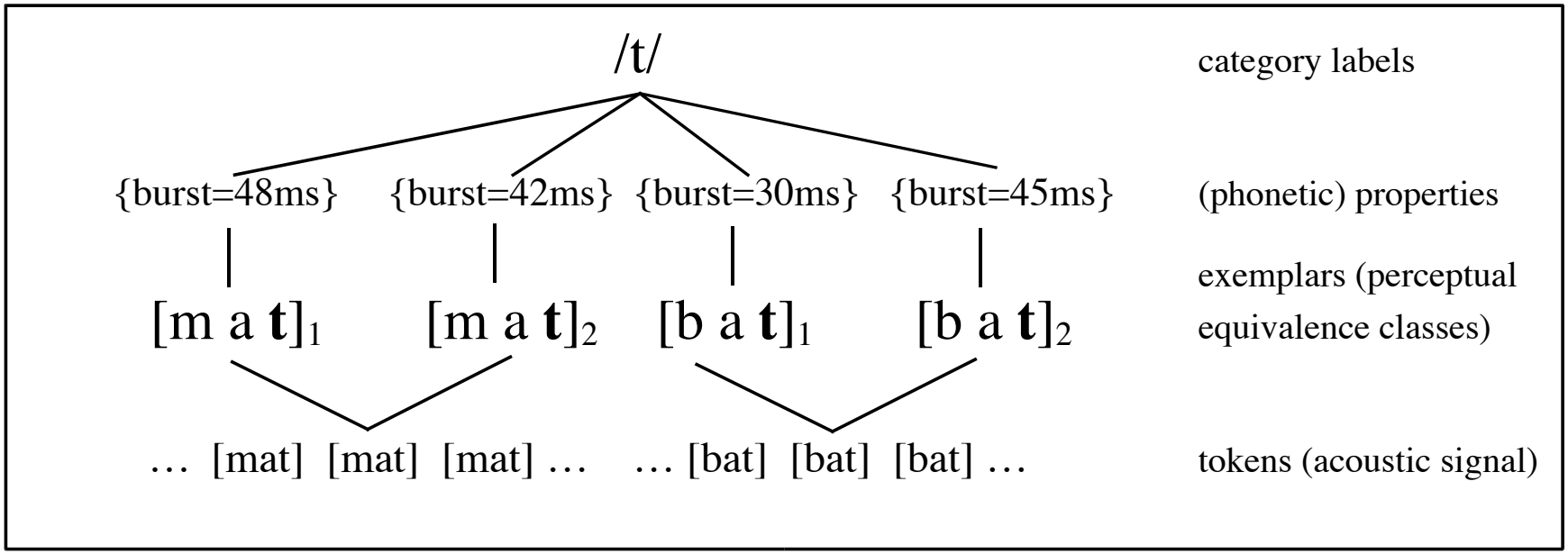
Exemplar storage: Units (knowledge state)



- Individual exemplars represented as (property, label) pairs

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

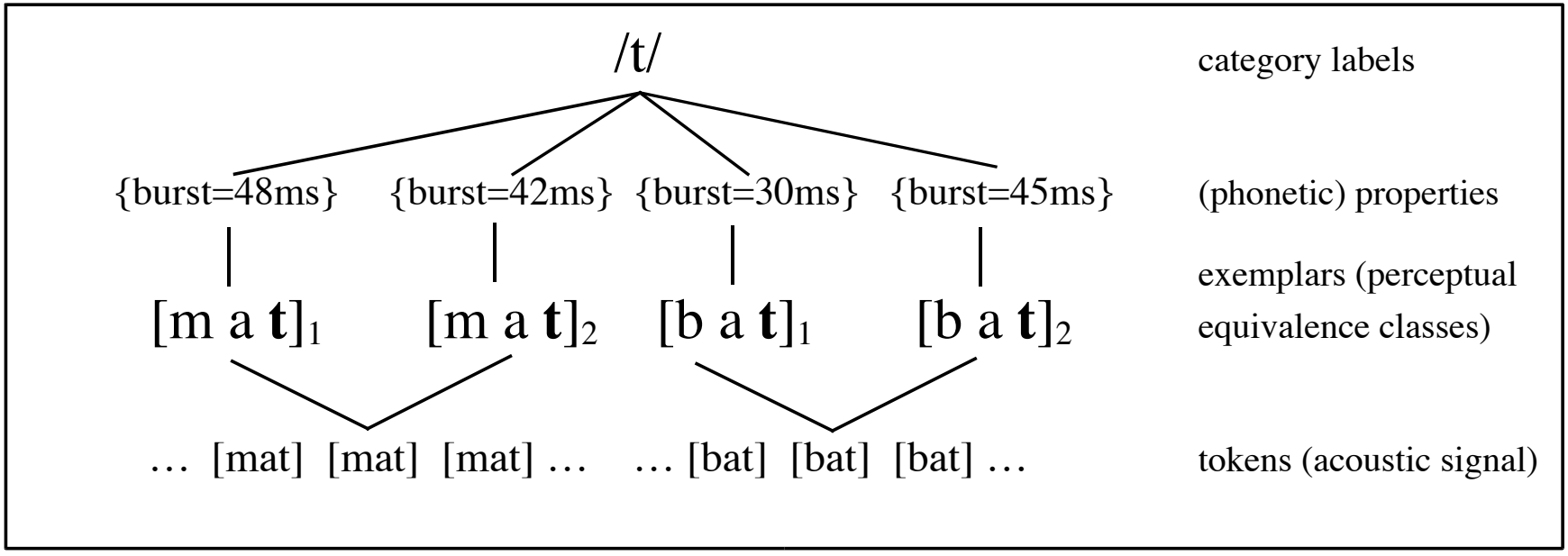
Exemplar storage: Units (knowledge state)



- Individual exemplars represented as (property, label) pairs

$$e_1^L = \begin{bmatrix} burst, & 48\,ms \\ ons_{f0}, & 122\,Hz \\ \dots & \dots \end{bmatrix}, e_2^L = \begin{bmatrix} burst, & 42\,ms \\ ons_{f0}, & 113\,Hz \\ \dots & \dots \end{bmatrix}, \dots$$

