Using Bayesian Approaches to Study Human Sound and Word Learning

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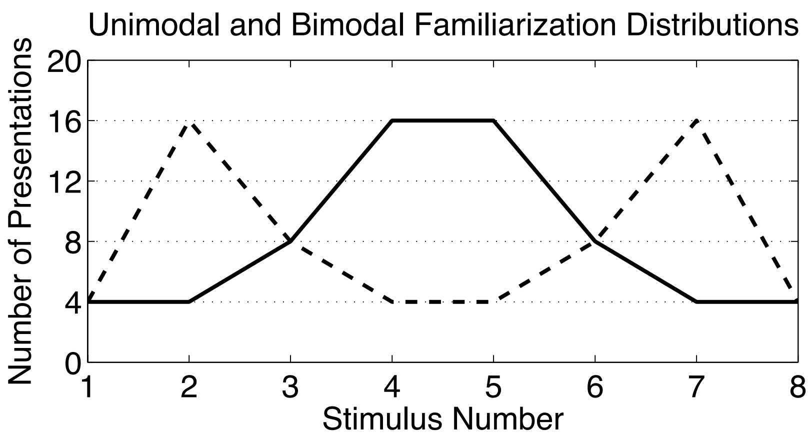
University of Maryland

CLSP Miniworkshop:
Zero Resource Speech Technologies
and Models of Early Language Acquisition
July 17, 2012

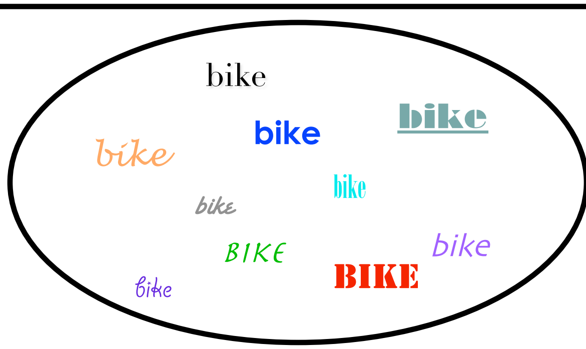
Joint work with Erin Bennett, Sharon Goldwater, Tom Griffiths, Yakov Kronrod, James Morgan, Emily Myers, Katherine White

Language Acquisition

Infants have a machine learning problem to solve…



Phonetic Categories



Words

Language Acquisition

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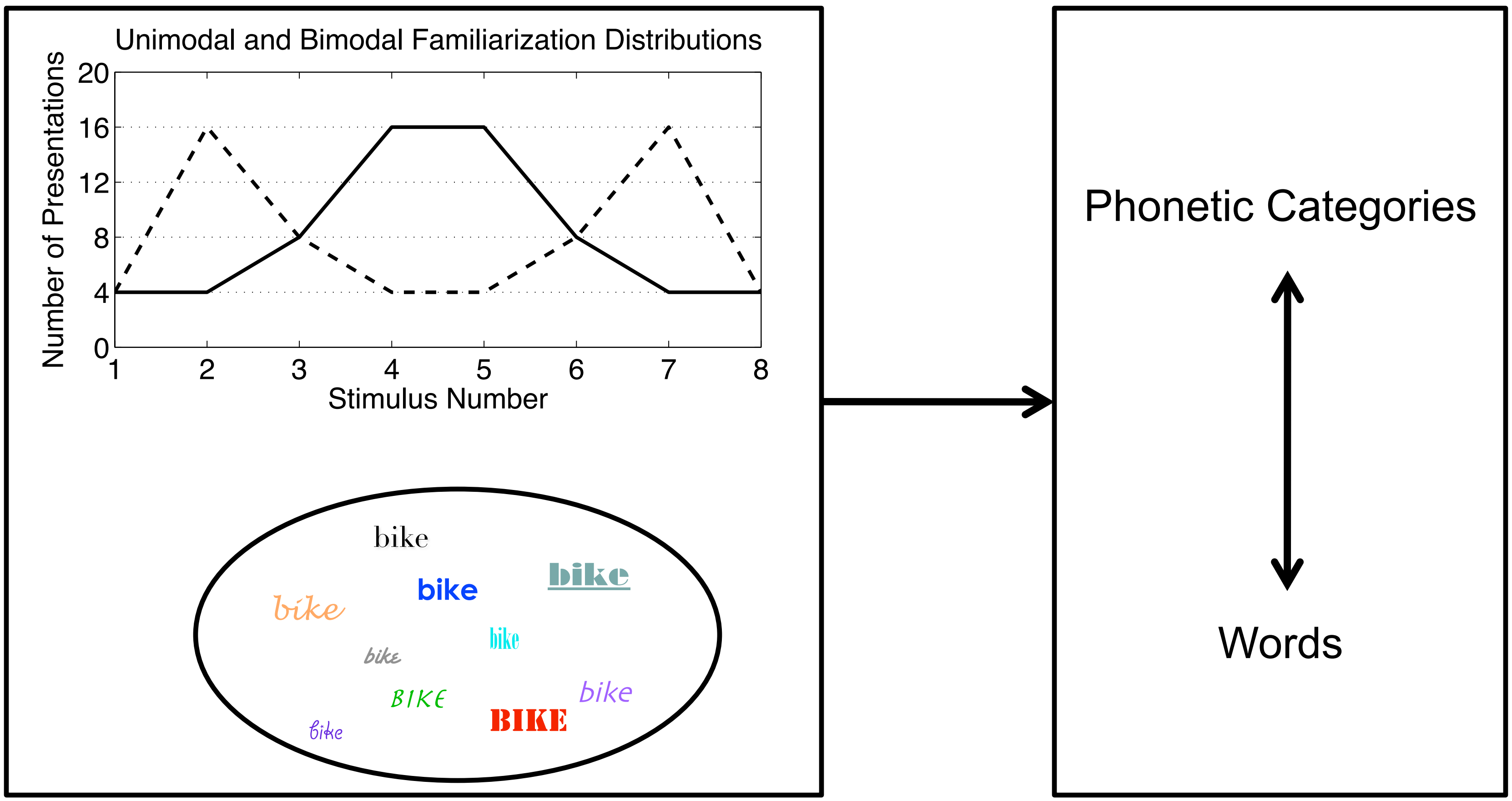
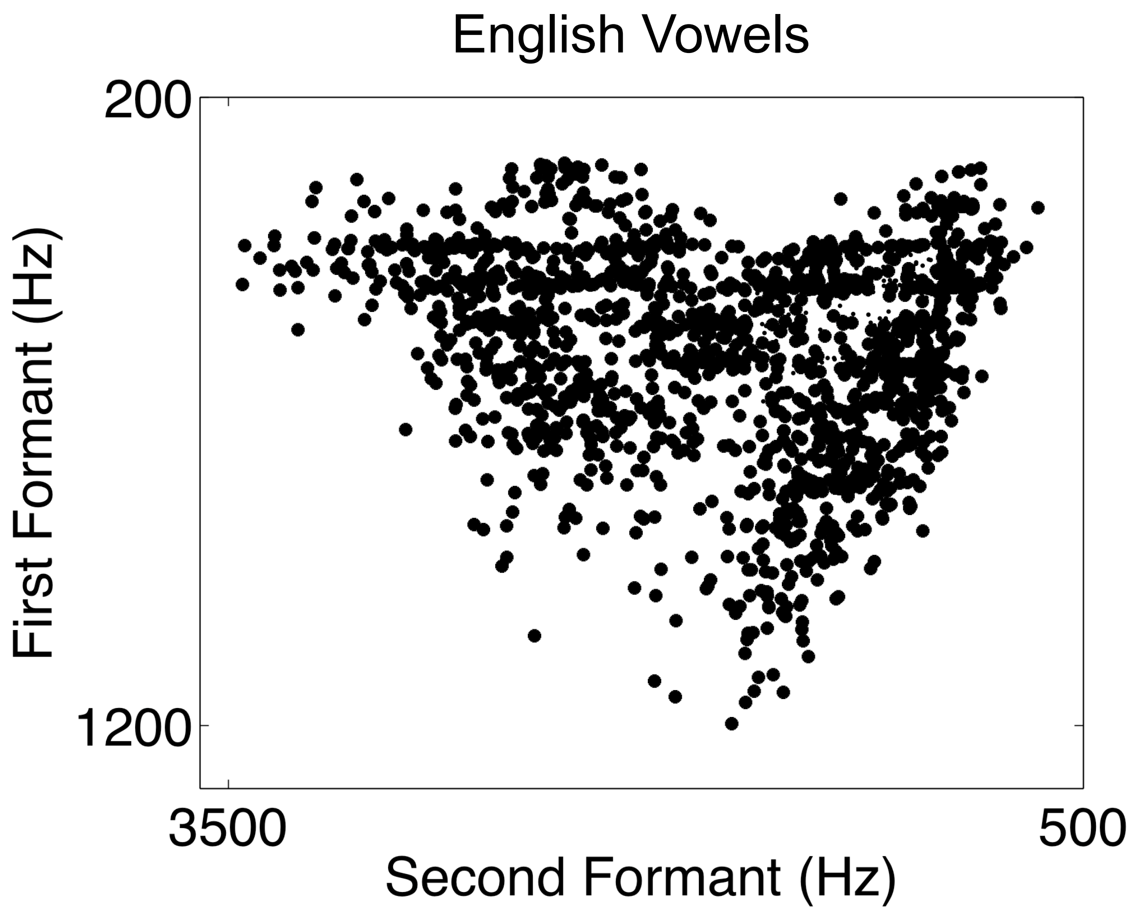


A Difficult Problem



(Hillenbrand, Getty, Clark, & Wheeler, 1995)

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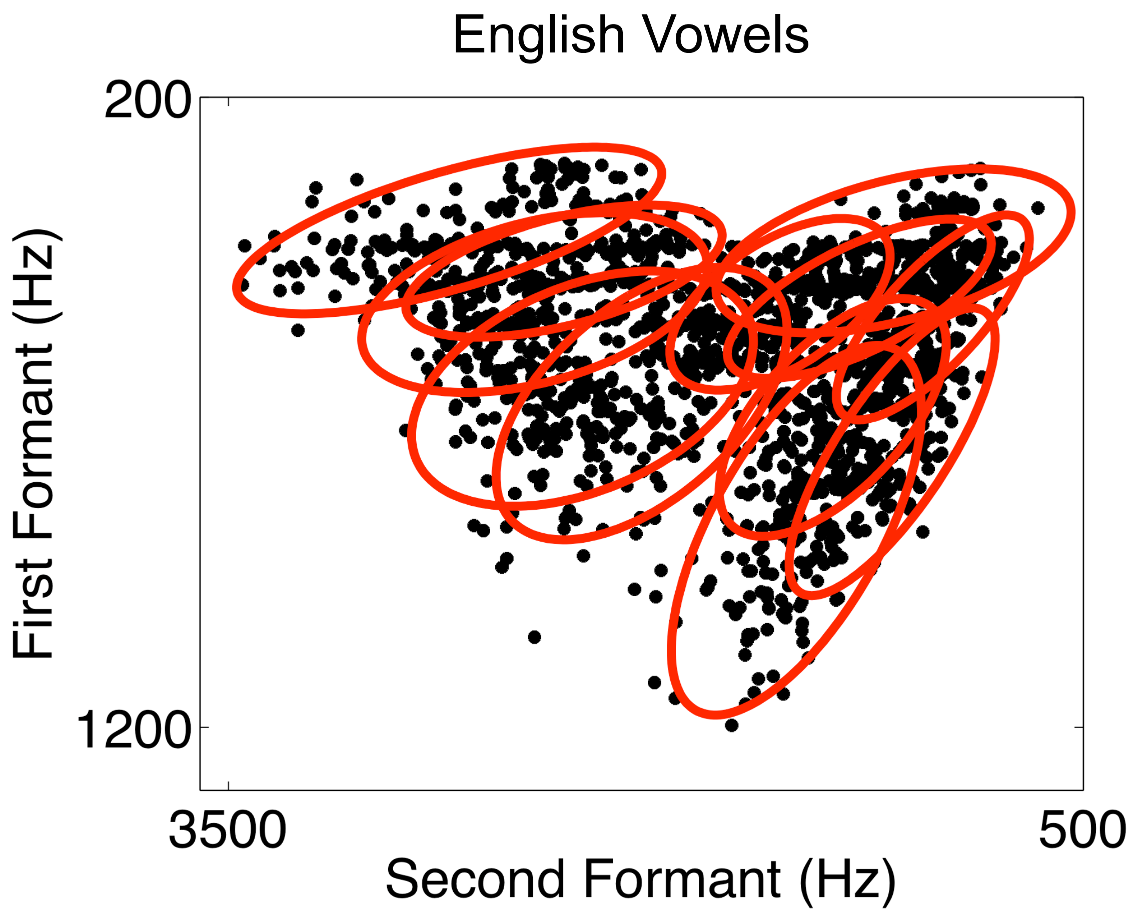

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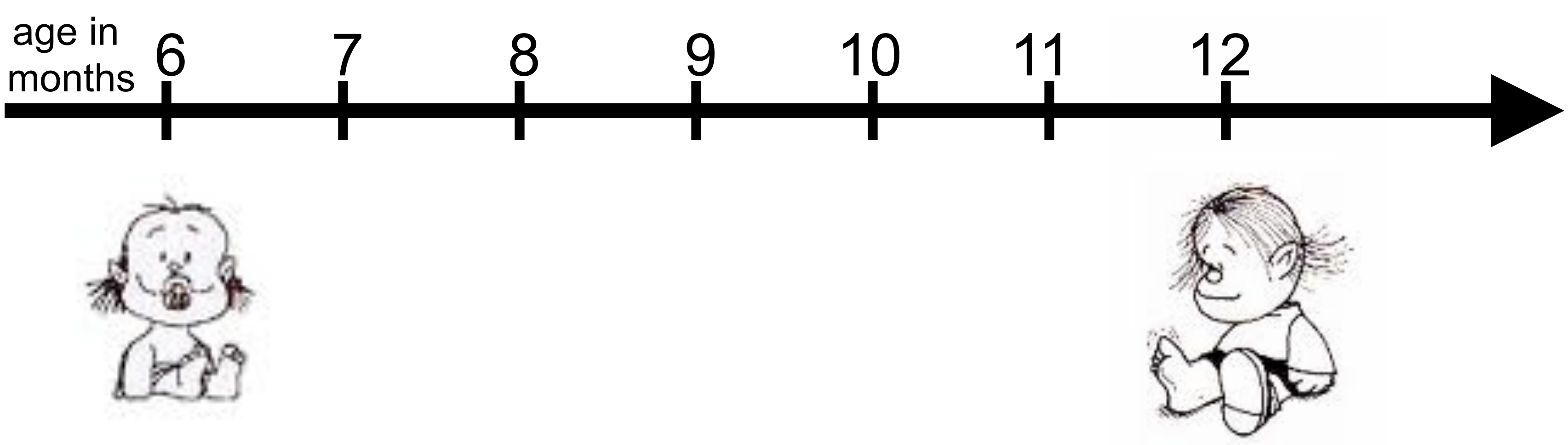
Phonetic Category Acquisition

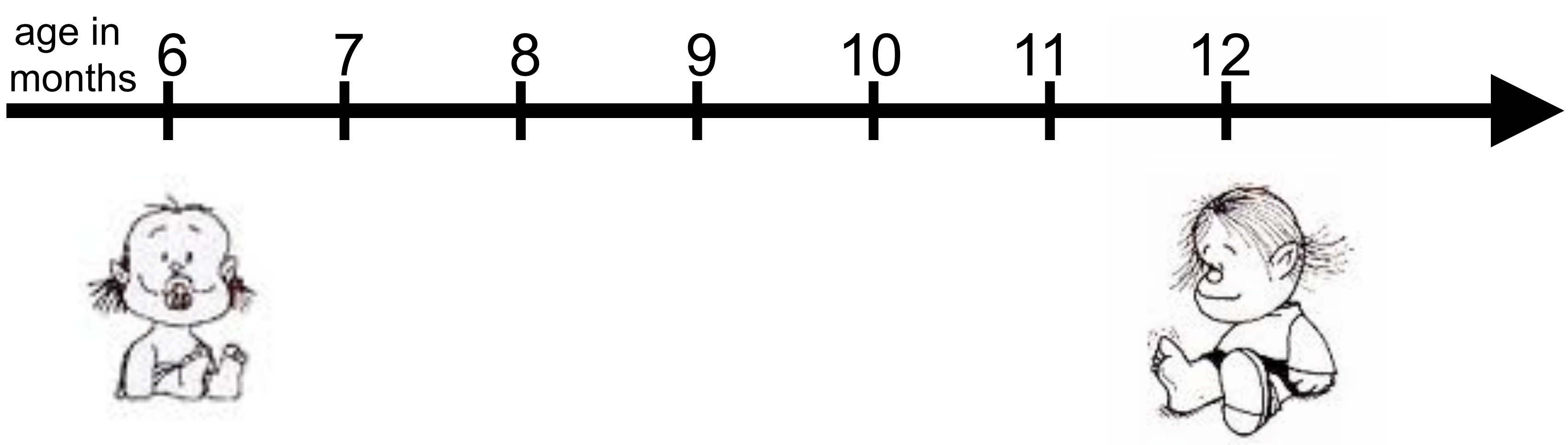


Phonetic Category Acquisition

6-8 months:
discriminate non-native consonant contrasts

10-12 months:
poor discrimination of non-native consonant contrasts

(Werker & Tees, 1984)