Exemplar storage: Constraints

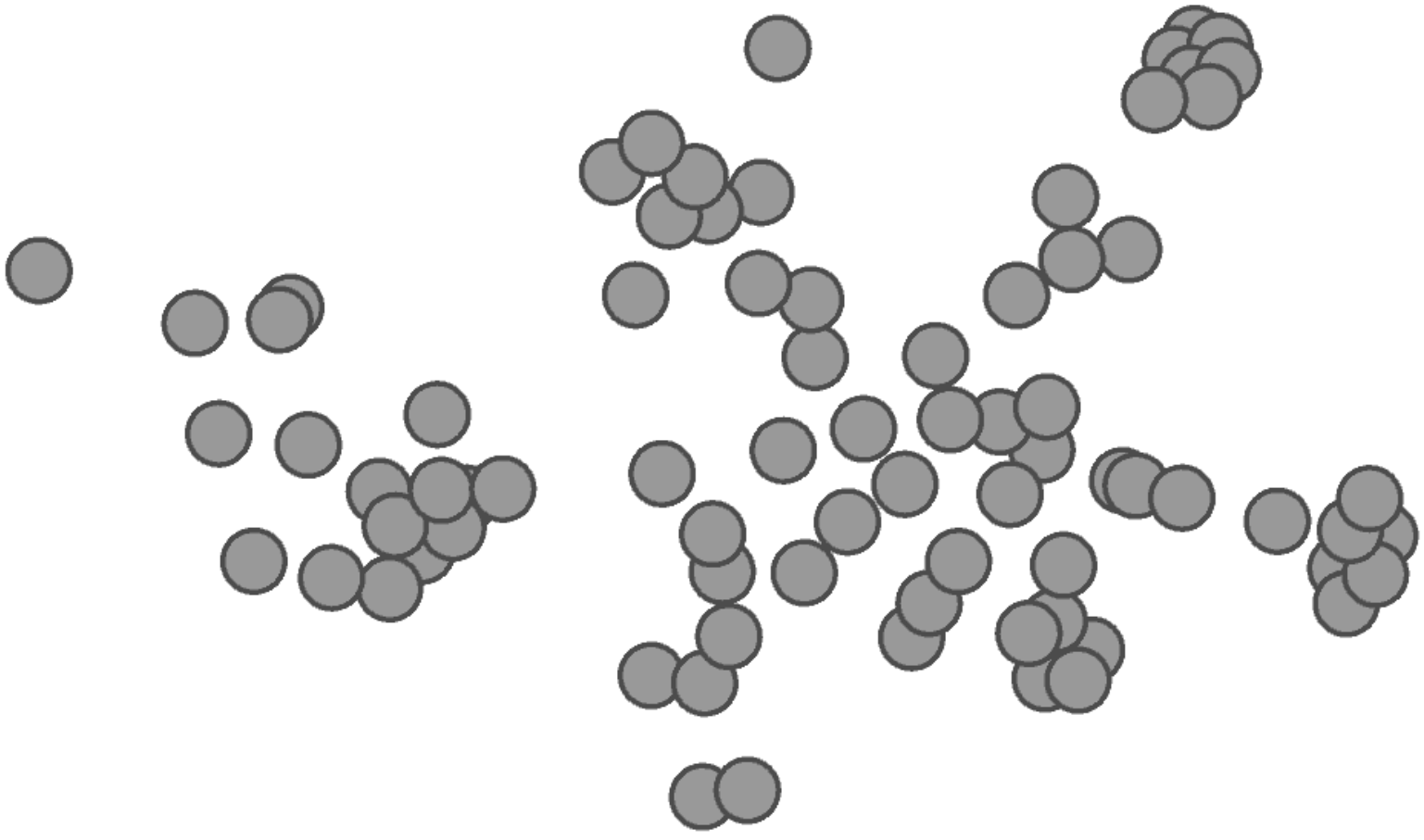


- Memory limitations → memories decay
- Perceptual limitations → granular representations

Model 1: Single category

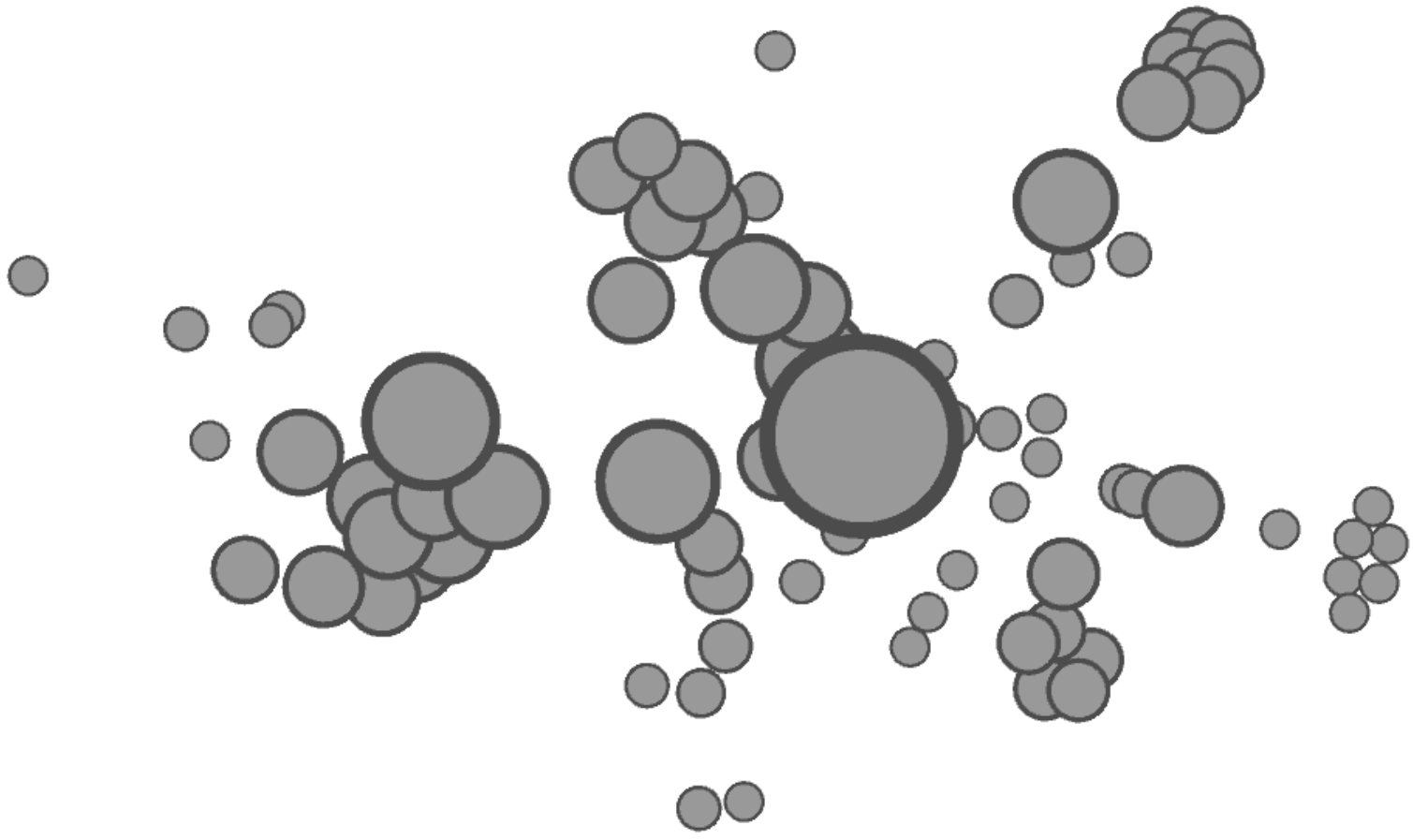
- Single speaker/hearer, talking to themself
- Entails simple(st) network structure
- Knowledge state as detailed above
- What are the assumptions about communication and learning?

Model 1: Production



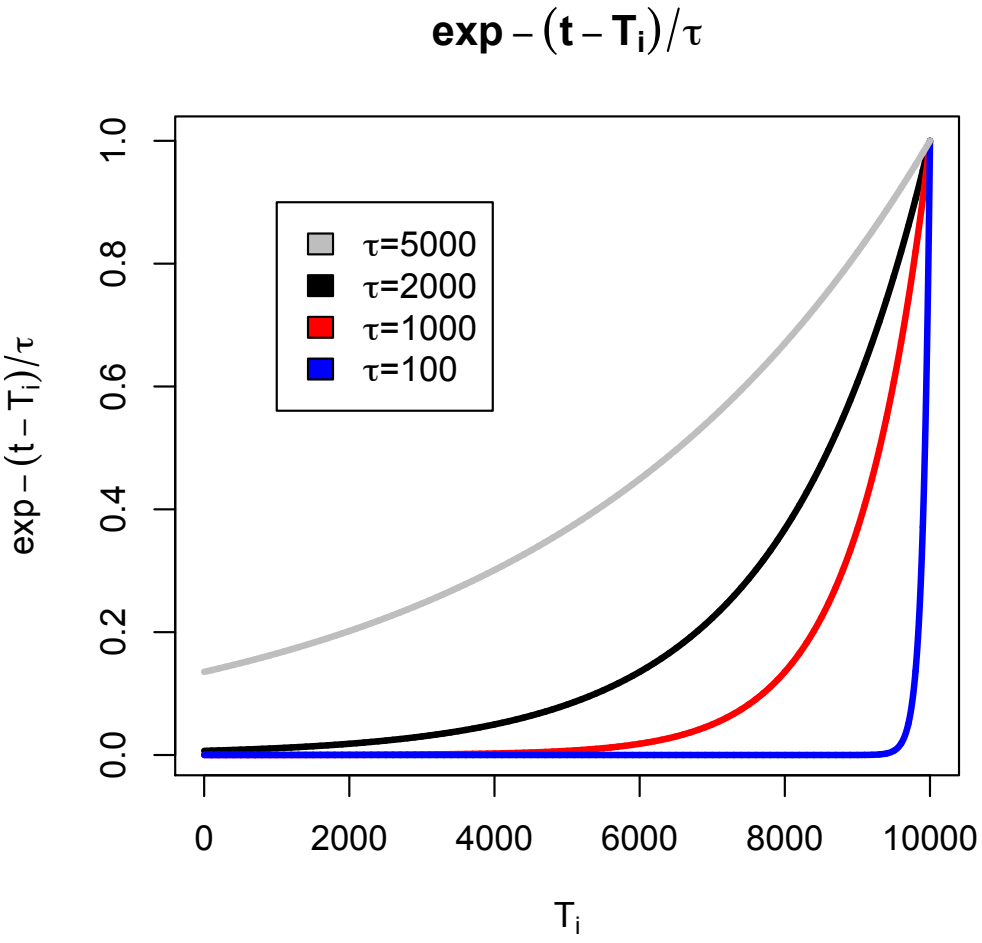
...if target were selected with uniform probability