Phonetic Category Acquisition

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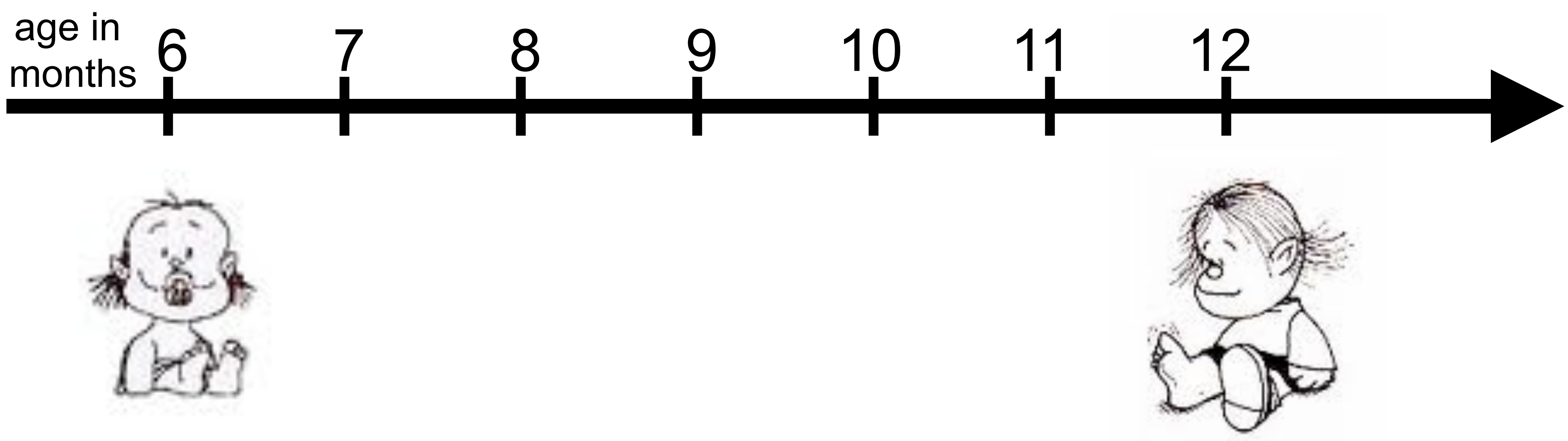
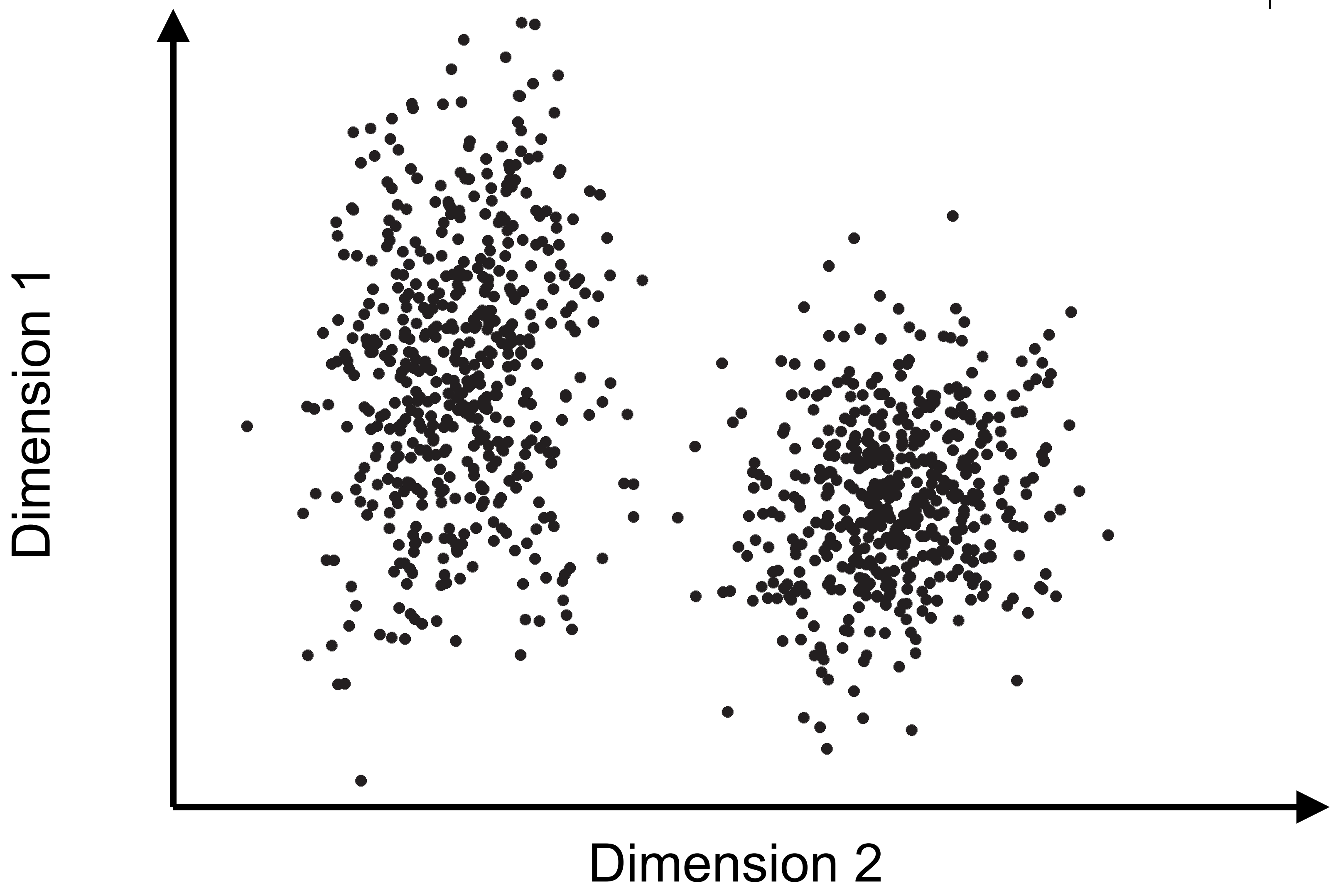


How are sound categories learned?

A Clustering Problem



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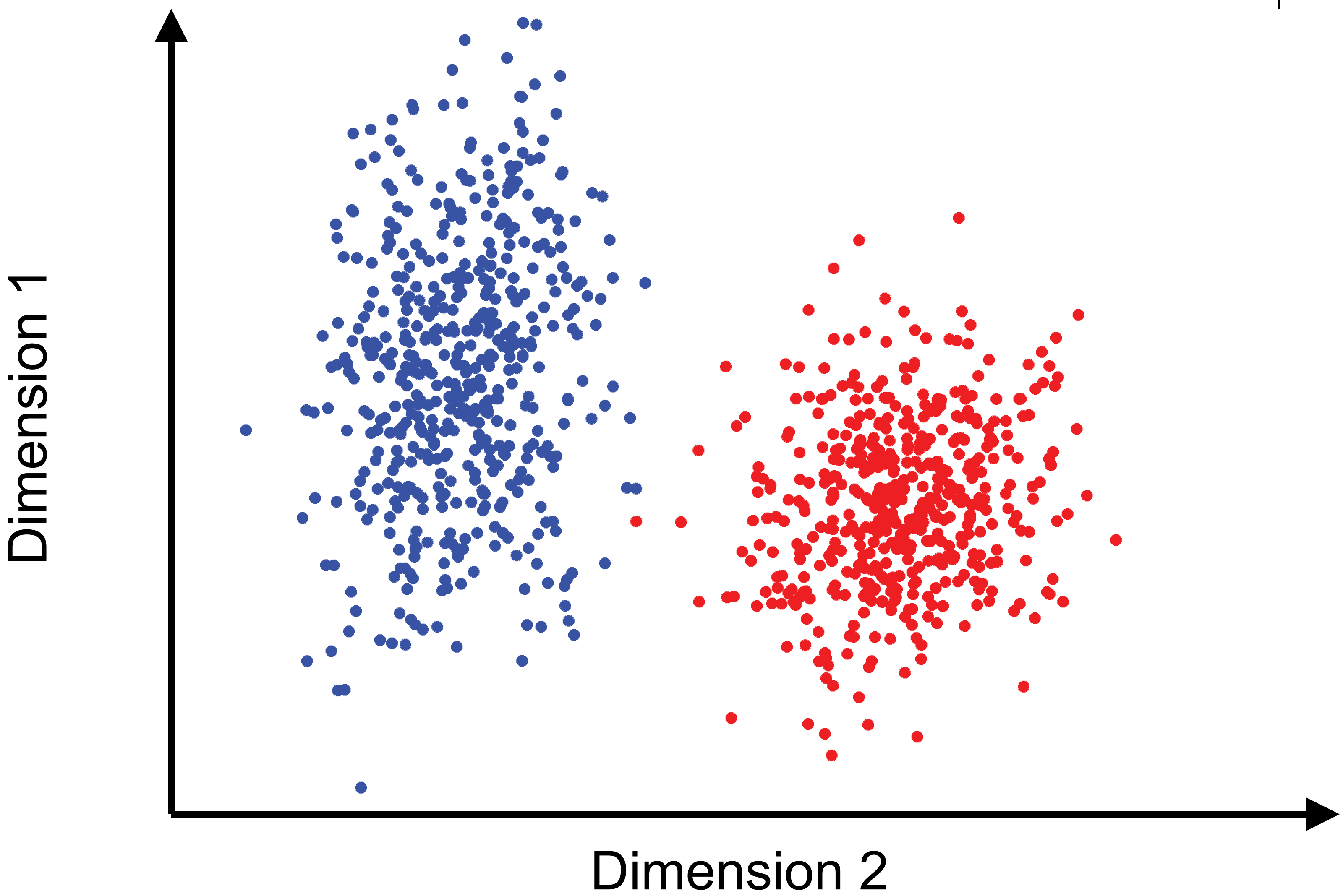
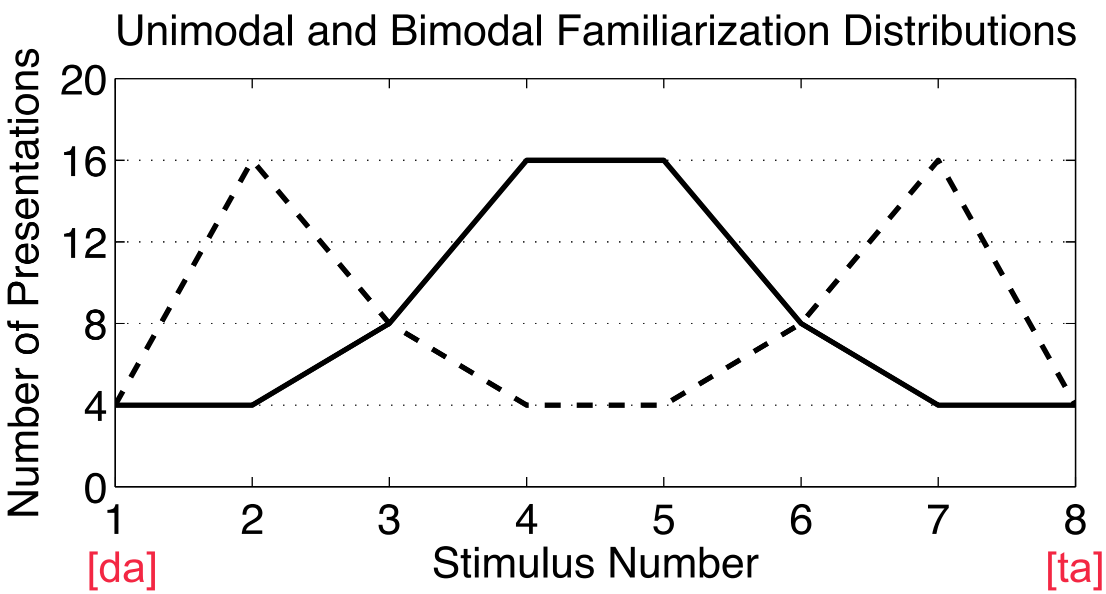


Distributional Learning



(Maye, Werker, & Gerken, 2002)

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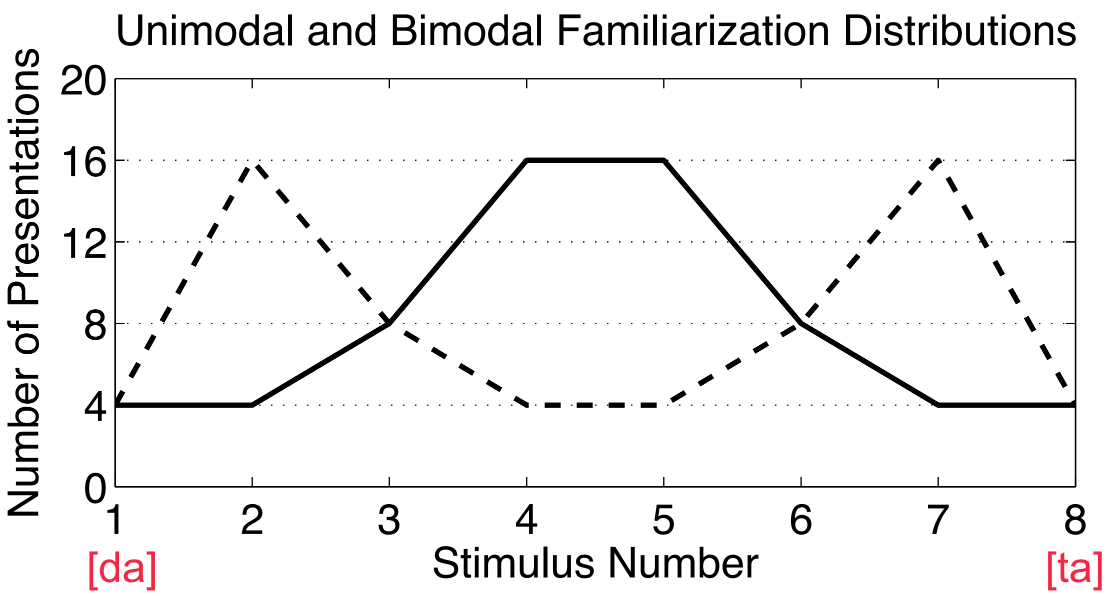


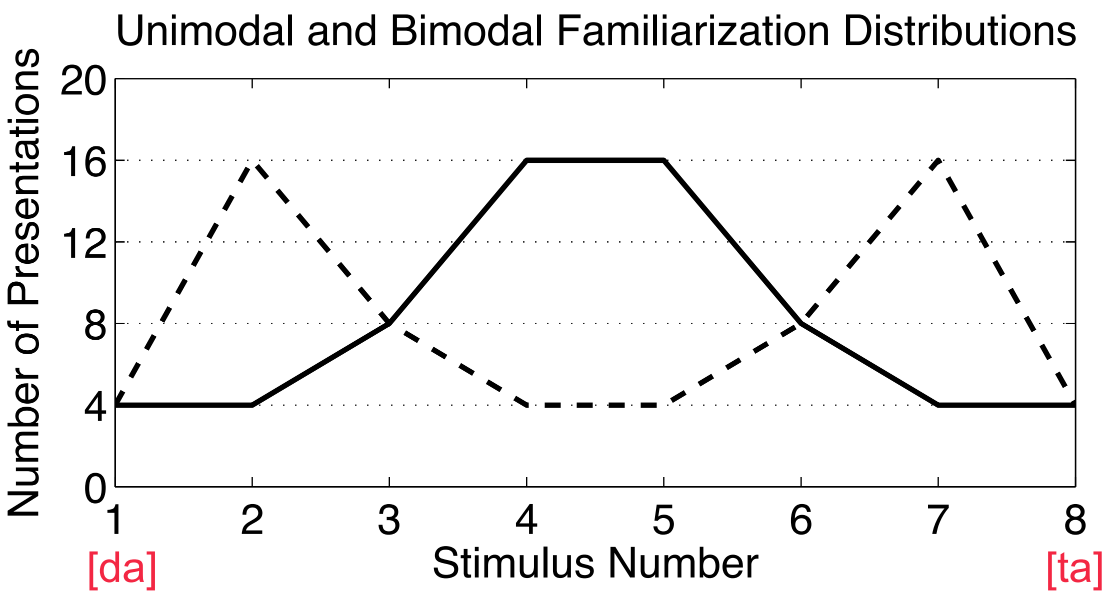
Test stimuli

Alternating trials (da_1-ta_8-da_1-ta_8)

Non-alternating trials (da_3-da_3-da_3-da_3, ta_6-ta_6-ta_6-ta_6)

(Maye, Werker, & Gerken, 2002)

Distributional Learning



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Bimodal ✔ Unimodal ✘

(Maye, Werker, & Gerken, 2002)

A Generative Model

To create a corpus

Phonetic Categories

↓

Corpus

A Generative Model

To create a corpus

1. Generate a phonetic category inventory

Phonetic Categories

↓

Corpus

A Generative Model

<u>To create a corpus</u>

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   - Sample a mean, covariance, and frequency of occurrence for each Gaussian category

Phonetic Categories

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Corpus

A Generative Model

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Phonetic Categories

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Corpus

A Generative Model

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   - For each sound, sample a phonetic category according to its frequency

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Phonetic Categories

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Corpus

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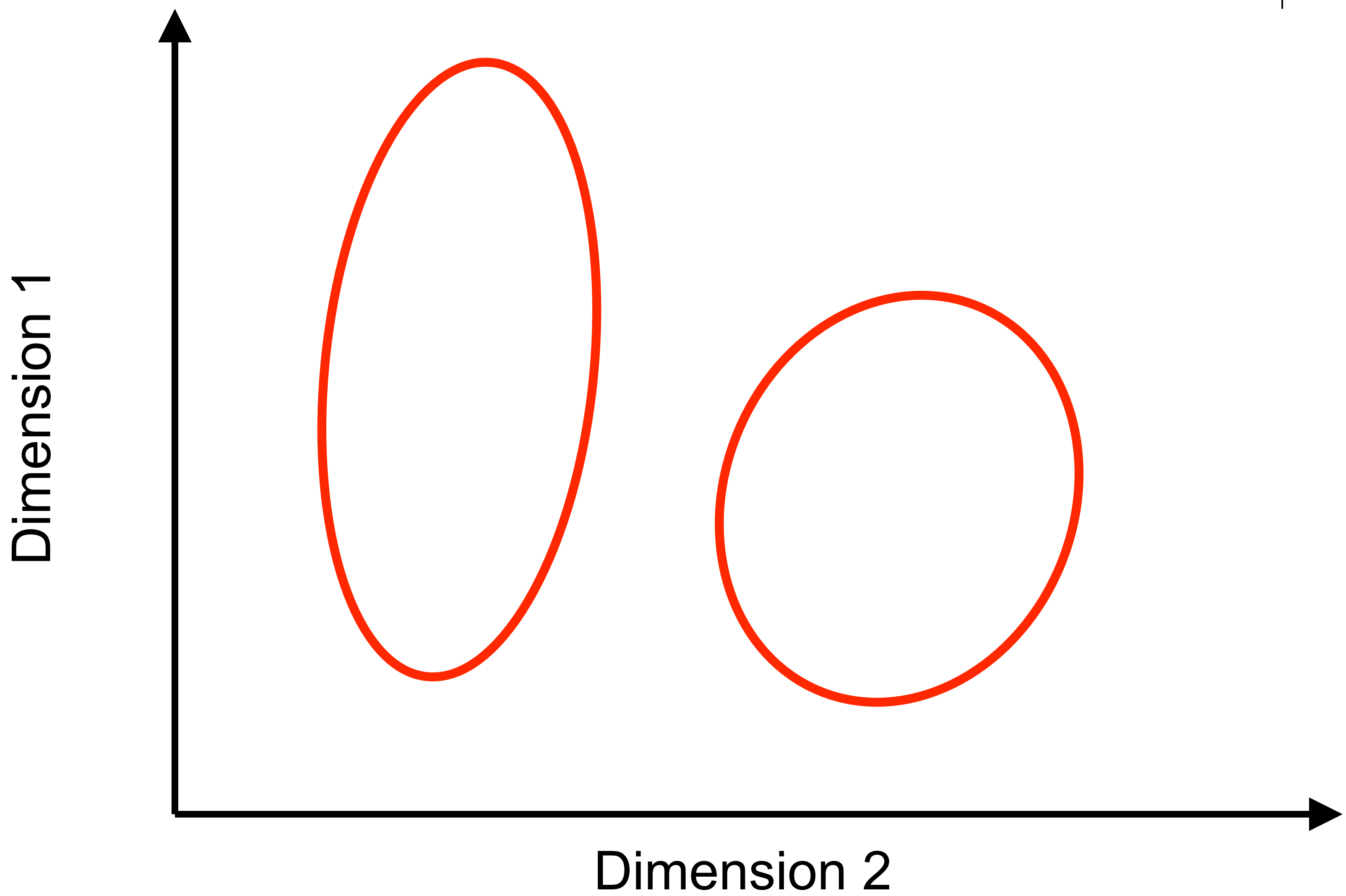

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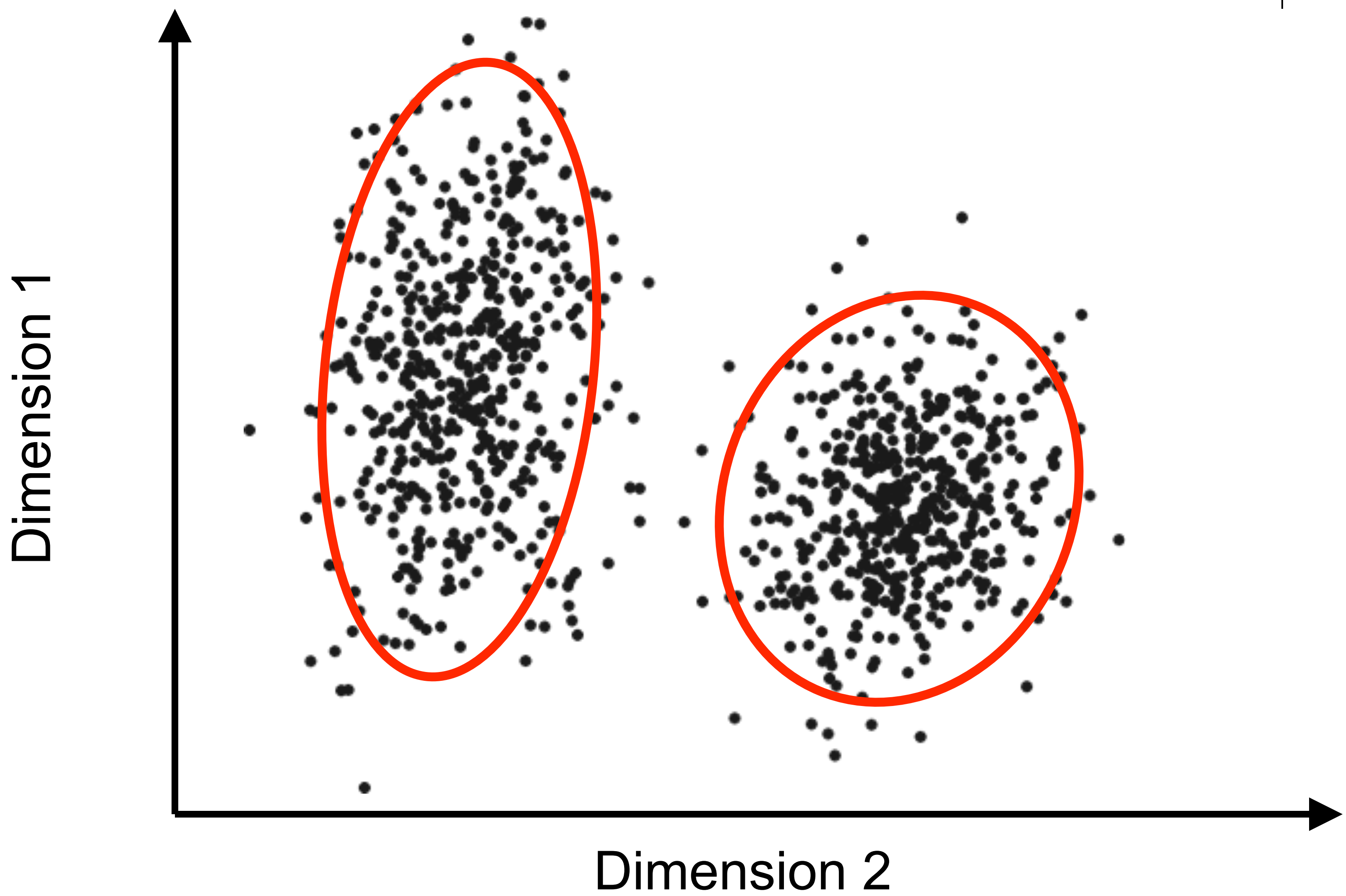