Model 1: Production



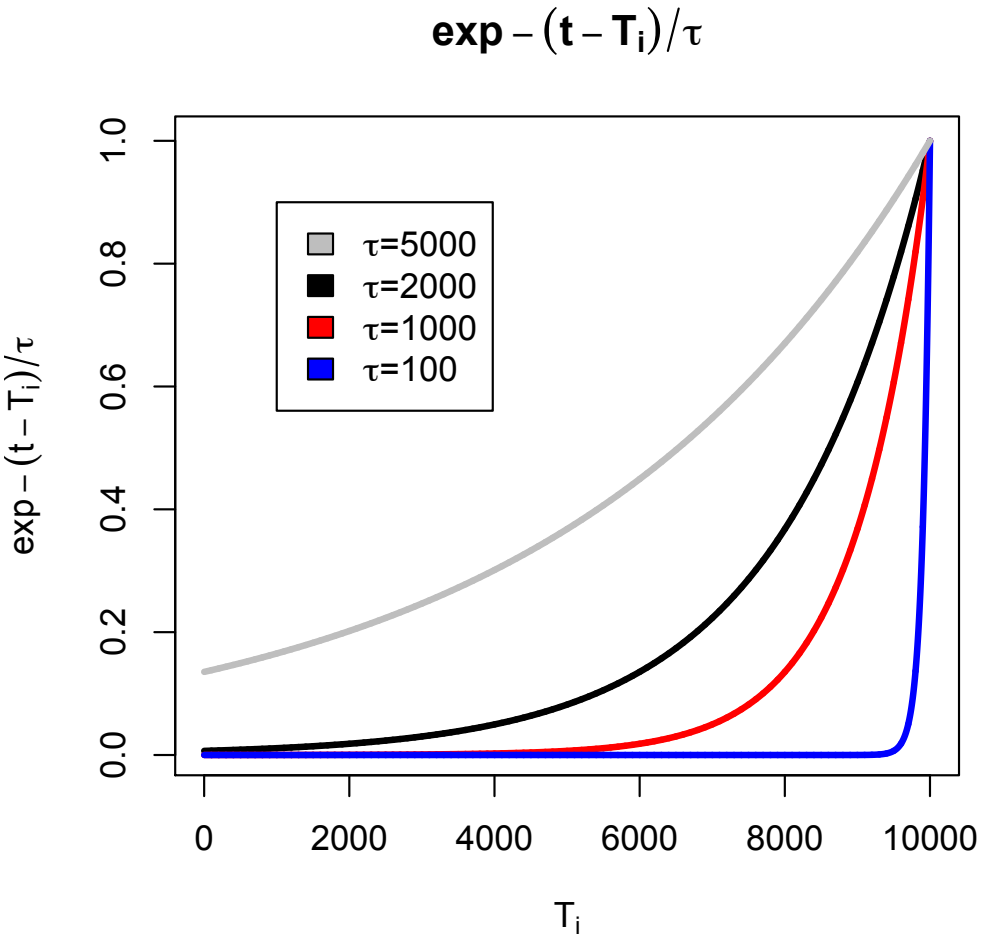
...target selected weighted by recency: $\exp(-\frac{t-T_i}{\tau})$

Model 1: Production



- Need some way model recency, based on:
  - current time
  - time exemplar was stored
  - memory decay weight
- Called resting activation level

Model 1: Production



- Resting activation level a function of time and τ:

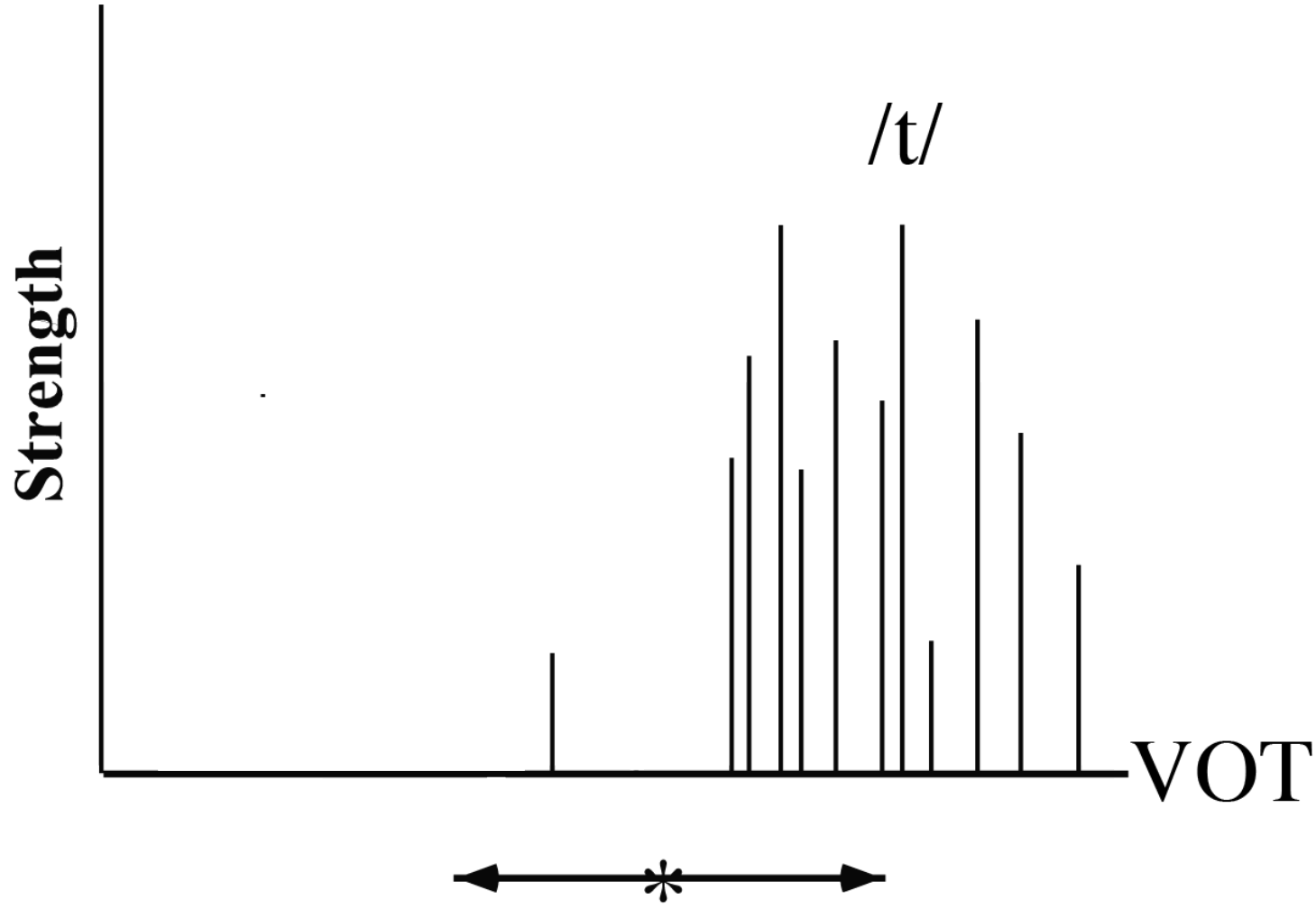
$$\exp(-\frac{t-T_i}{\tau})$$

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

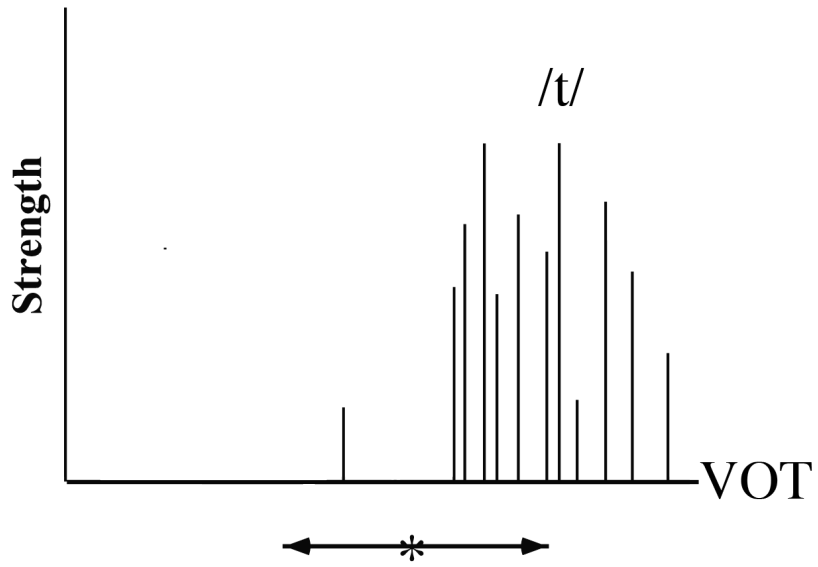
Model 1: Production

- 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 $.1$)
- (No one seems to have ever dealt with the problem of how to choose an empirically grounded ϵ...)

Model 1: Perception



Model 1: Perception

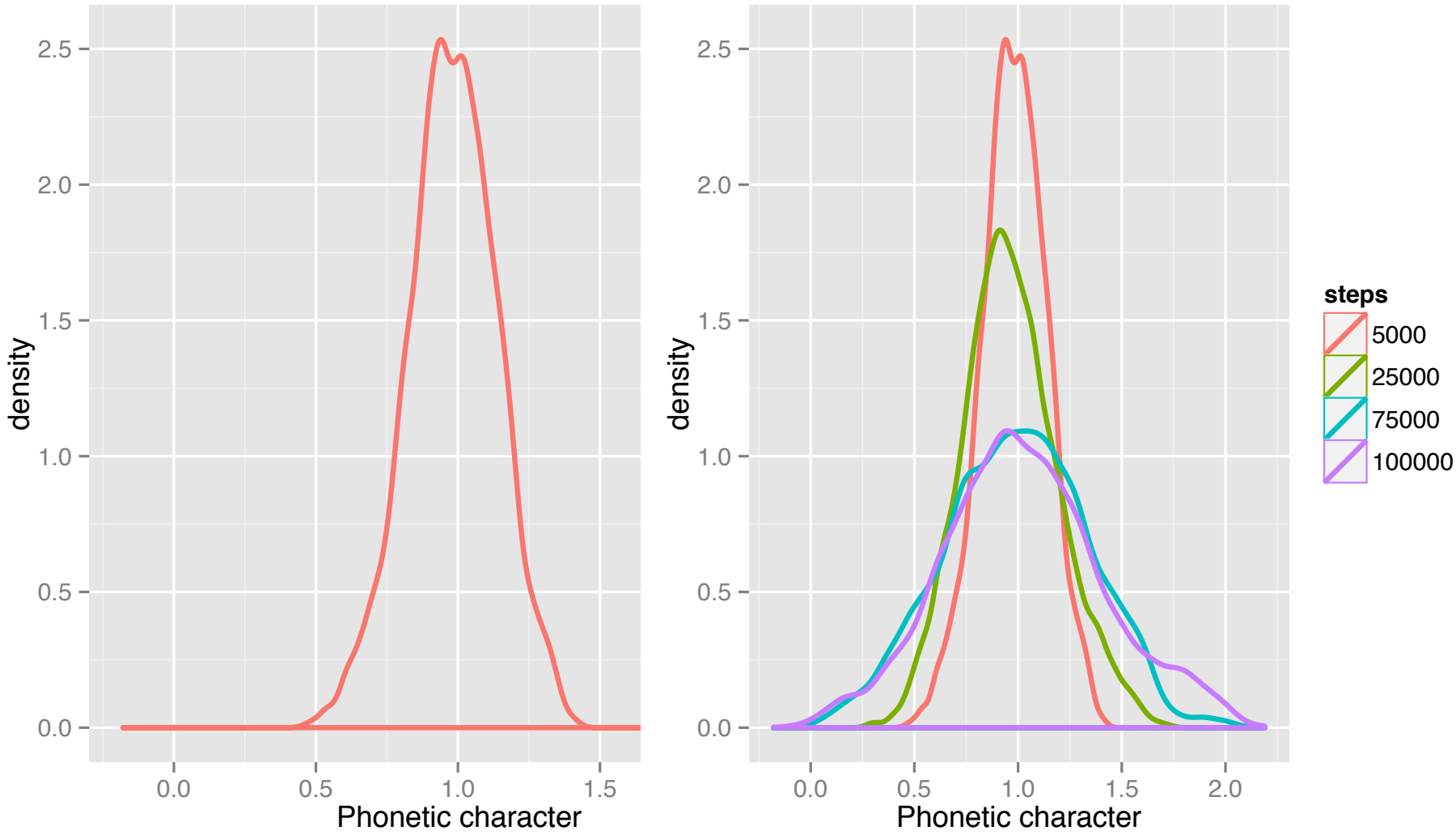


$$W(x - e_i^L) = \begin{cases} 1 & \text{if } |x - e_i^L| < 0.05 \\ 0 & \text{otherwise} \end{cases}$$

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

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

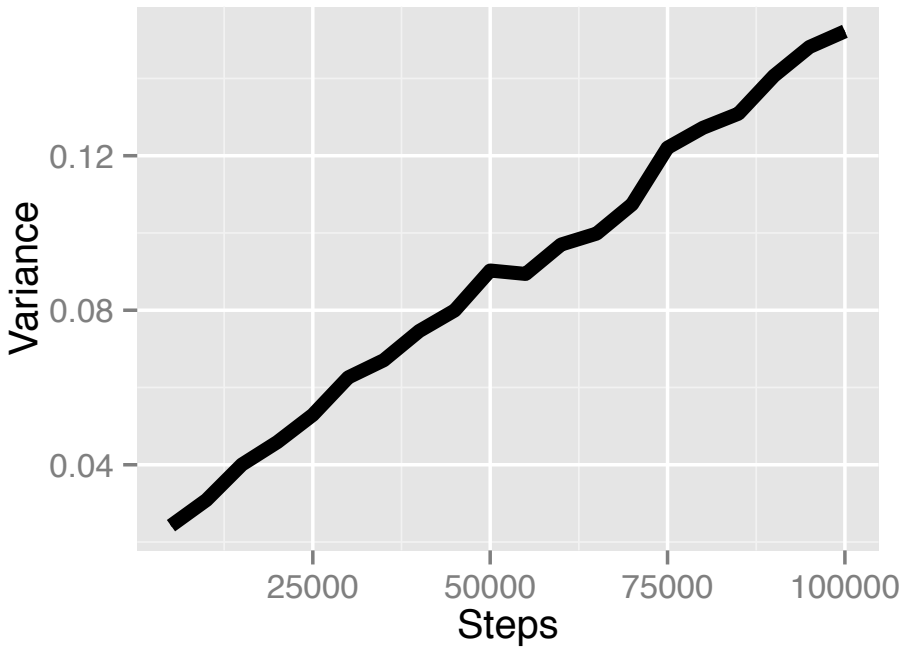
Model 1: Results



cf. Example 1.1

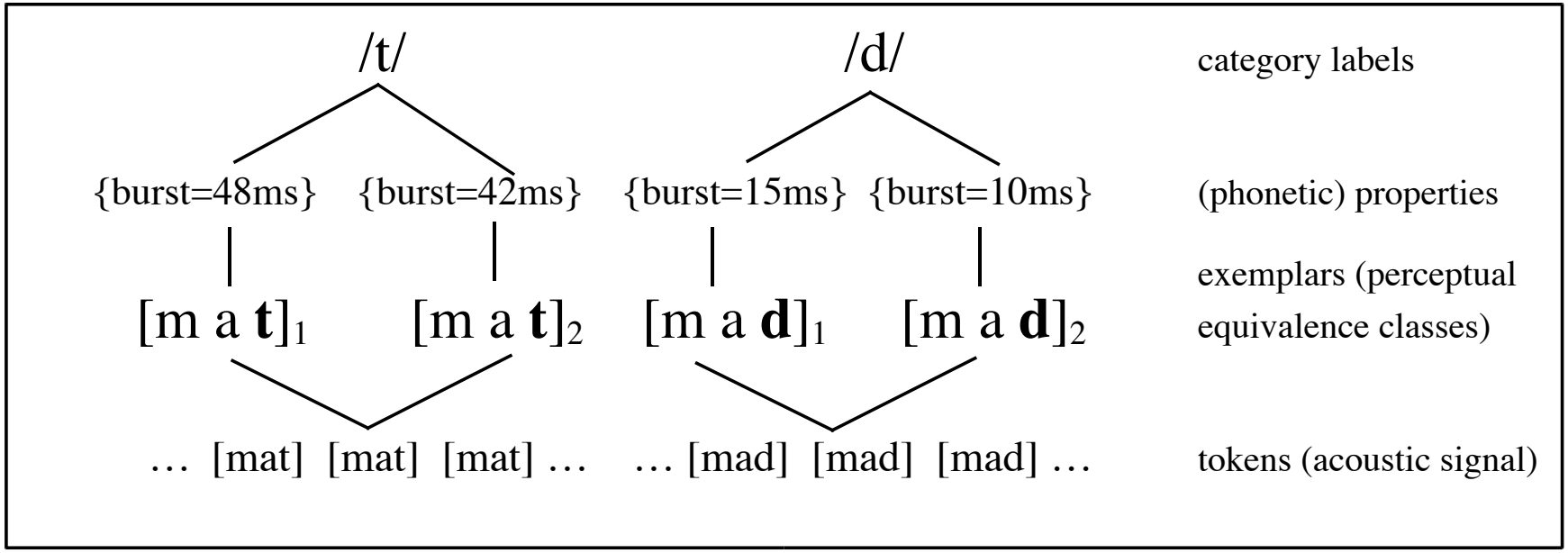
Model 1: Results

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 1a: Two categories

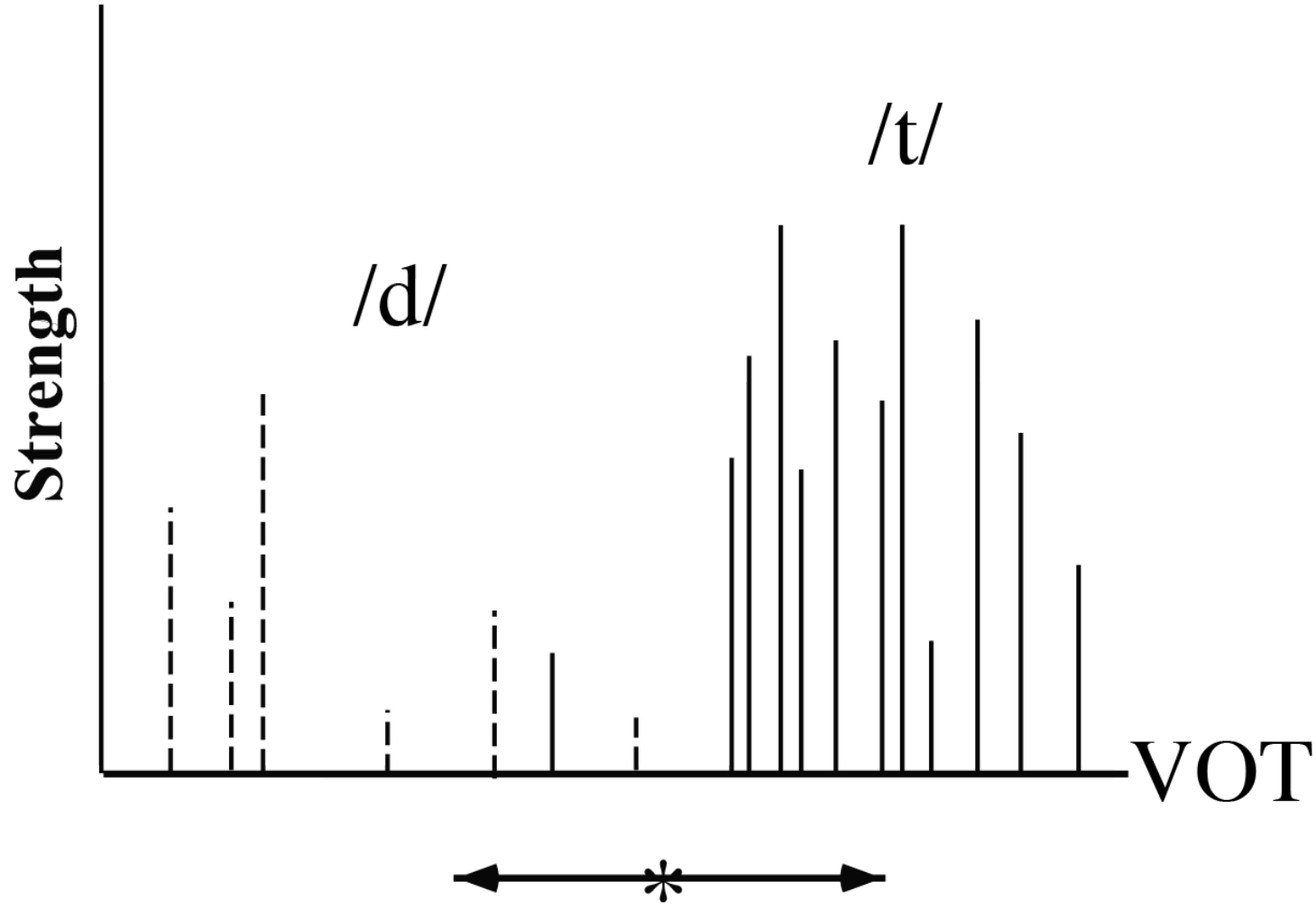


- How do we extend this model to more than one category?

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

- Now there is a meaningful score for each list (category) L:

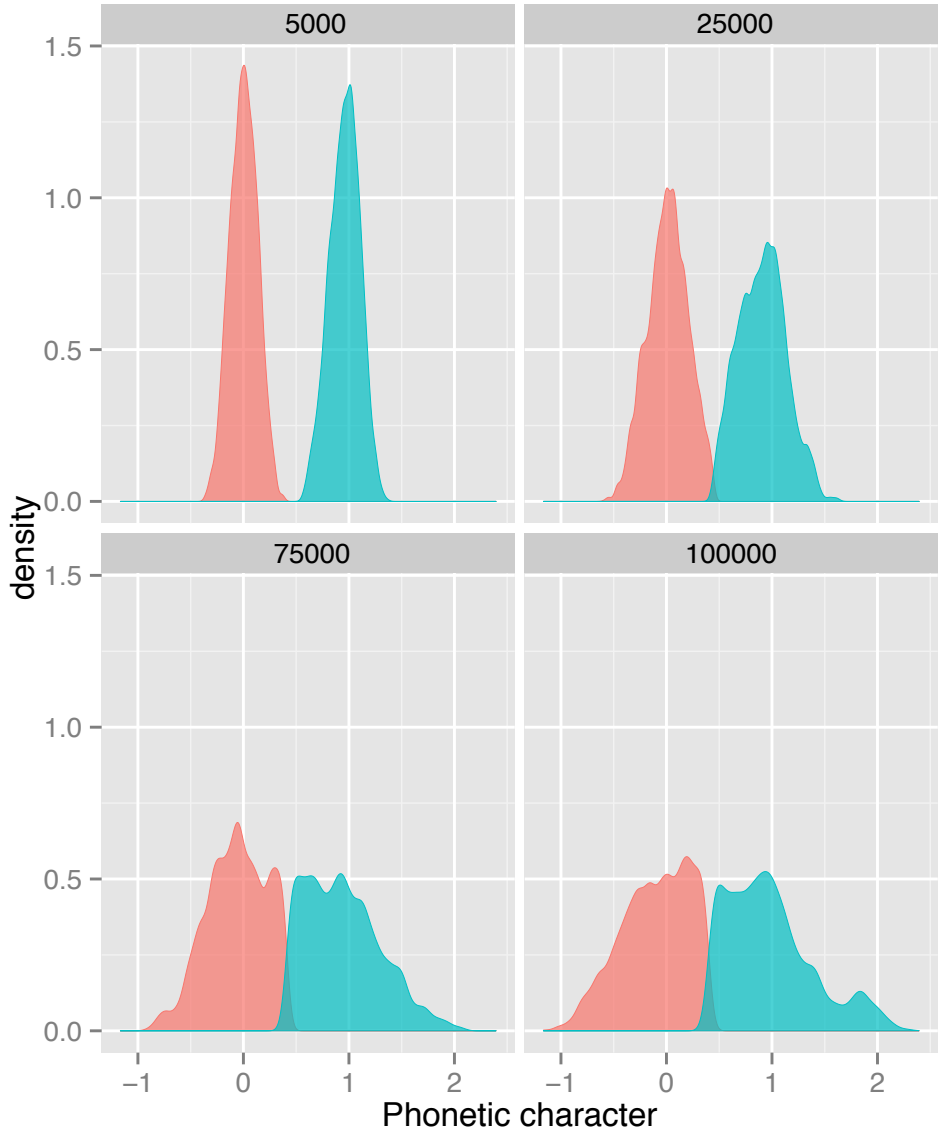
$$score(L, x) = \sum_{i}^{n} \underbrace{W(x - e_i^L)}_{\text{distance}} \overbrace{\exp(-\frac{t - T_i}{\tau})}^{\text{activation level}} \quad (1)$$

- Assign input x to list with the highest score:

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

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

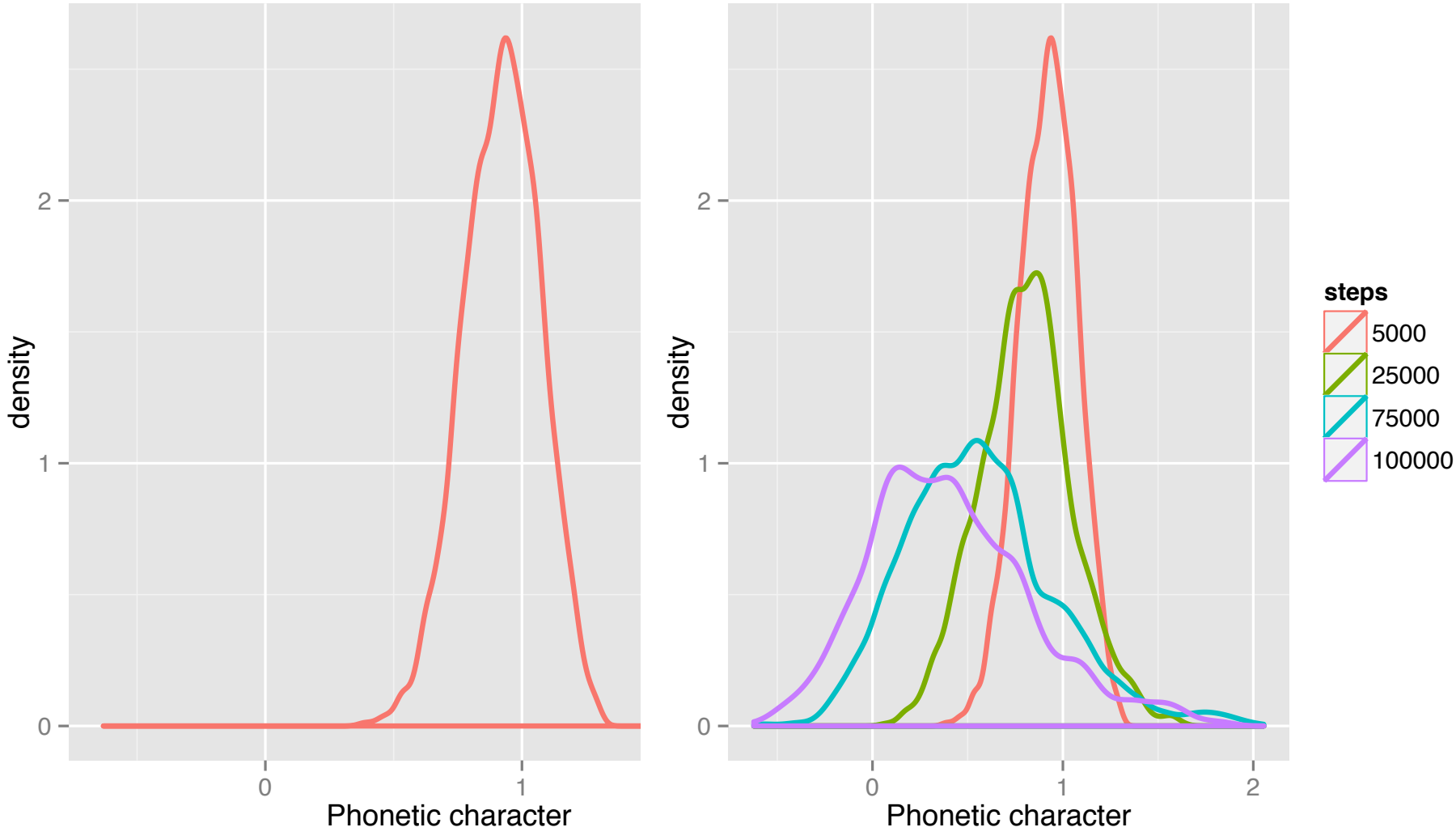
Model 1a: Results (cf. Example 2.1)



Model 2: Bias (lenition)

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

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?
- What is P’s synchronic interpretation of this result? What additional assumptions does it make or rely on?

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:

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

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

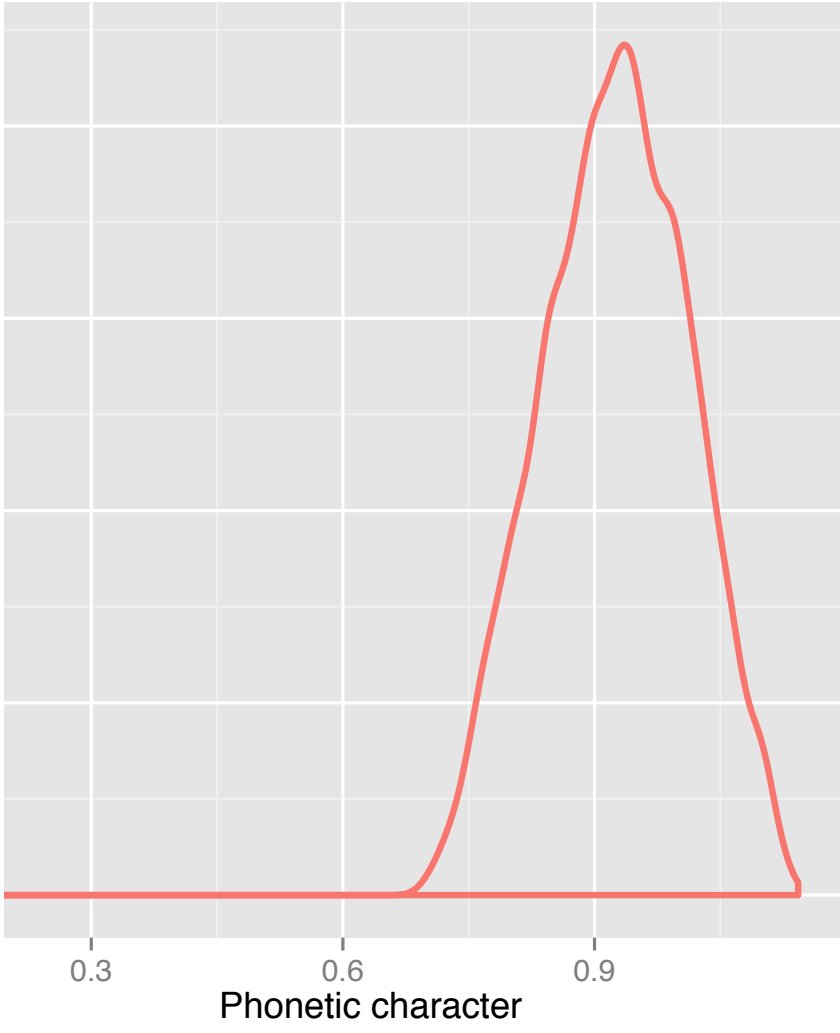
Model 3: Lenition + Entrenchment

- **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:

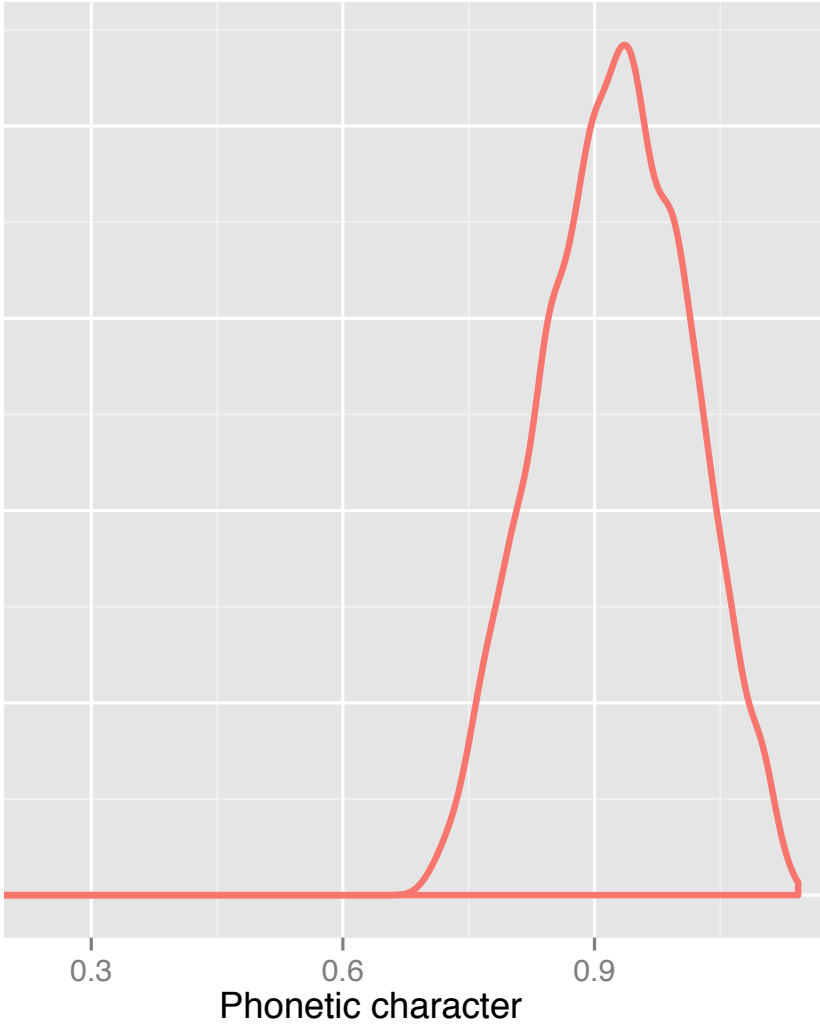
$$d_i = |x_{target} - e_i^L| \, \omega(T_i, t) \tag{5}$$

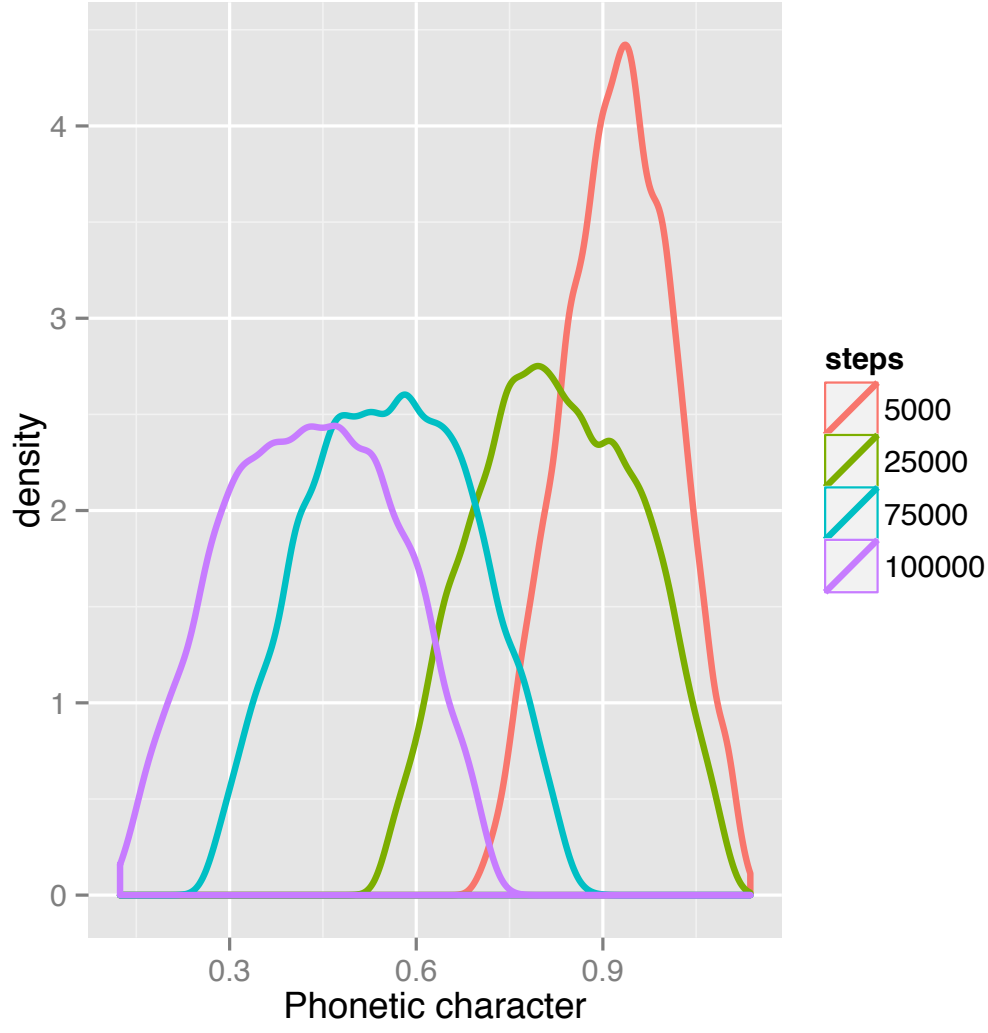
$$x = \frac{\sum x_i \omega(T_i, t)}{\sum \omega(T_i, t)} \text{ for } n_{trench} \text{ closest exemplars} \tag{6}$$