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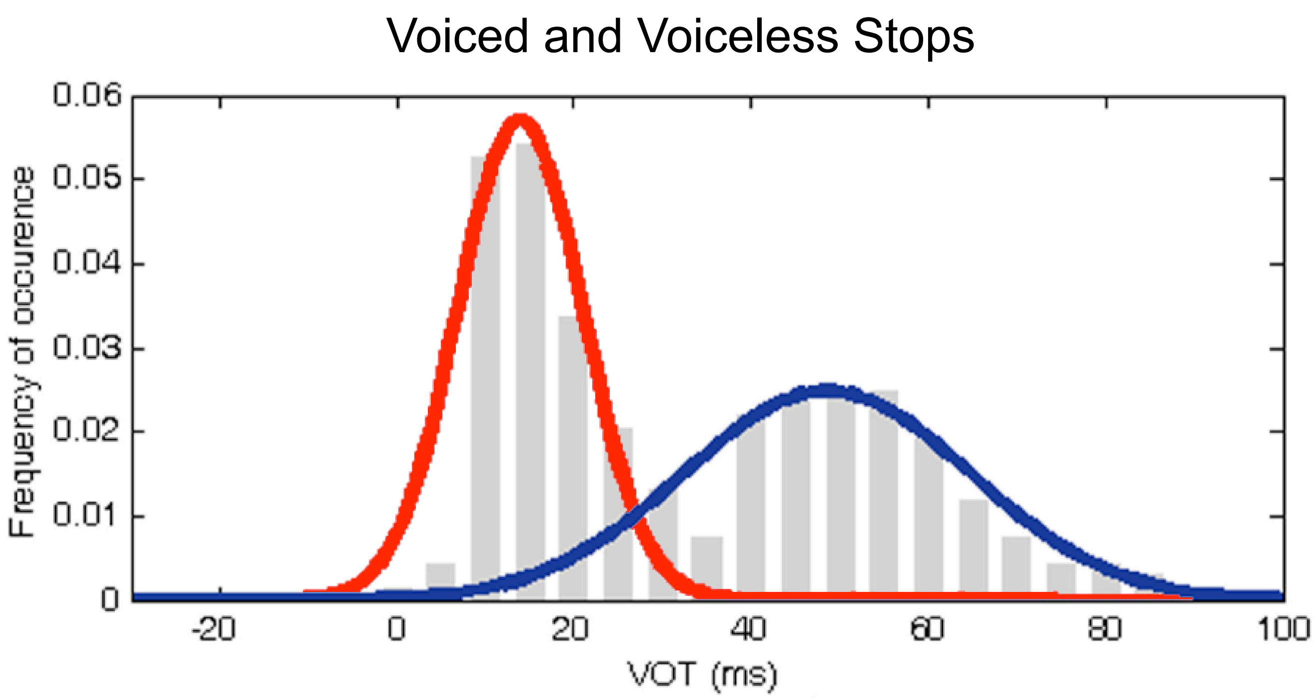
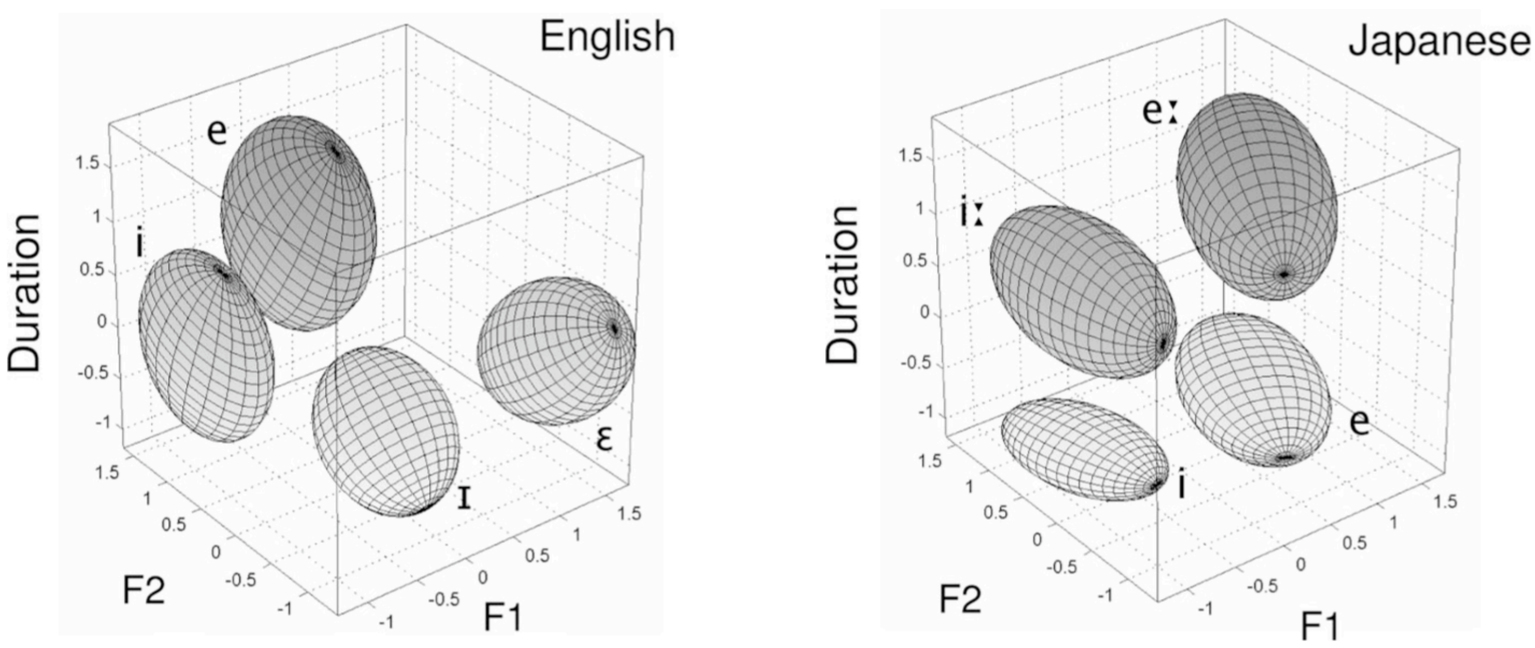


(Toscano & McMurray, 2008; McMurray, Aslin, & Toscano, 2009)

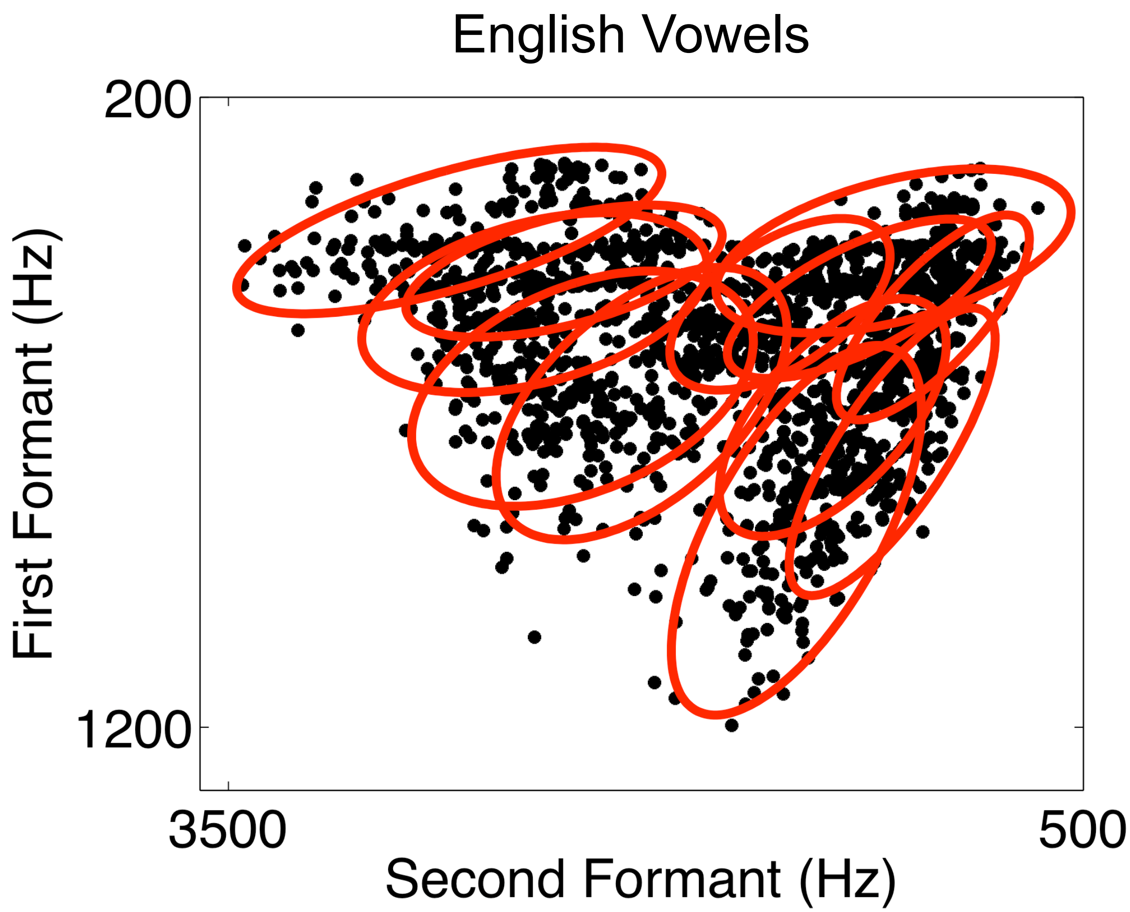
Distributional Learning

Vowel Categories (Single Speakers)



(Vallabha, McClelland, Pons, Werker, & Amano, 2007)

A Difficult Problem



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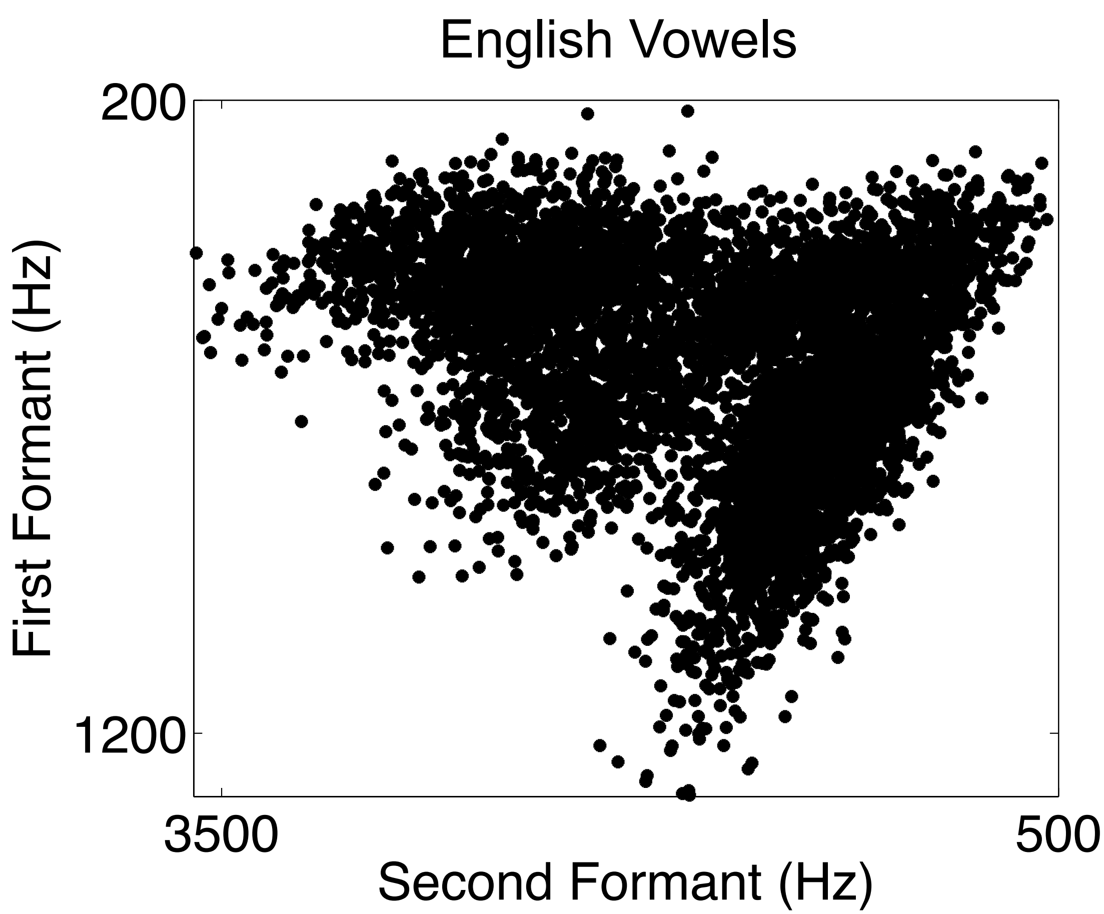
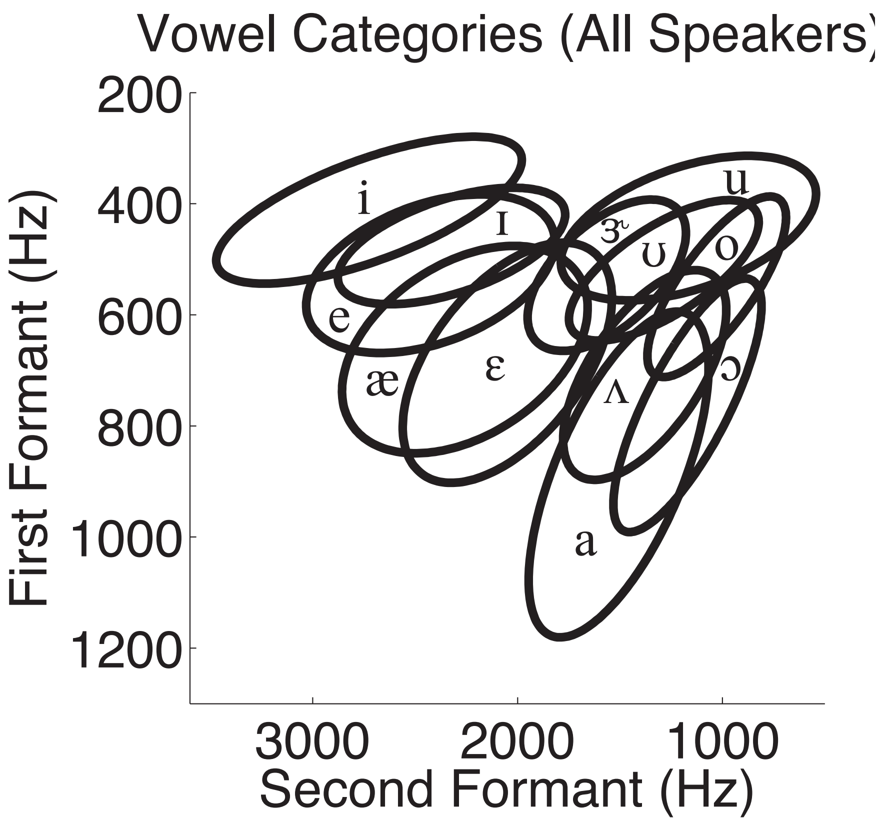
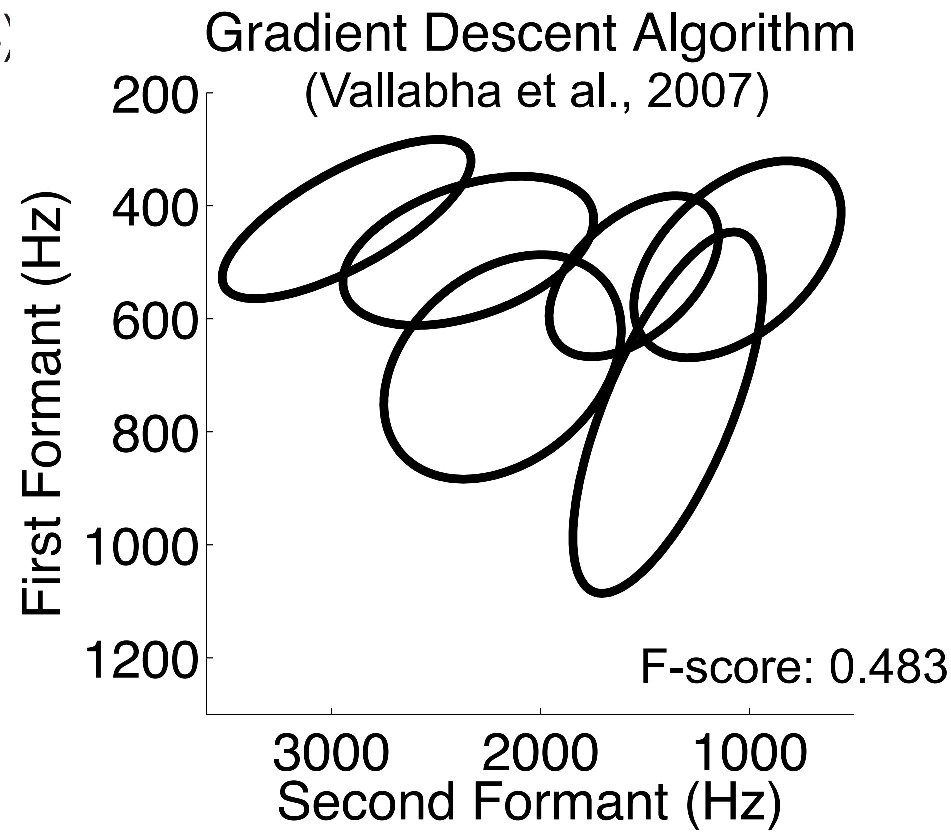
Training Corpus



Corpus of 6,409 vowel tokens generated from Gaussian categories from Hillenbrand et al. (1995); frequencies match corpus frequencies

Distributional Learning





(Feldman, Griffiths, Goldwater, & Morgan, in prep; see also Dillon, Dunbar, & Idsardi, in press)

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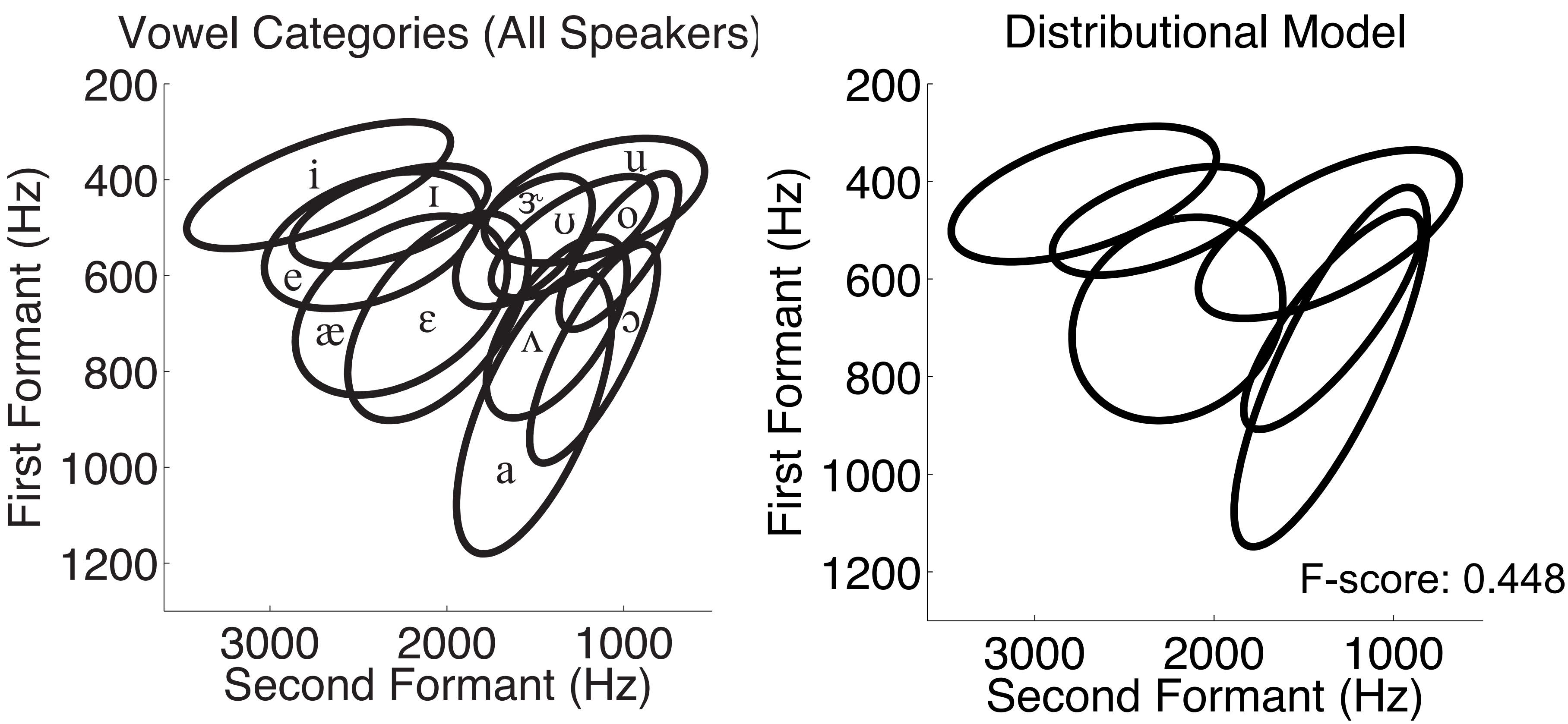

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Corpus

Hypothesis

Infants use top-down constraints
from words when acquiring
phonetic categories

(see also Swingley & Aslin, 2007; Swingley, 2009; Thiessen, 2007, 2011)

Word Segmentation Tasks

Familiarization:

Test:

A B

Word Learning

bike BIKE

bike bike

bike bike

bike

bike

bike

BIKE

Word Learning

bike

BIKE

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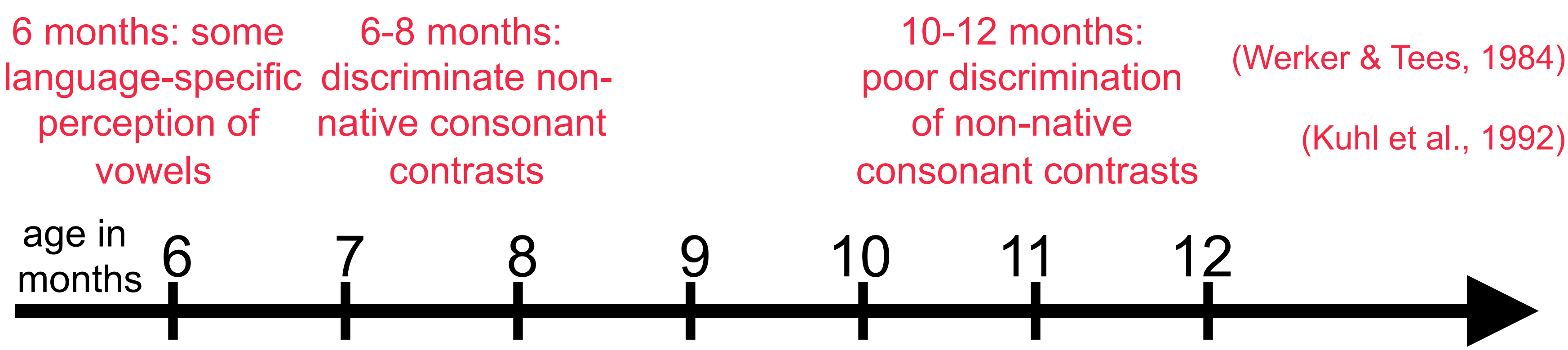
BIKE

Timecourse of Acquisition



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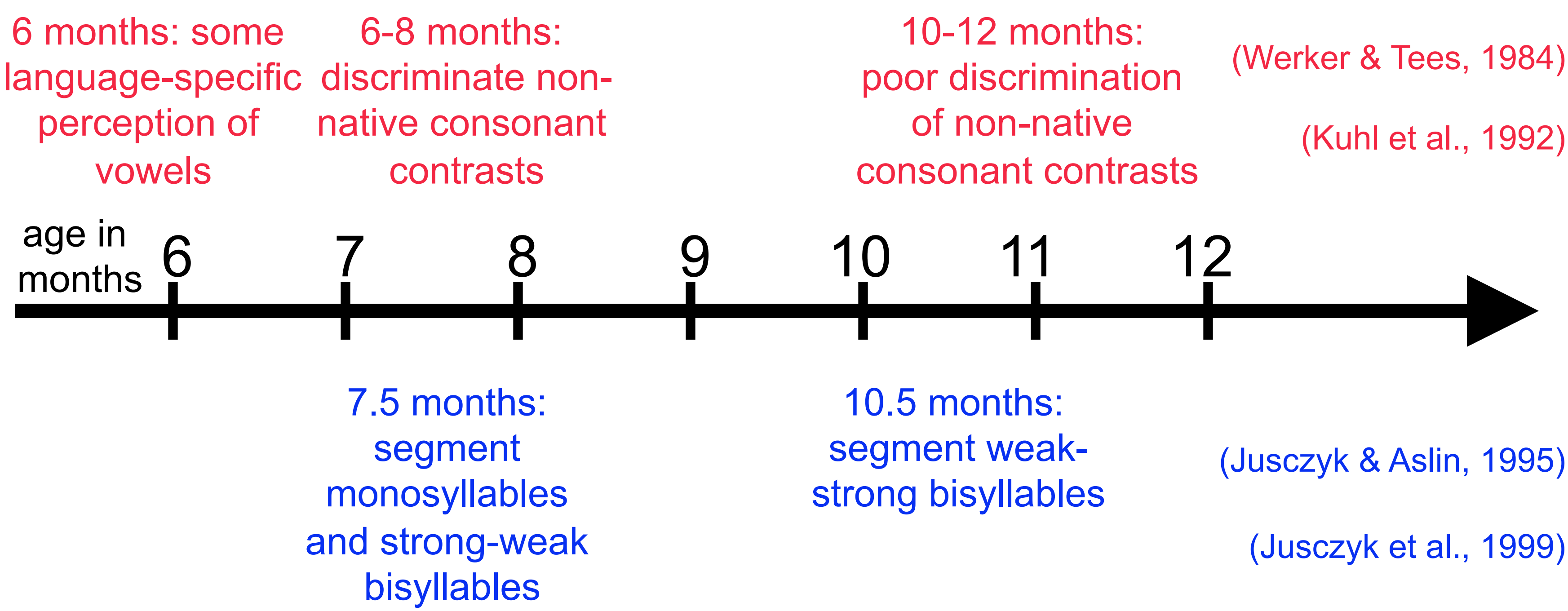

Timecourse of Acquisition

6 months: some language-specific perception of vowels

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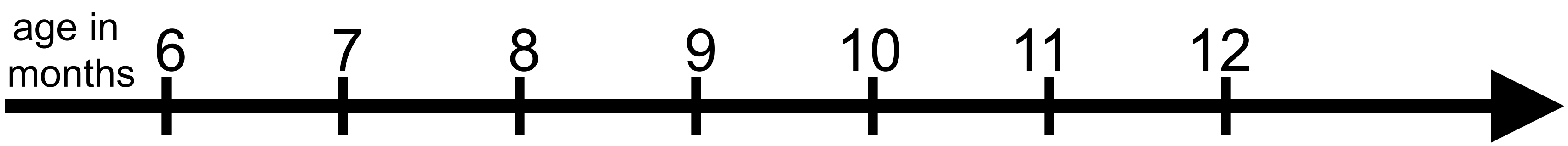

6 months: segment words next to “Mommy” or baby’s own name

7.5 months: segment monosyllables and strong-weak bisyllables

10.5 months: segment weak-strong bisyllables

(Jusczyk & Aslin, 1995)

(Jusczyk et al., 1999)

(Bortfeld et al., 2005)

Hypothesis

Infants use top-down constraints from words when acquiring phonetic categories

1. Formalize a model that can simultaneously learn sounds and words

2. Show that infants are sensitive to words in ways the model would predict

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A Better Generative Model

To create a corpus

Phonetic Categories

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Lexicon

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Corpus

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Phonetic Categories

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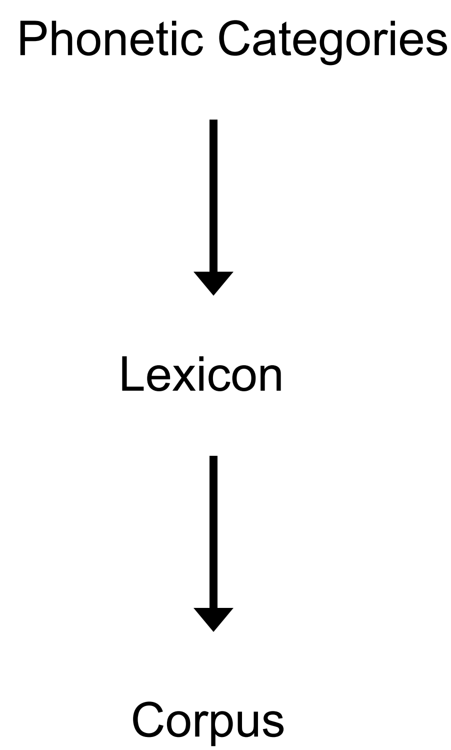

A Better Generative Model

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   - Sample a length and frequency of occurrence for each lexical item
   - For each phoneme slot, sample a phonetic category from the phonetic category inventory

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Lexicon

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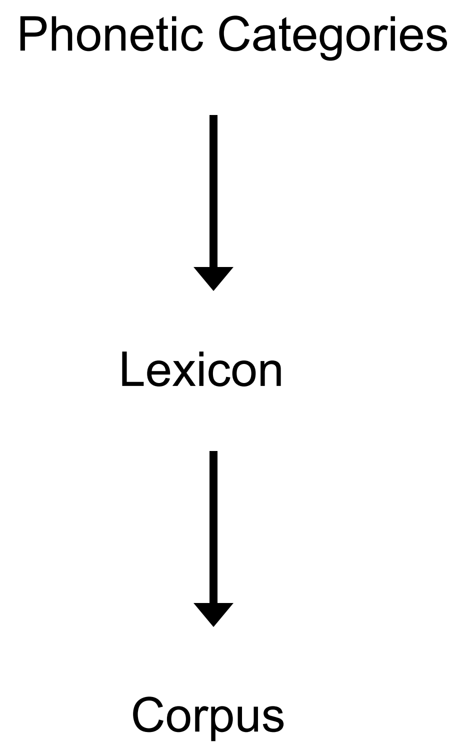
   - Generate an acoustic value each phonetic category contained in that lexical item



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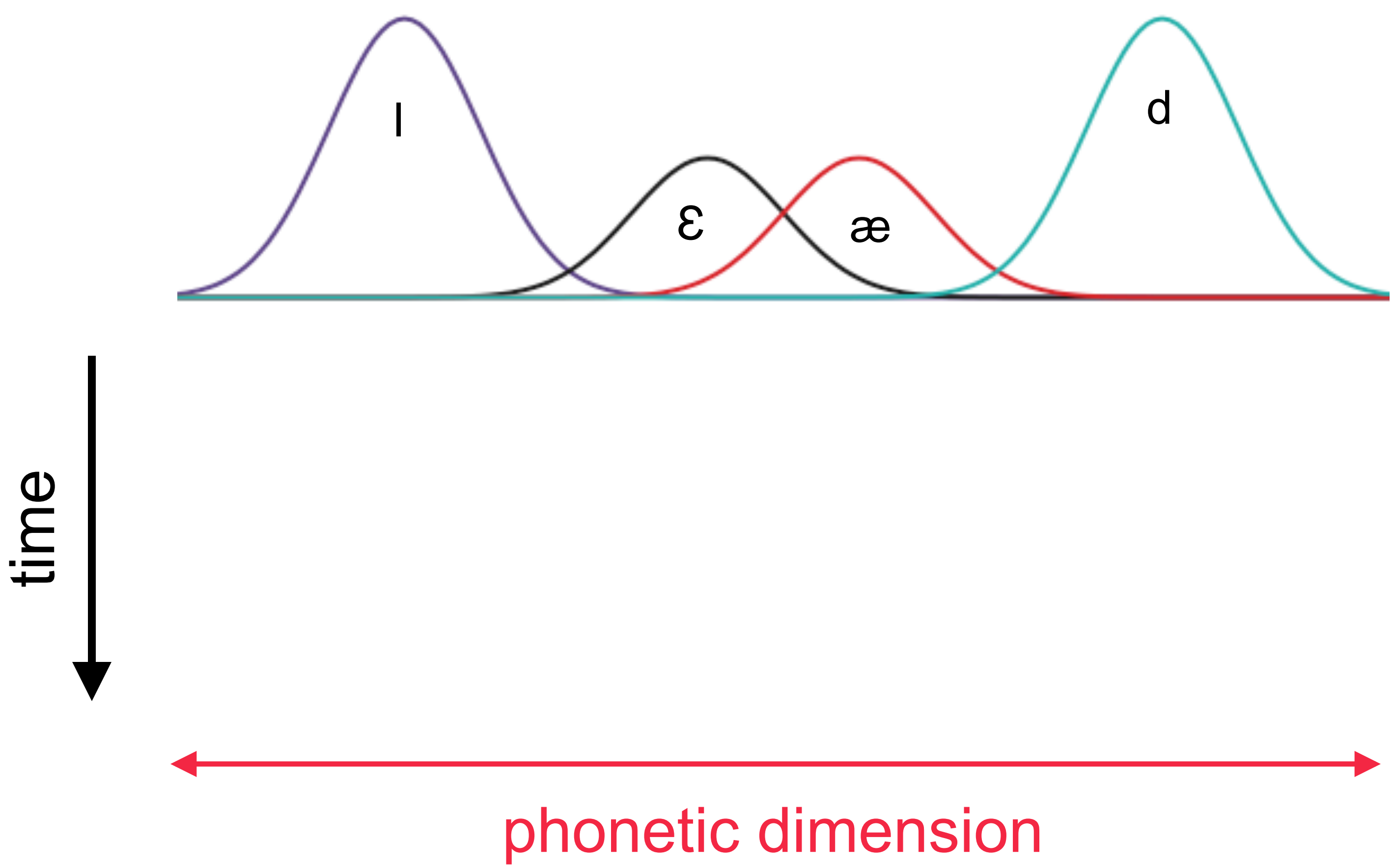
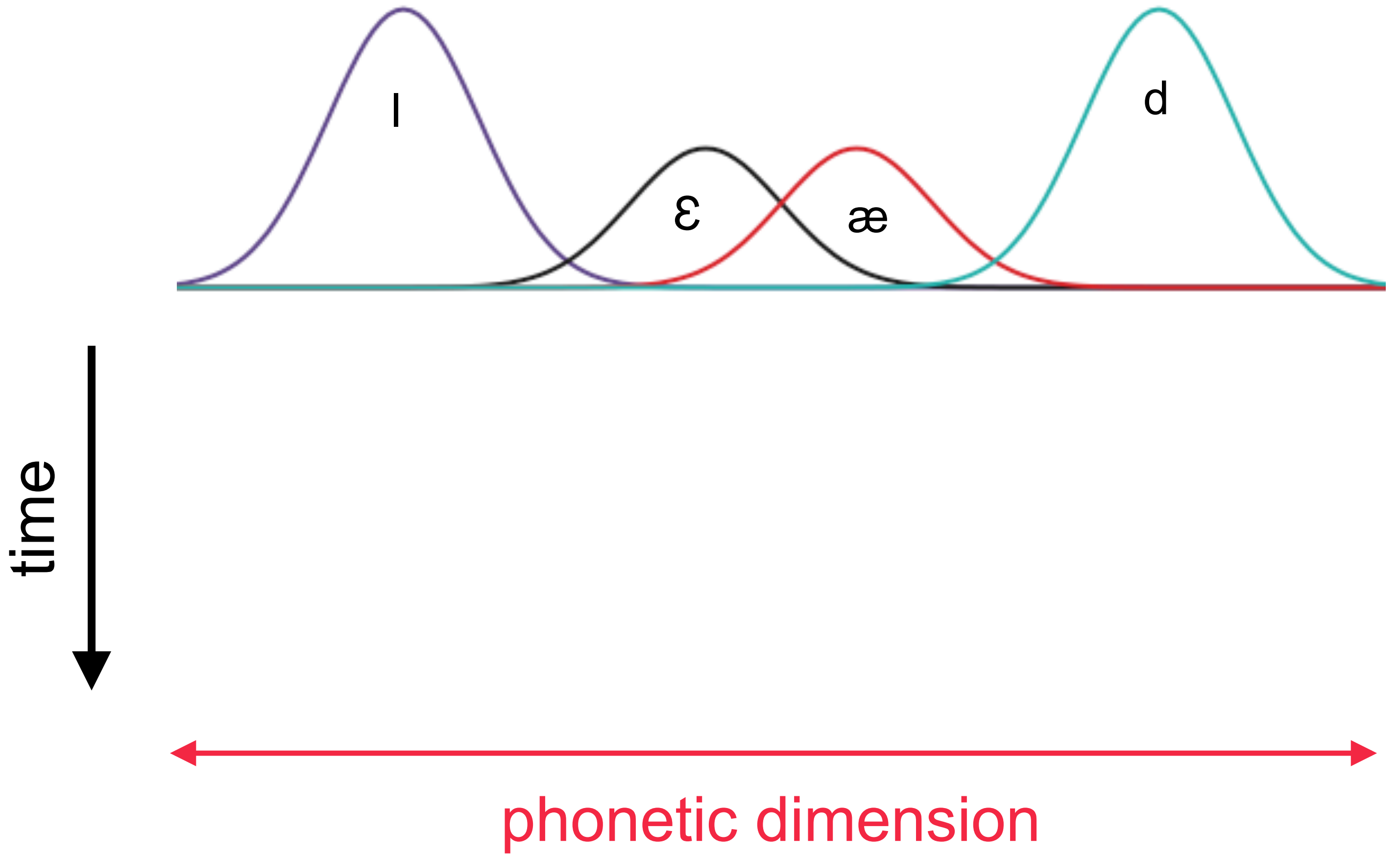


A Better Generative Model

Lexicon: /læd/, /lɛd/
'lad' 'led'