Model 3: Results

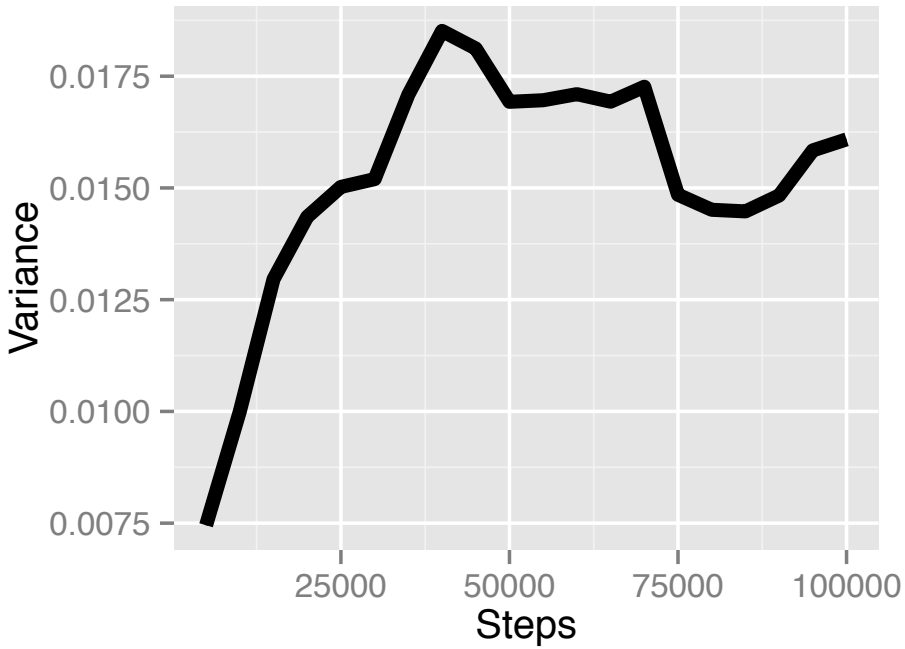


Model 3: Results



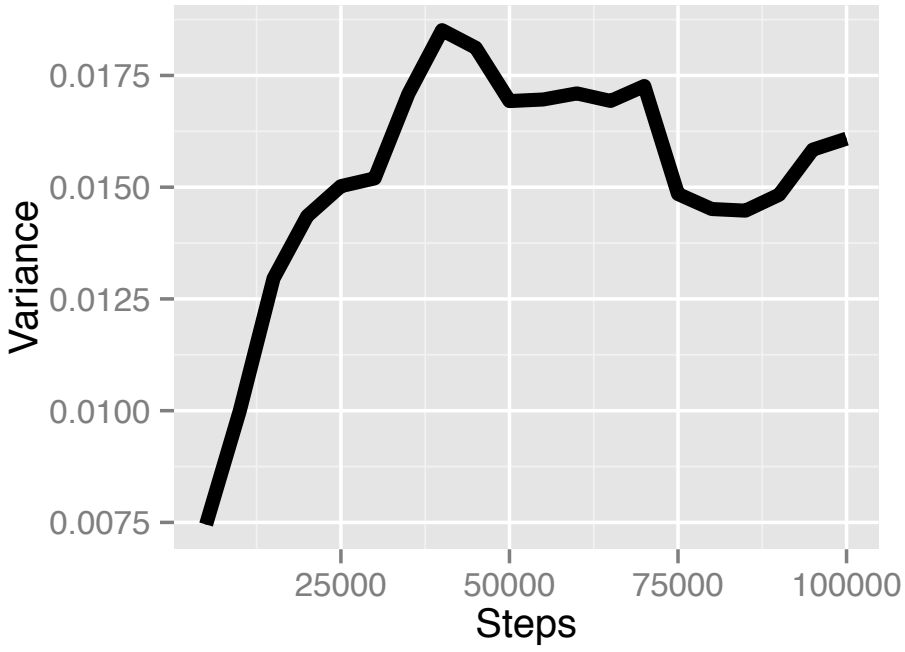


Model 3: Conclusions



- ‘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.’

Model 3: Conclusions



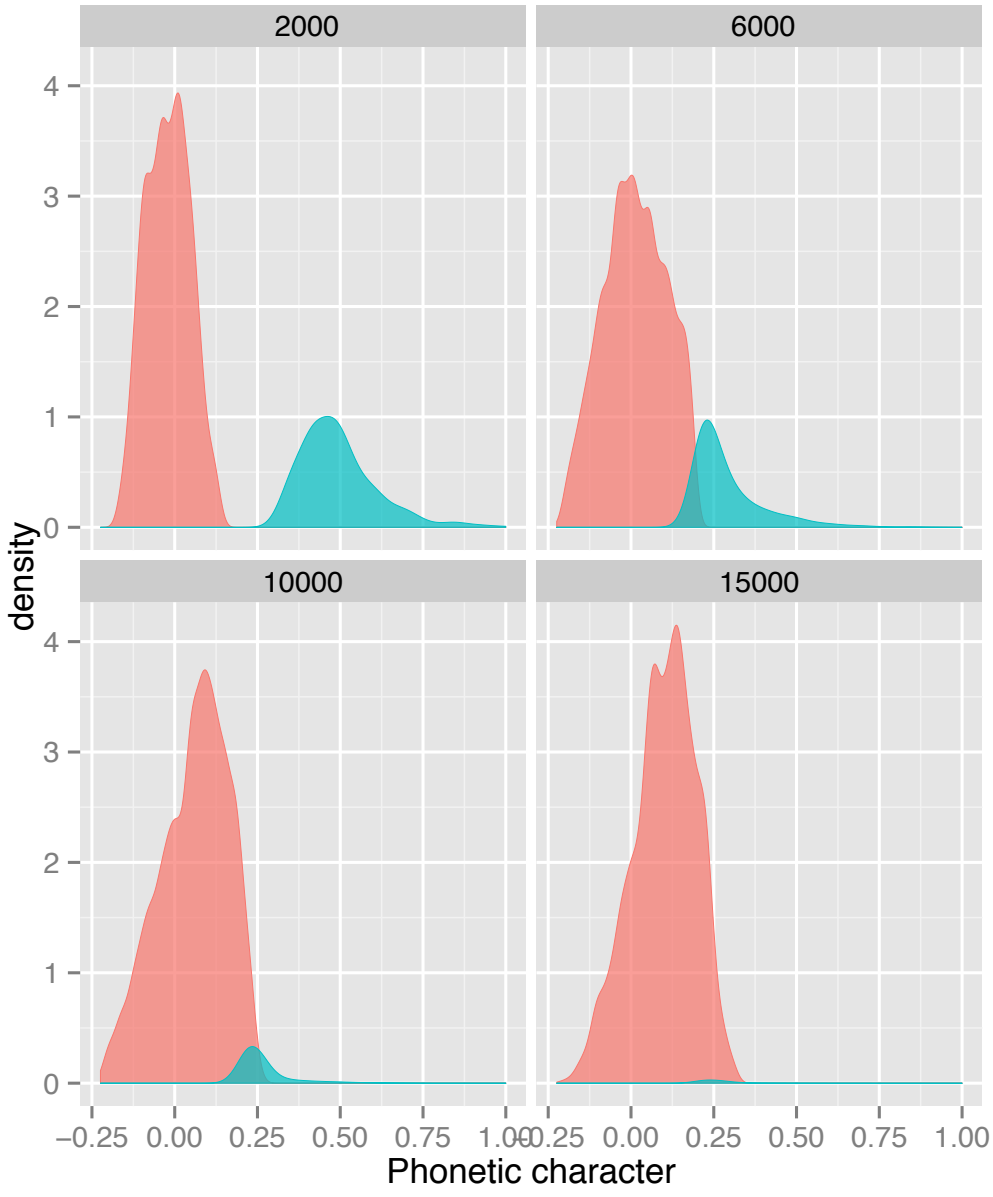
- In other words: variance stabilizes at some point
- For what range of parameter settings will this property obtain?

- (Extra credit: why does Wedel's model not seem to need this?)

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 e.g. just unequal frequencies, full stop?)

Model 4: Results



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

Assumptions/limitations

- **Category labels.** Here: given. Where do they come from?
- **Words vs. phonemes.** What level of granularity is being modeled here? How do these levels relate to one another?
- **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?

Lab: 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?

Lab: 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
- Posts due **5pm Sunday 26 July**