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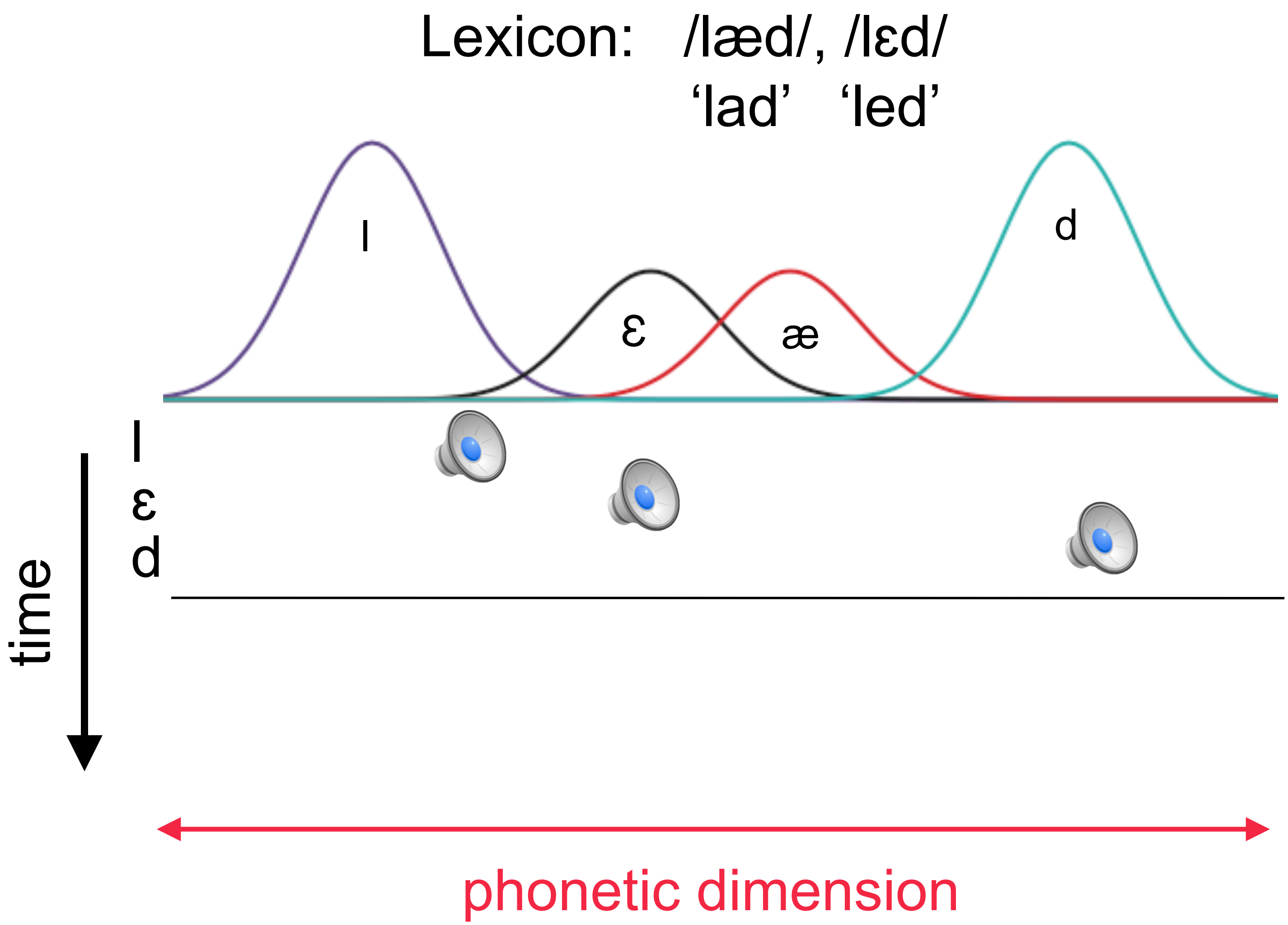

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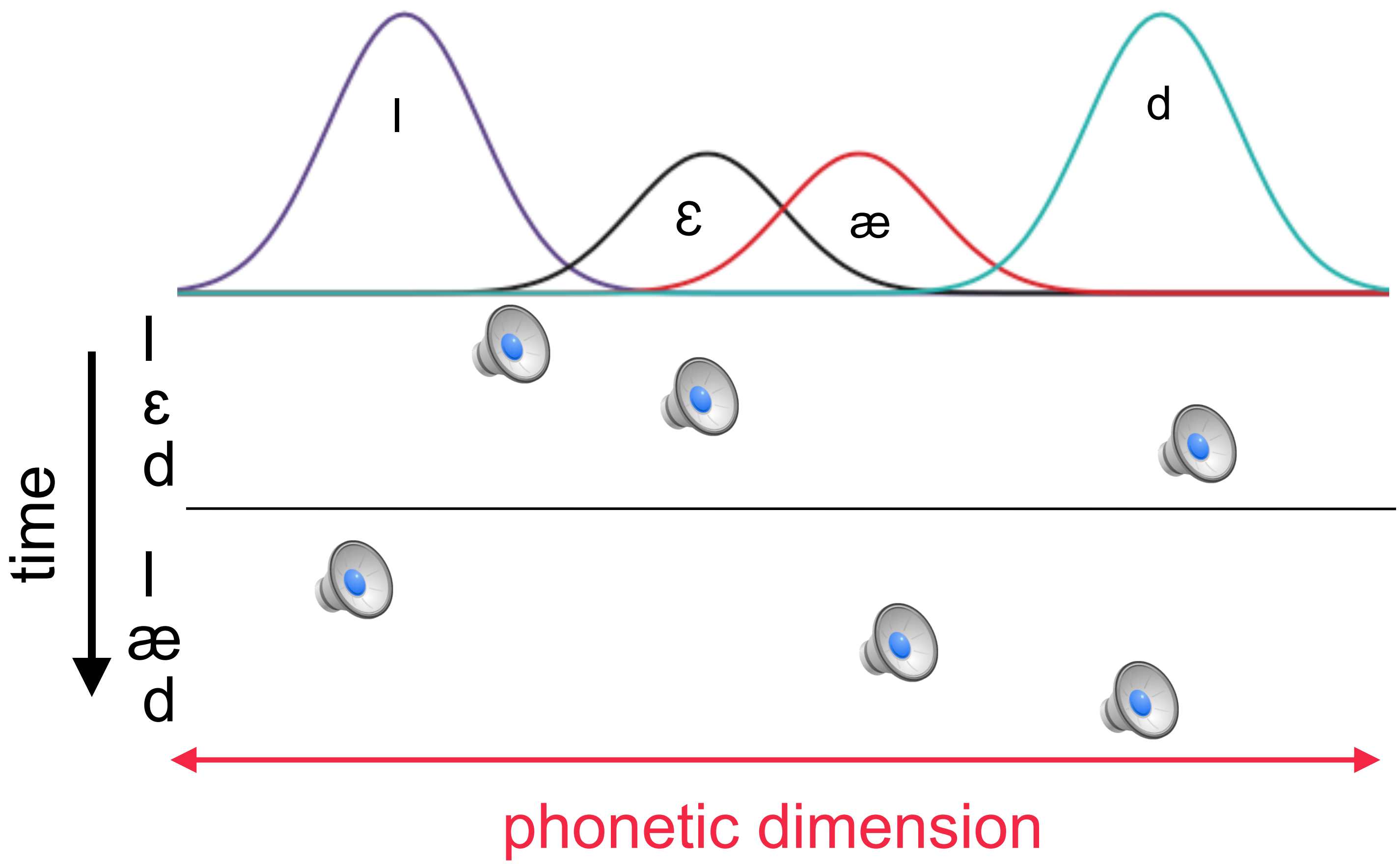

Qualitative Behavior

Compare lexical-distributional model's behavior on two lexicons

- Non-minimal pair lexicon: 'add', 'el'
- Minimal pair lexicon: 'add, 'Ed', 'Al', 'el'

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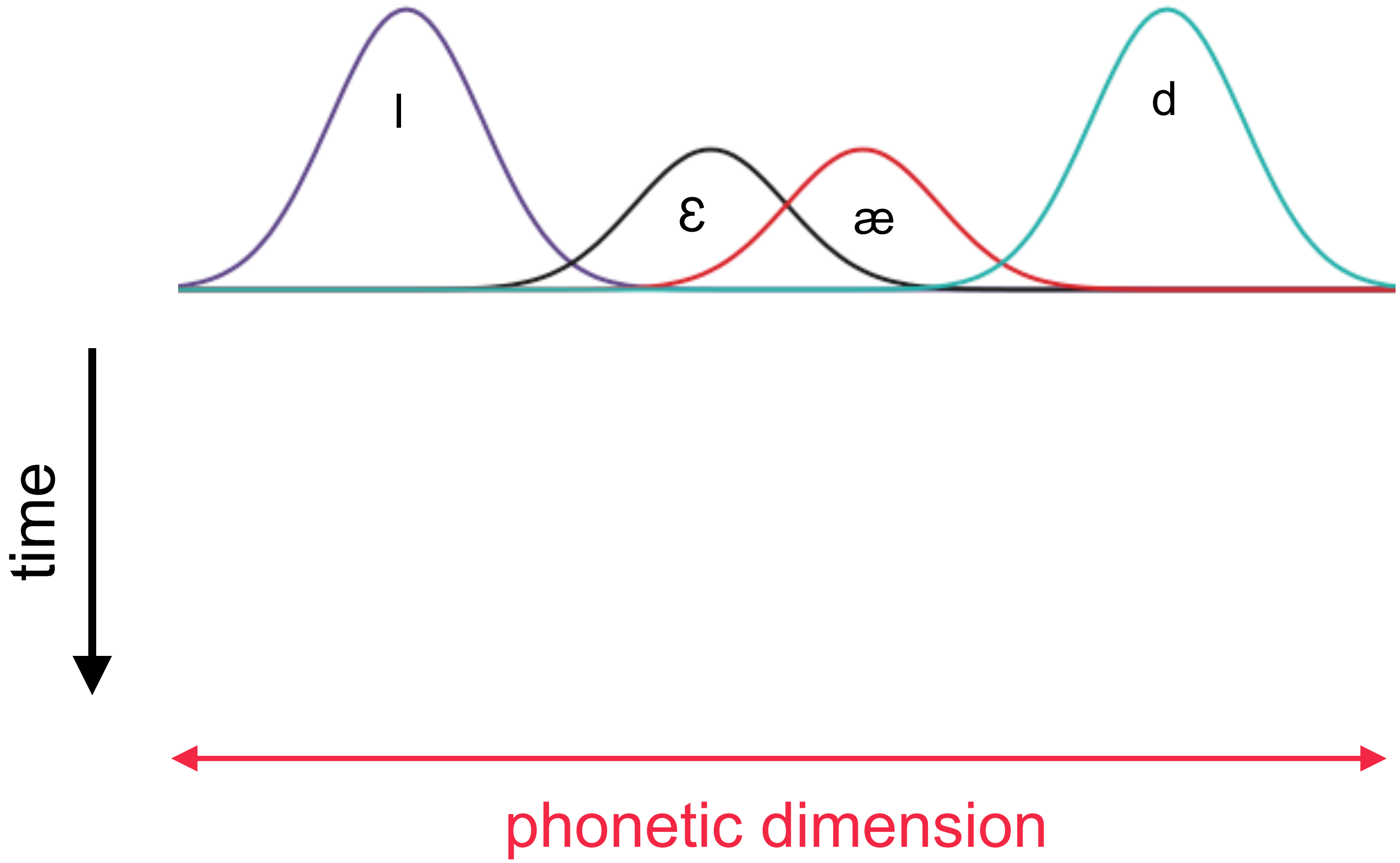
Minimal pairs:

add vs. Ed

Typically taken as evidence
that sounds are different

Non-Minimal Pair Lexicon

Lexicon: /æd/, /ɛl/
‘add’ ‘el’



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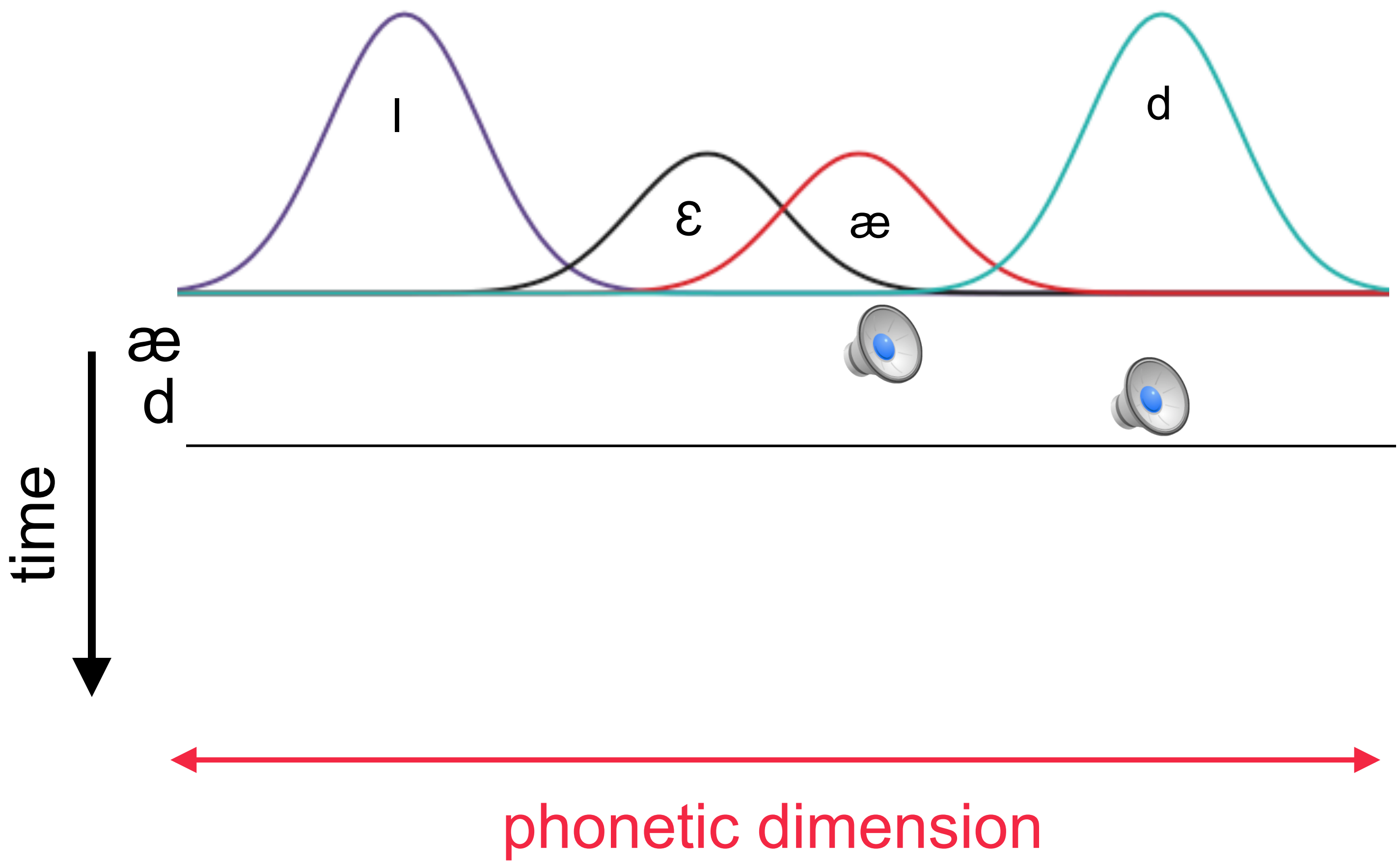

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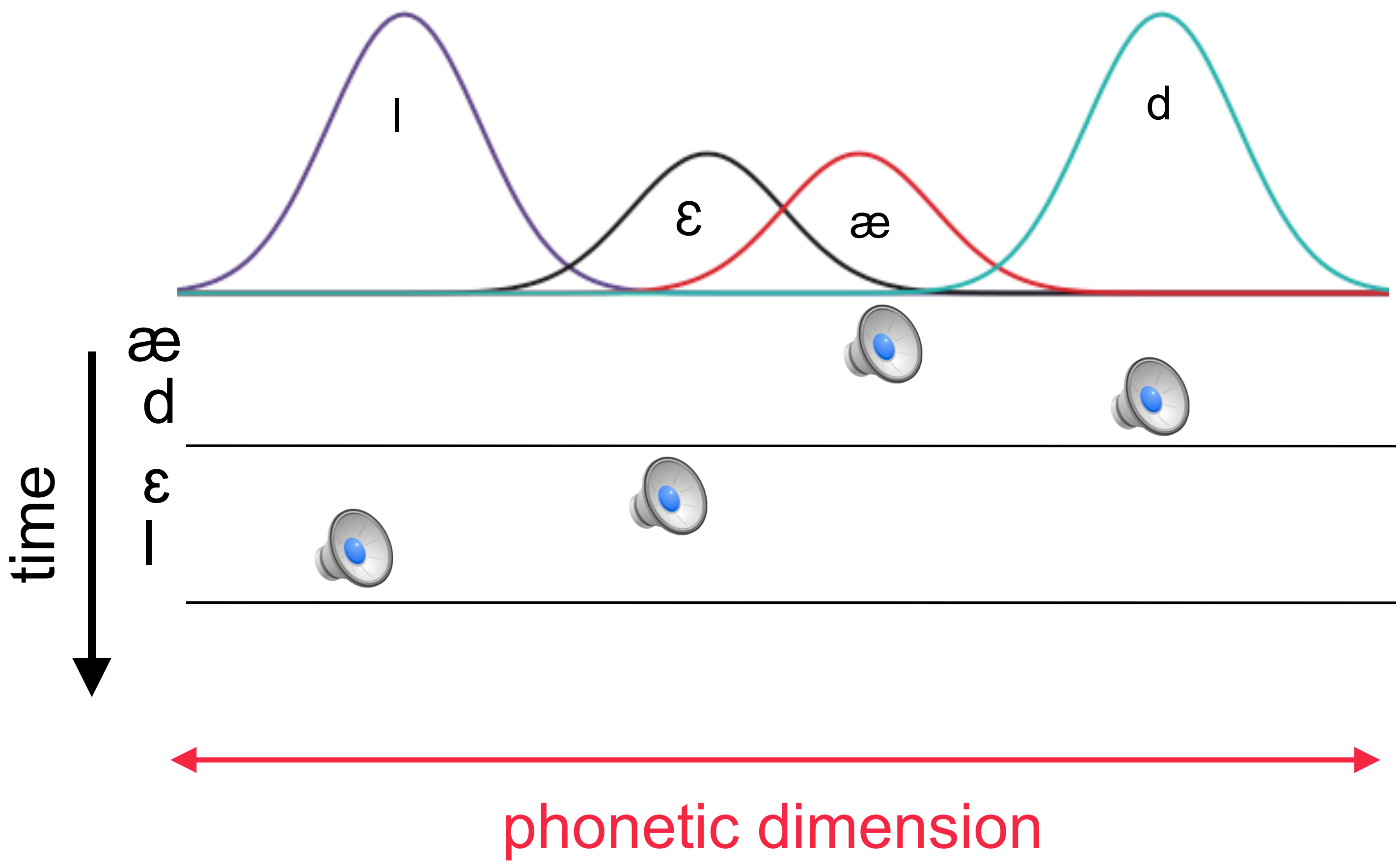

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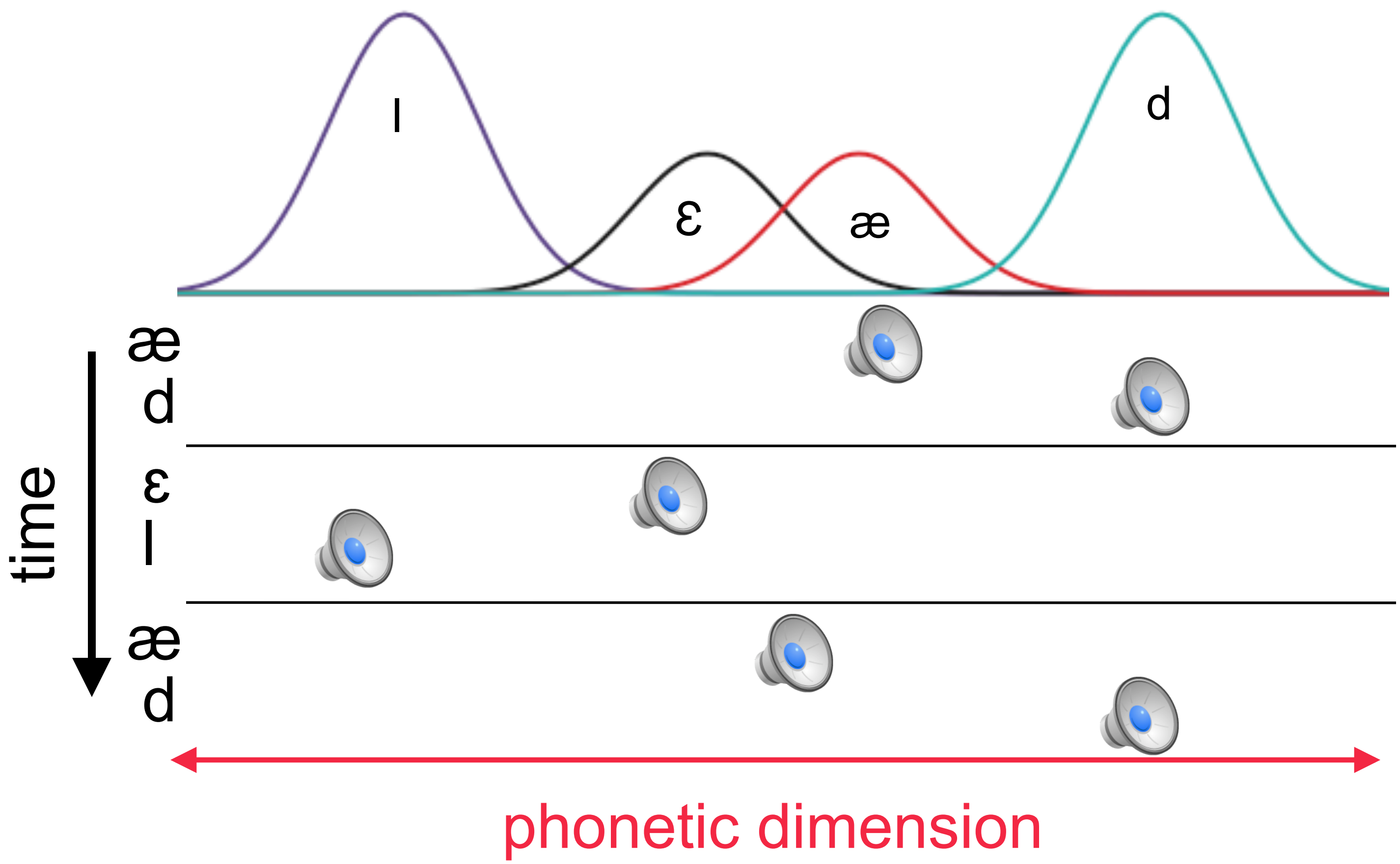

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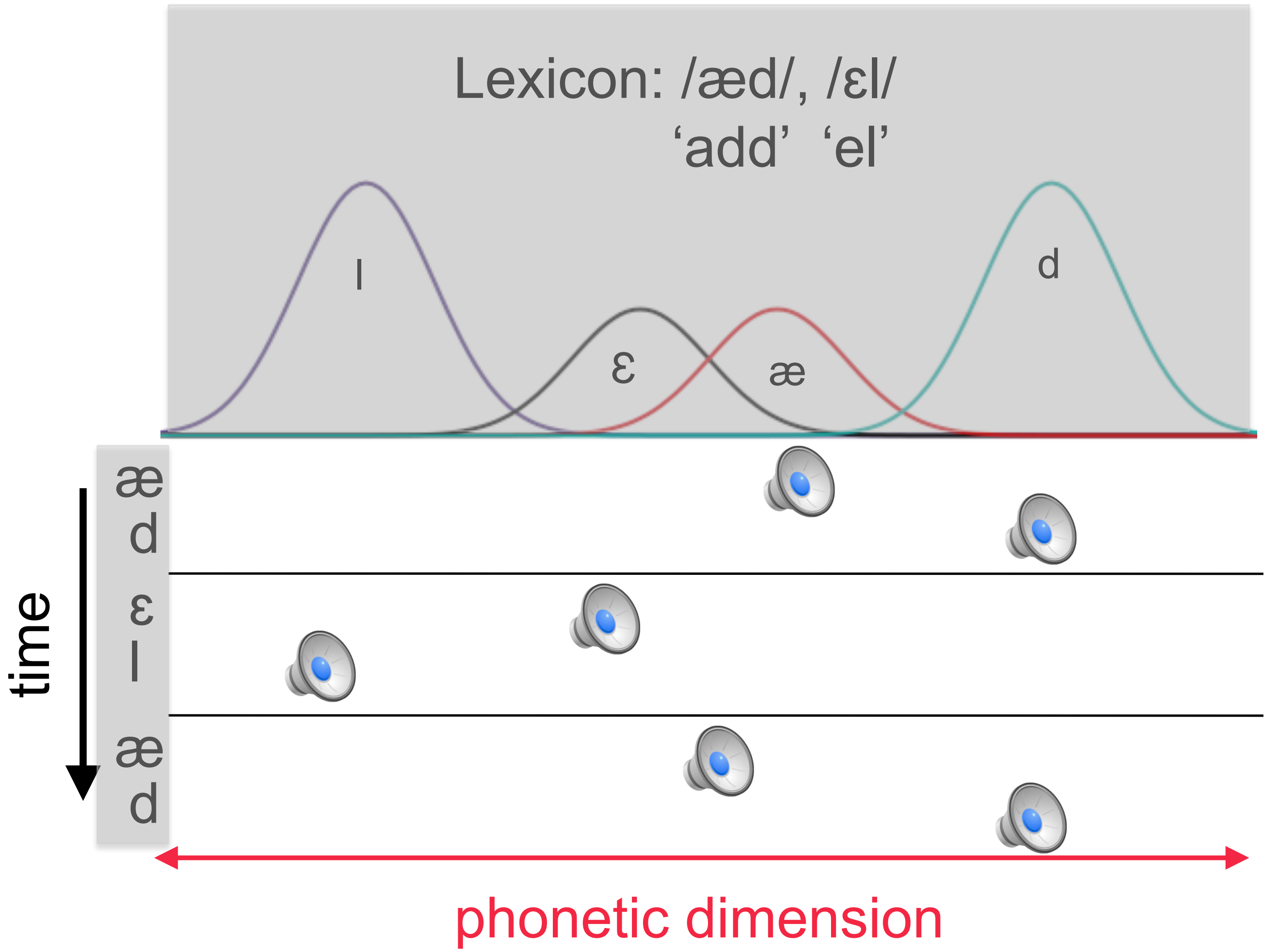

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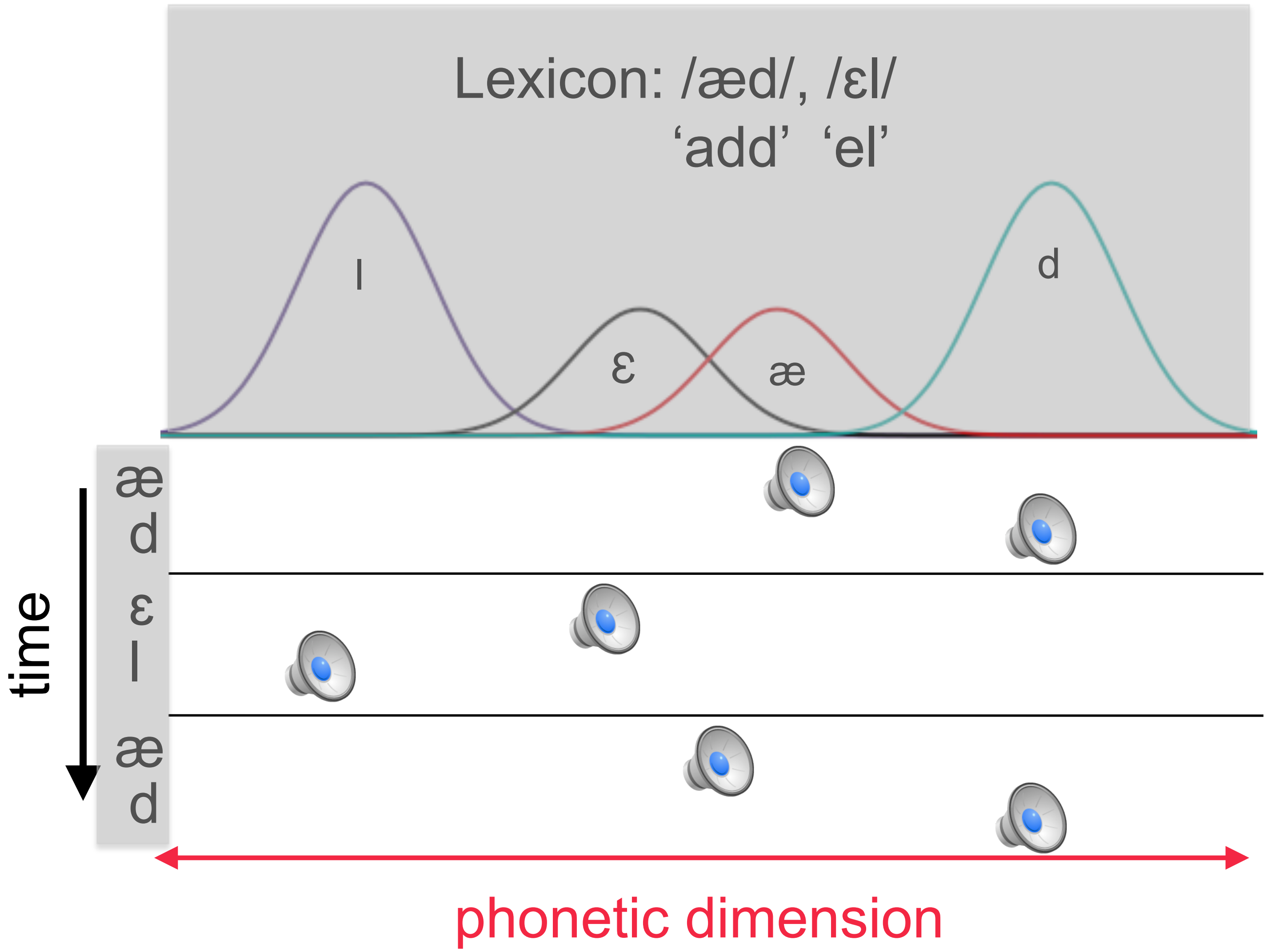

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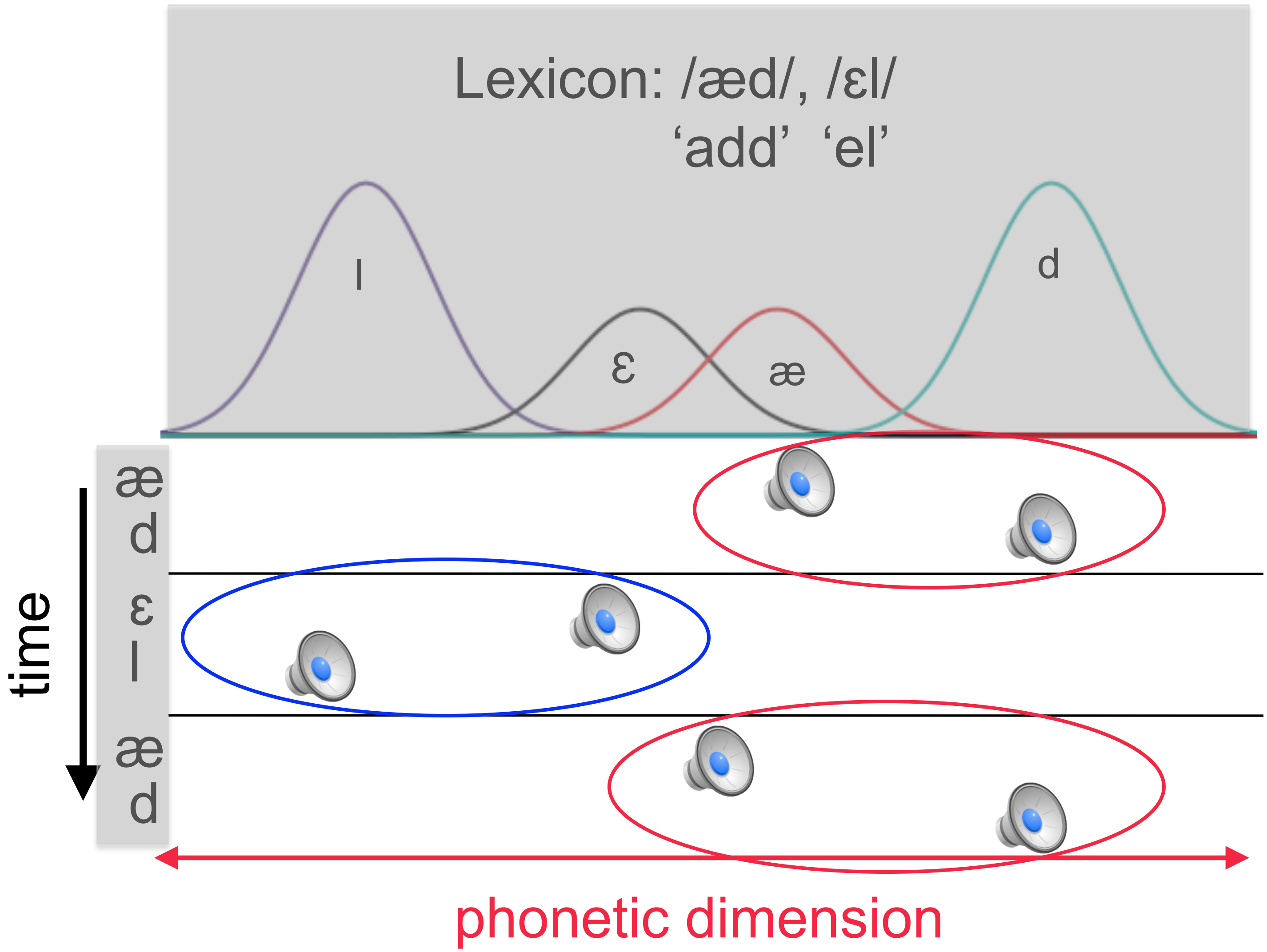


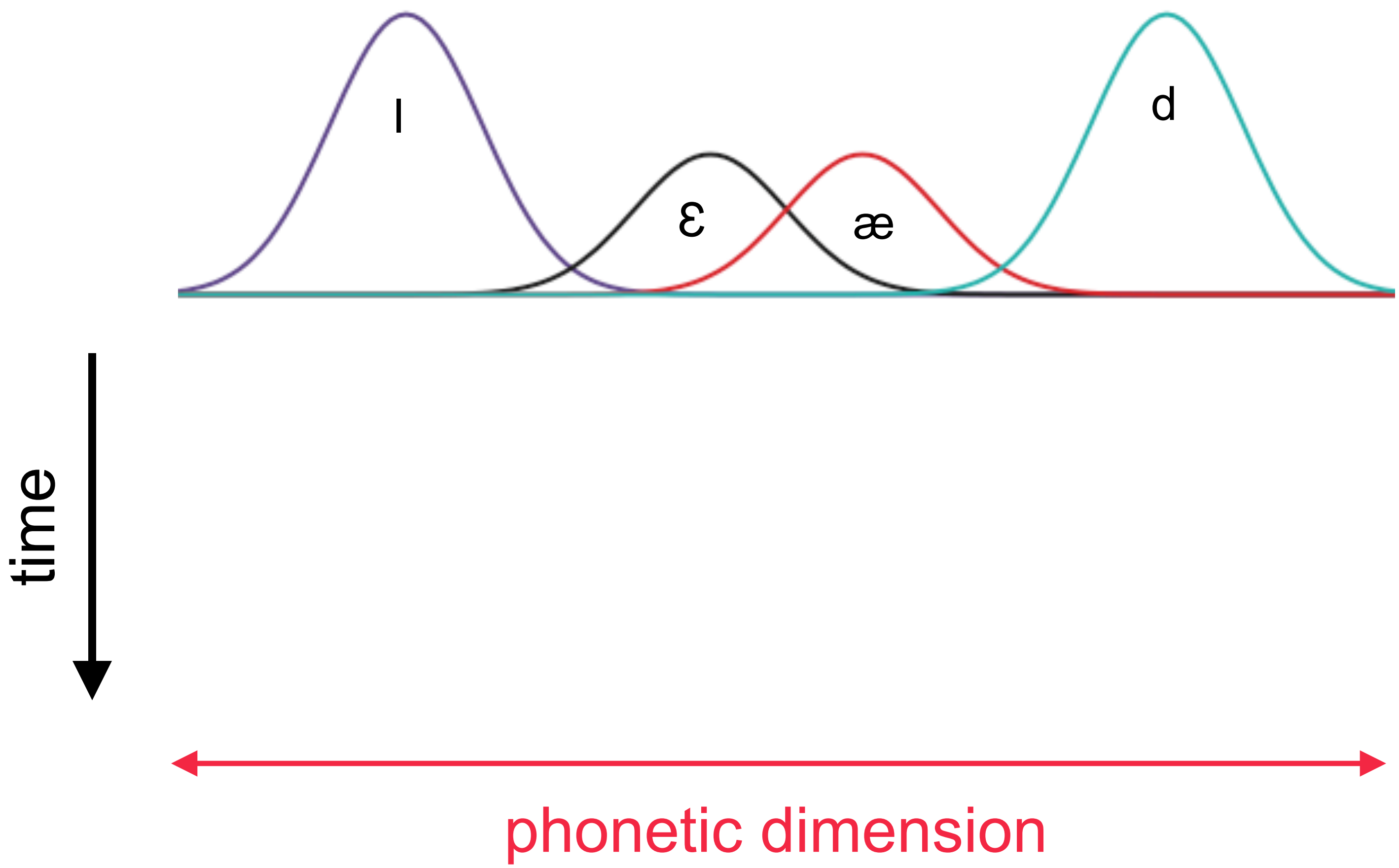
Non-Minimal Pair Lexicon

el

add

Minimal Pair Lexicon

Lexicon: /æd/, /ɛd/, /æl/, /ɛl/
'add' 'Ed' 'Al' 'el'



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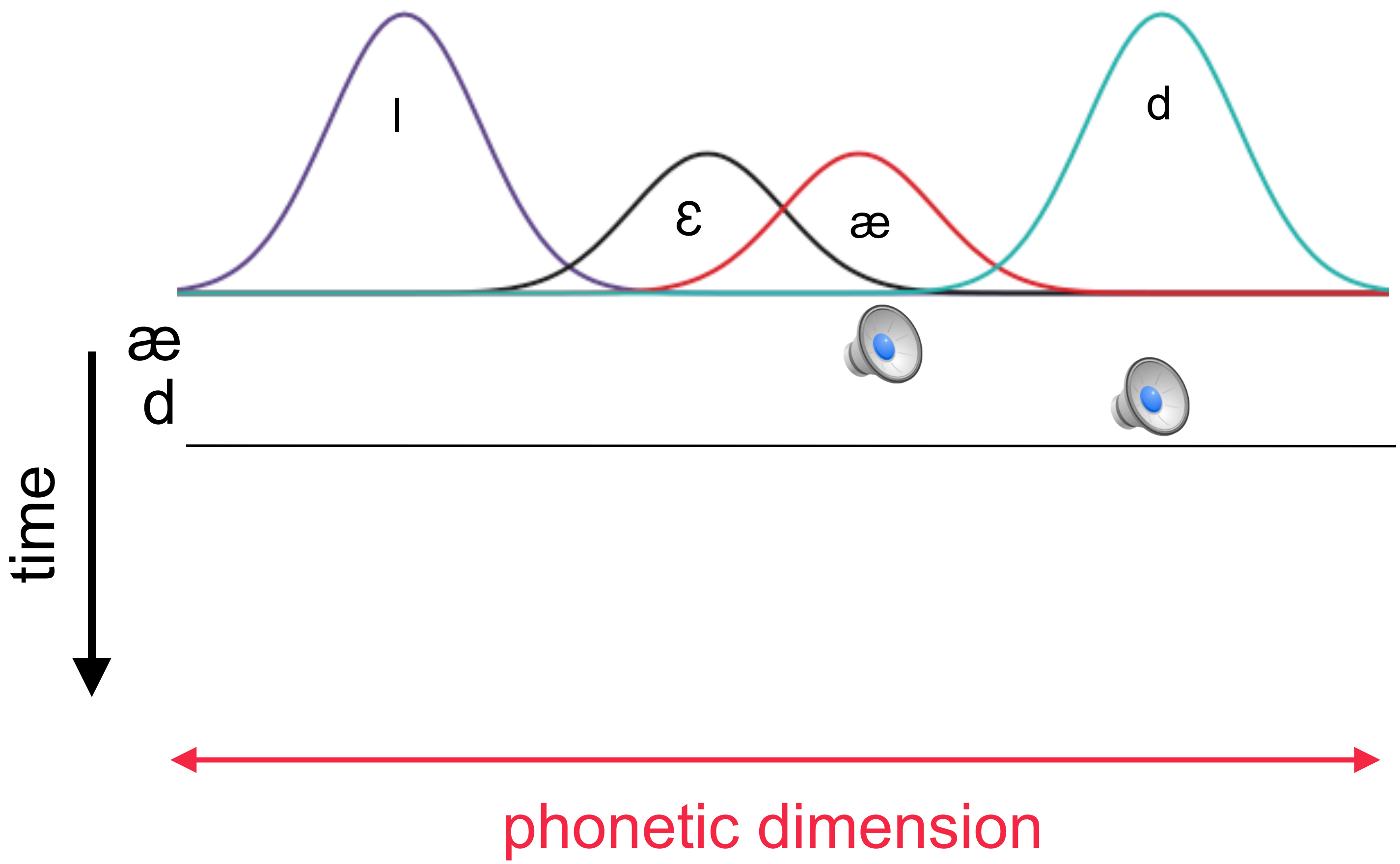

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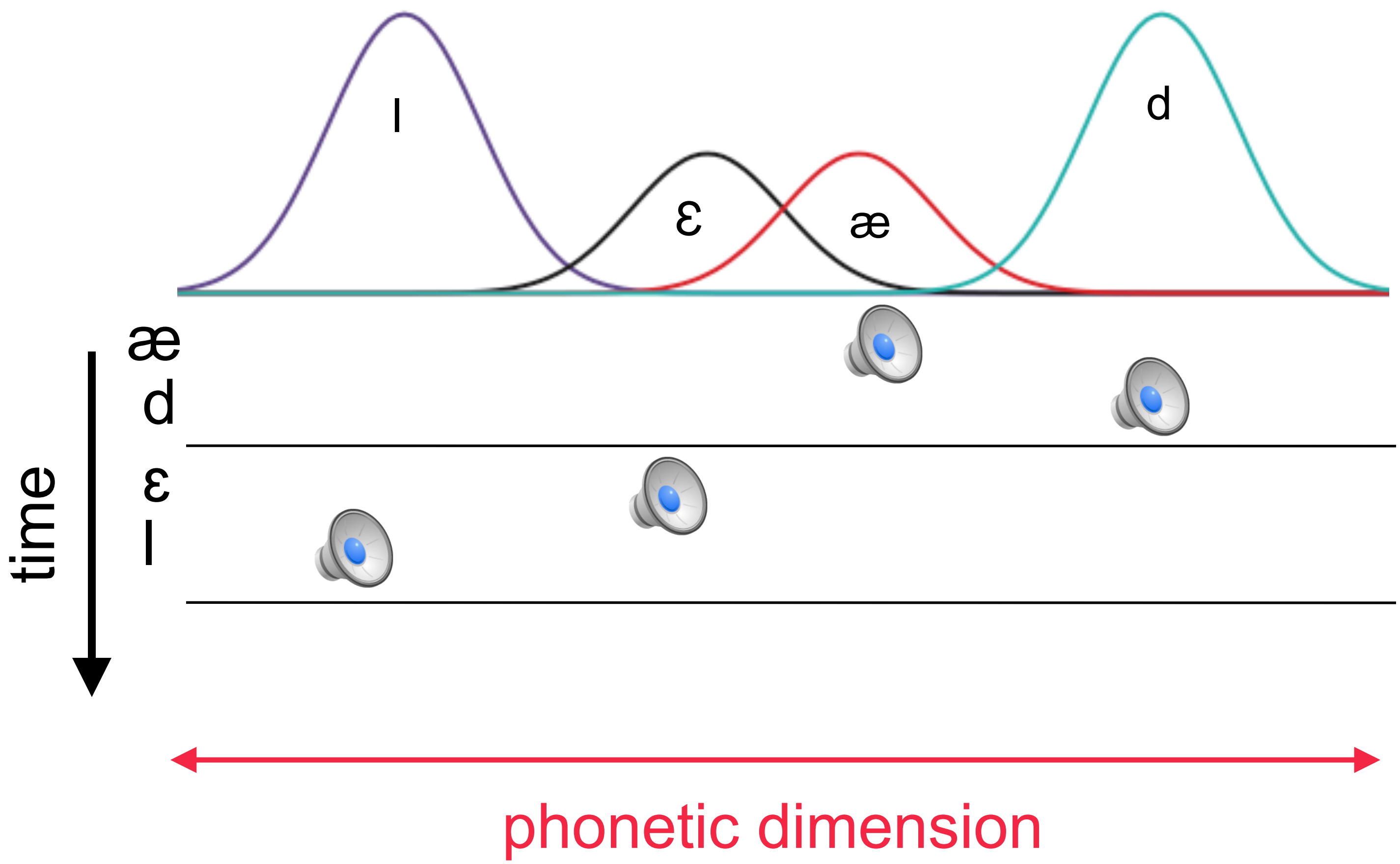

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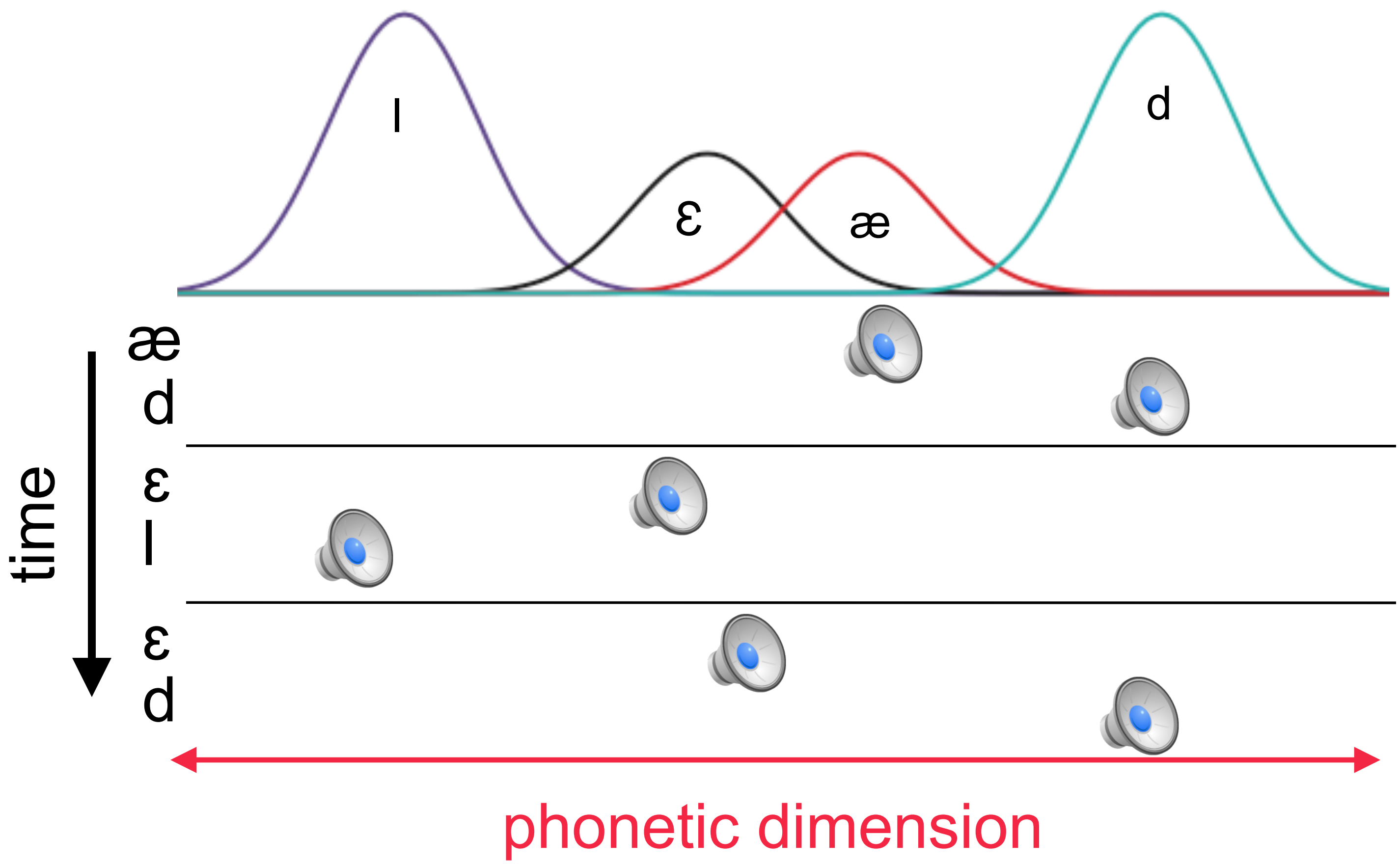

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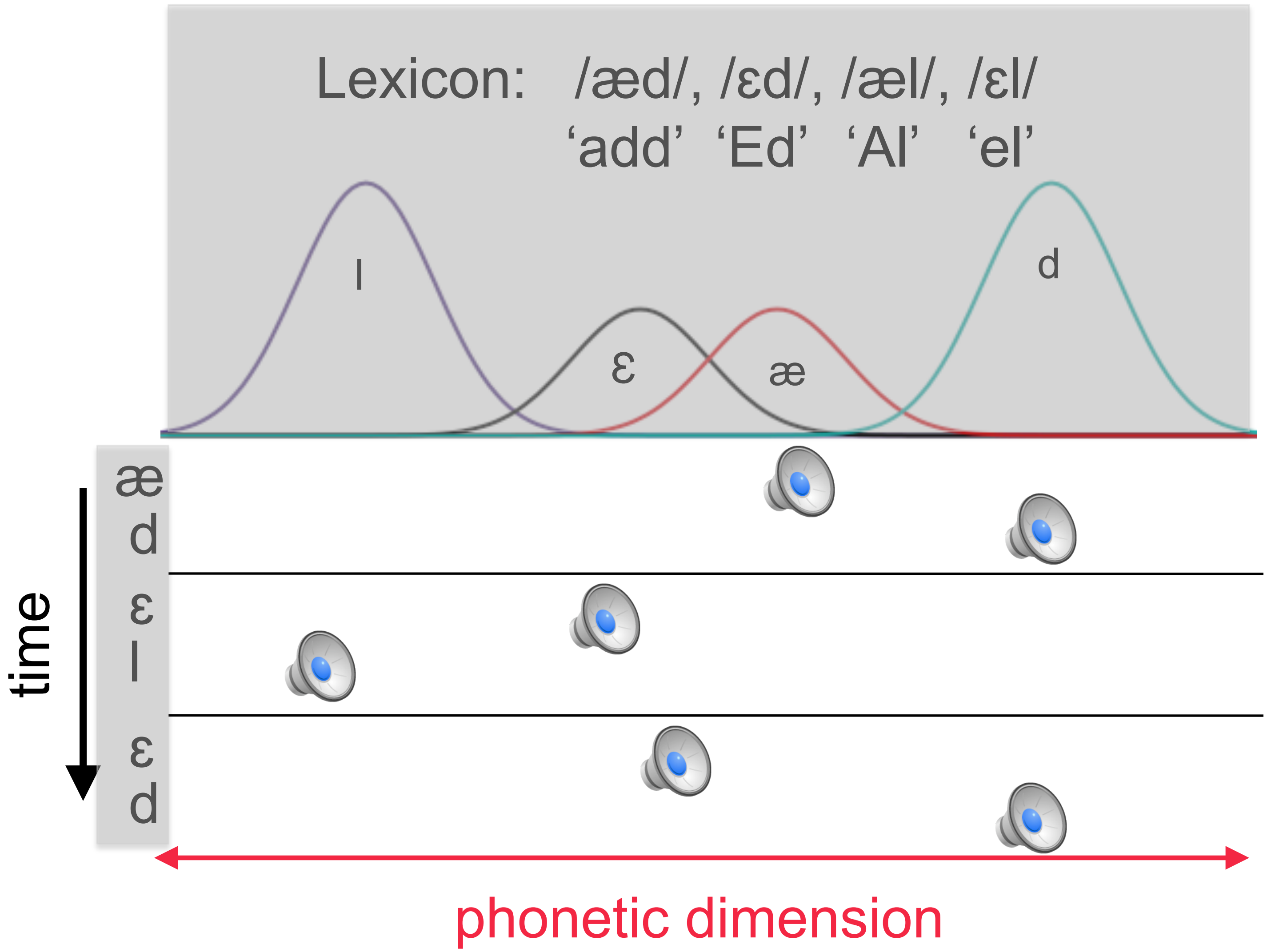

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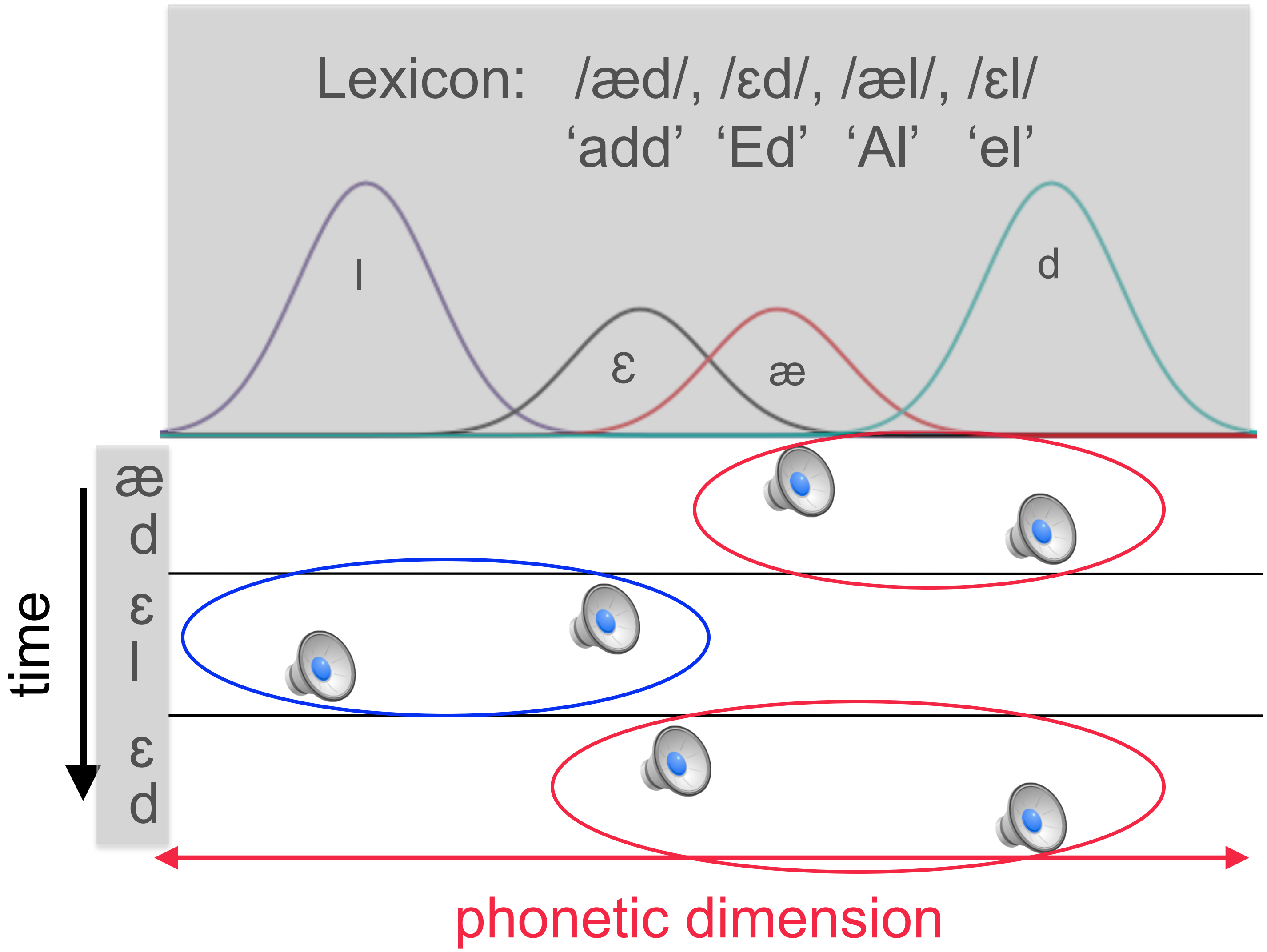

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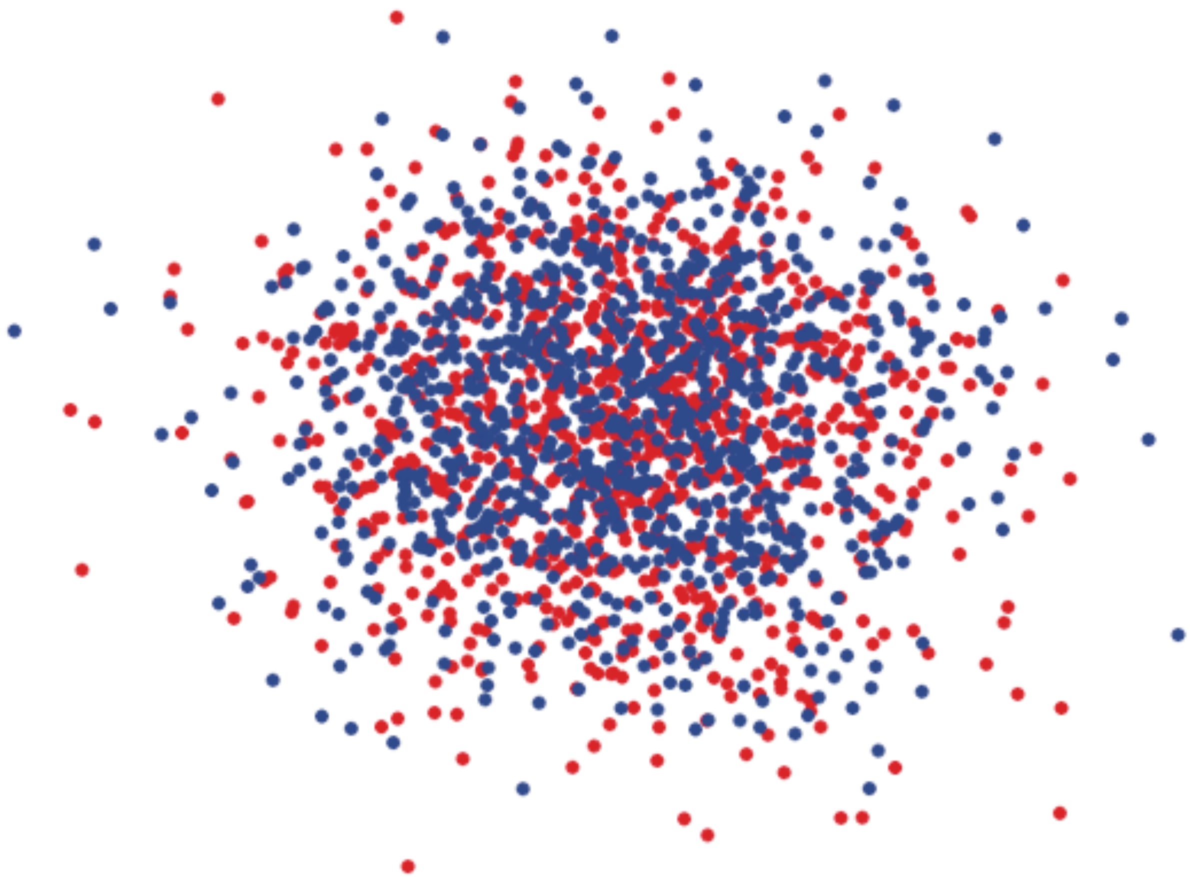
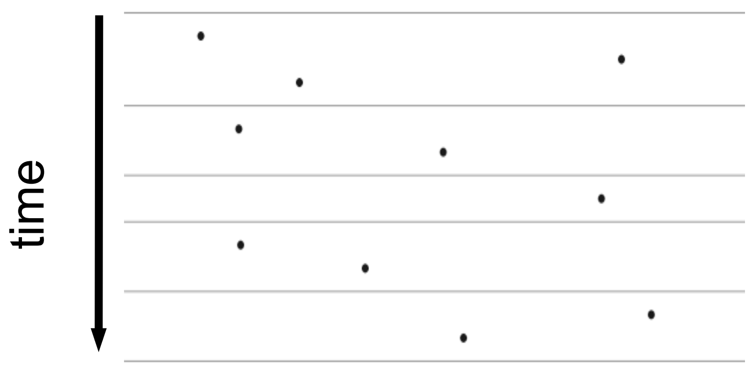


Al

Ed el

add

Lexical-Distributional Learning



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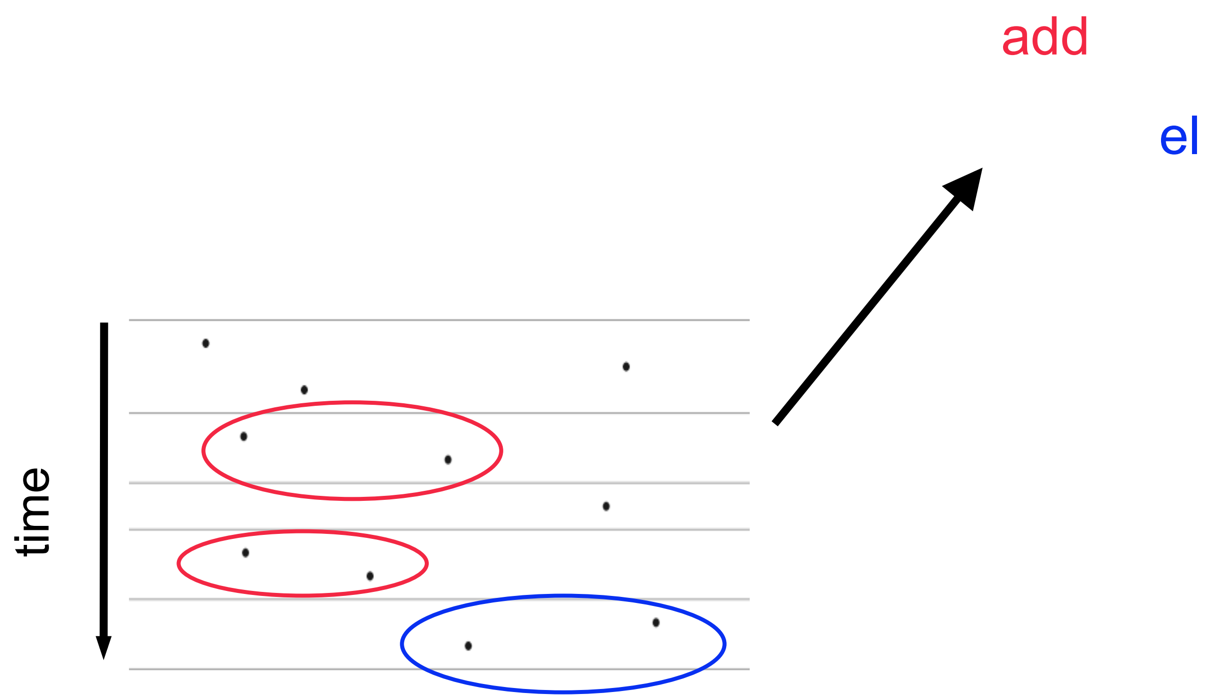

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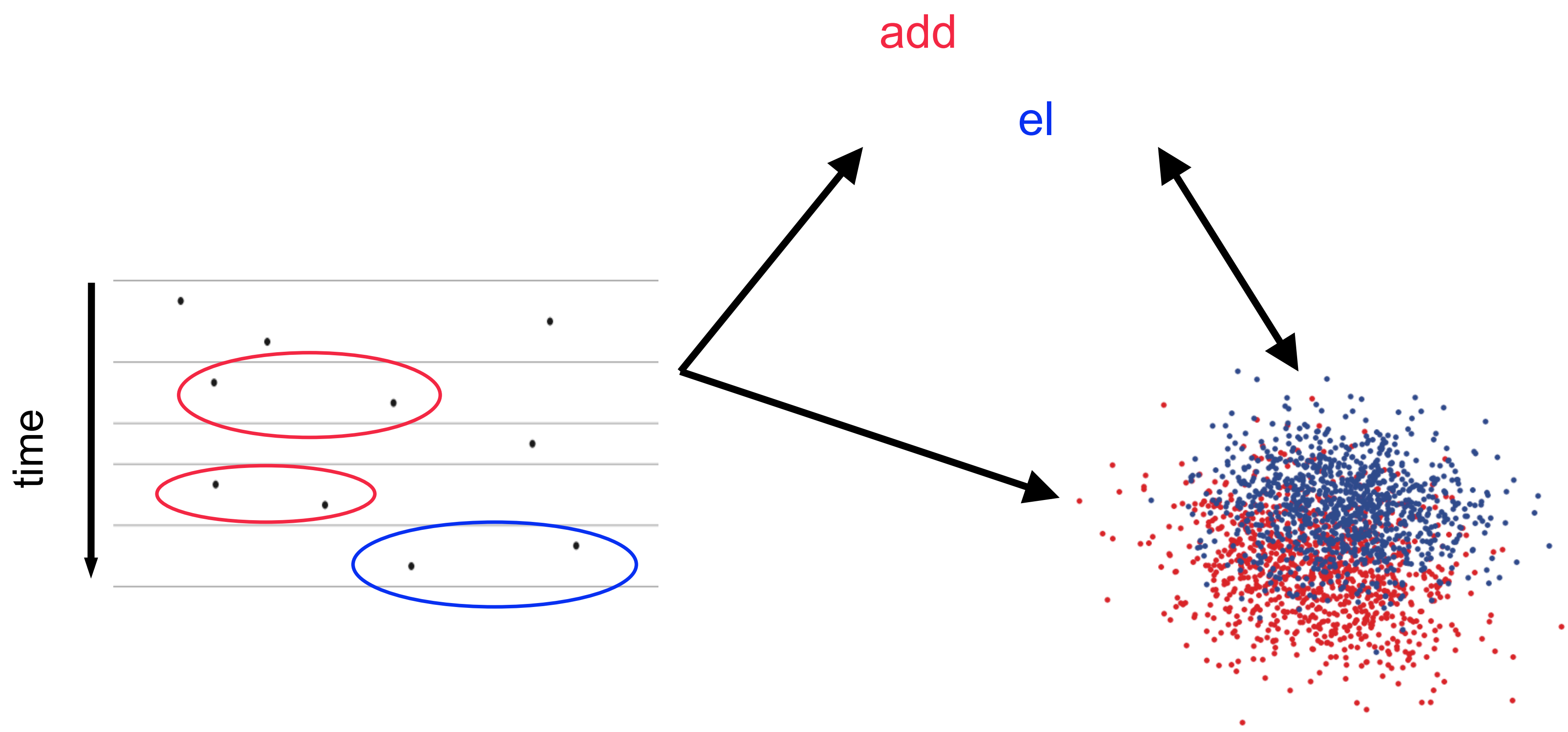

Two Generative Models

Distributional Model

Phonetic Categories

↓

Corpus

Lexical-Distributional Model

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Lexicon

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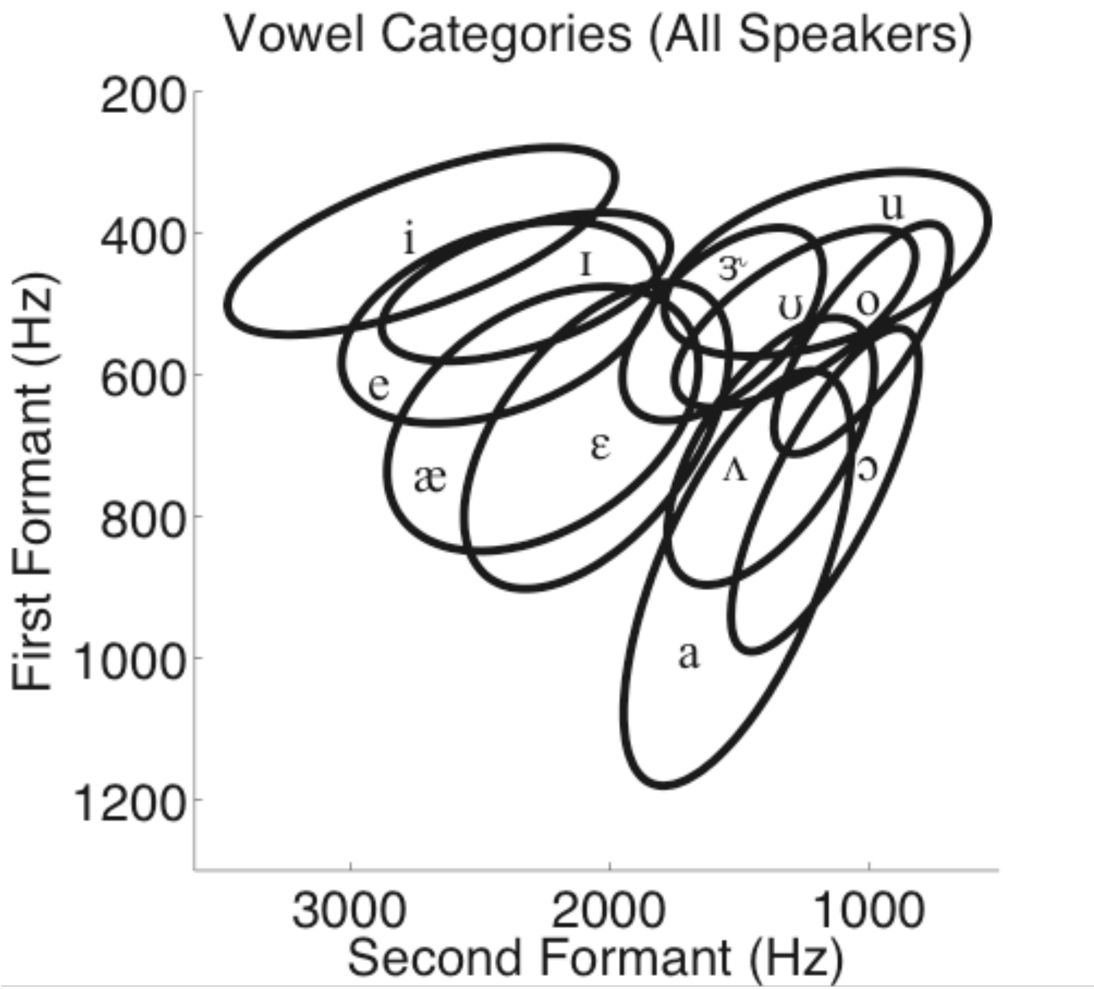
Corpus

Words Can Help Ideal Learners



(Hillenbrand et al., 1995)

Words Can Help Ideal Learners

- Created corpus of 5000 word tokens from CHILDES Parental Corpus (Li & Shirai, 2000)
  - Orthographic forms phonematized using Carnegie Mellon Pronuncing Dictionary
  - Words sampled according to corpus frequency
  - 6,409 vowel and 8,917 consonant tokens

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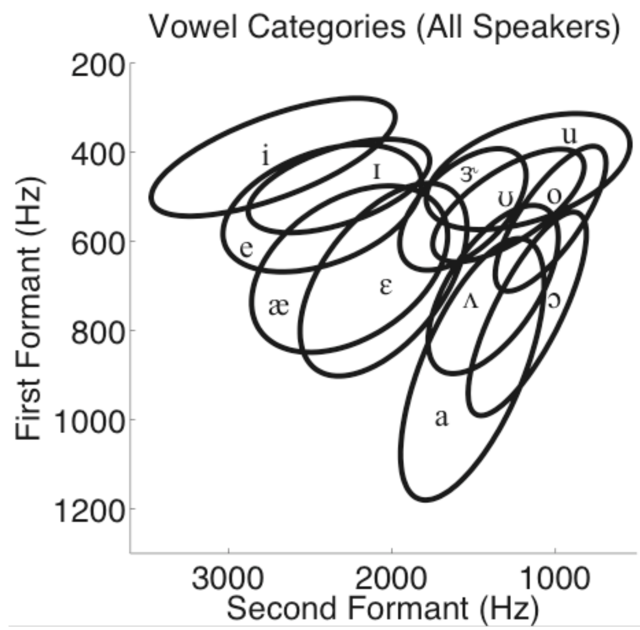
  - Speech sounds generated from Gaussians



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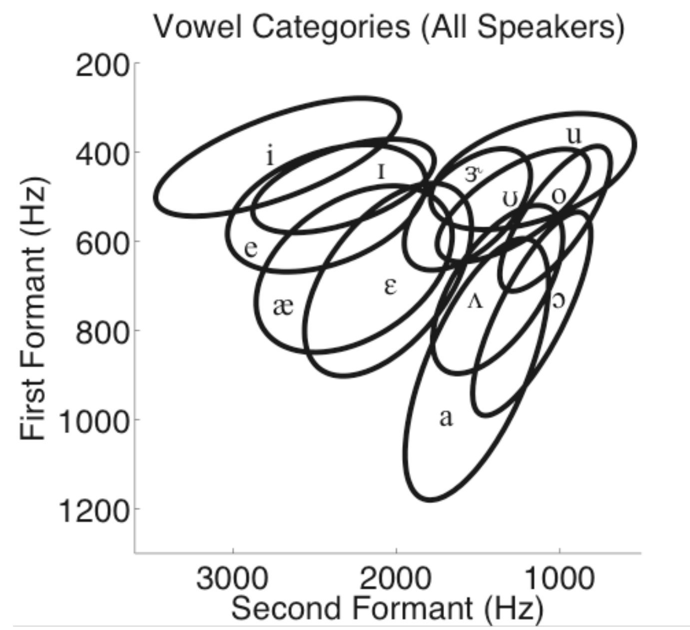
'school' represented as

$$\mathrm{s\ k} \begin{bmatrix} 423 \\ 1152 \end{bmatrix} \mathrm{l}$$



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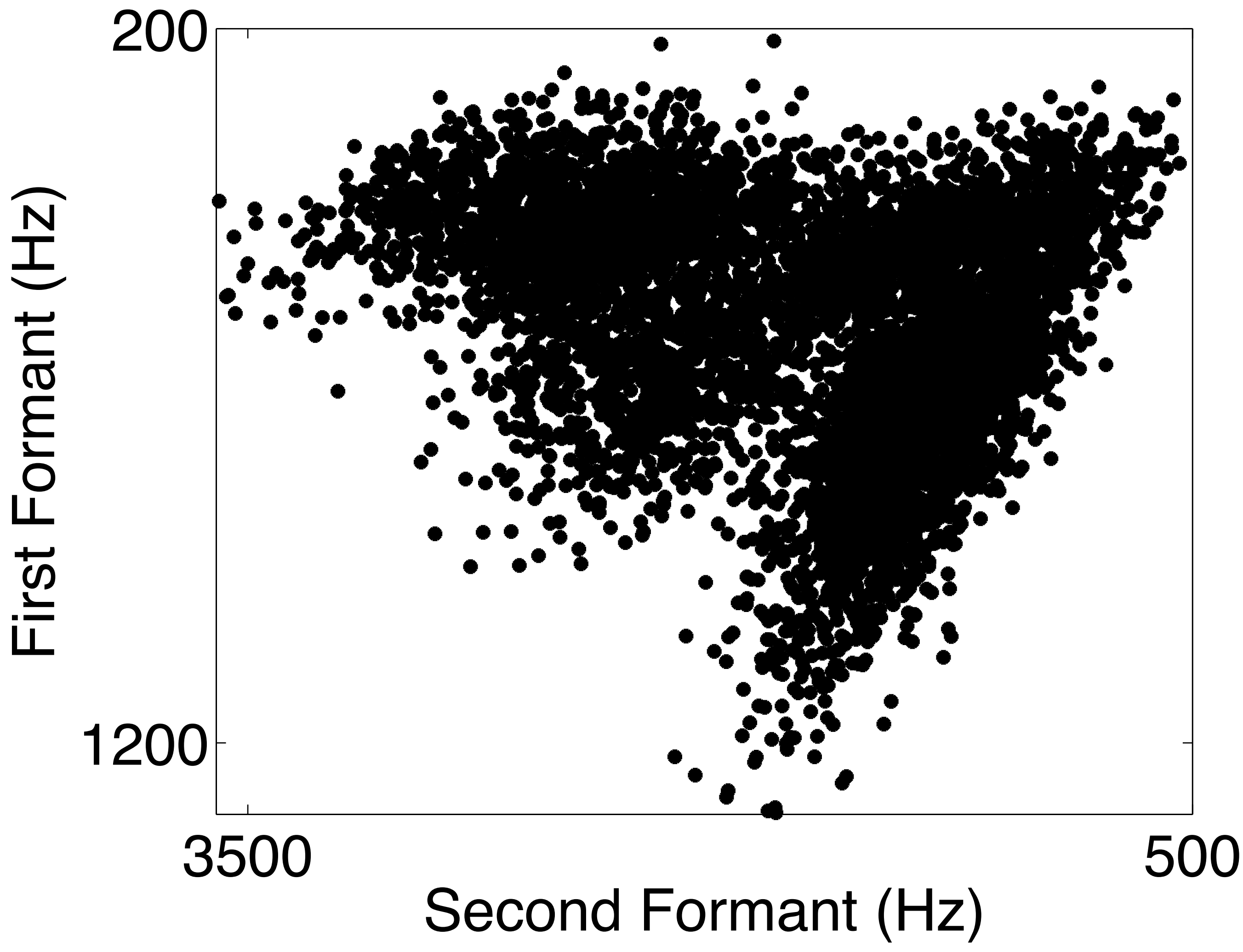
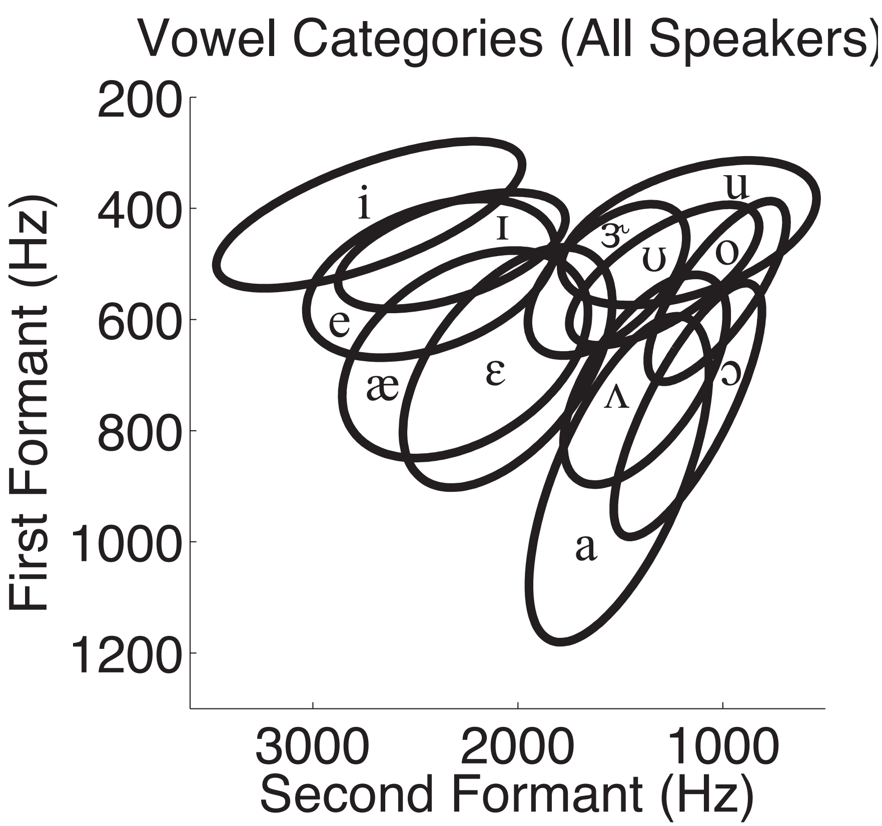
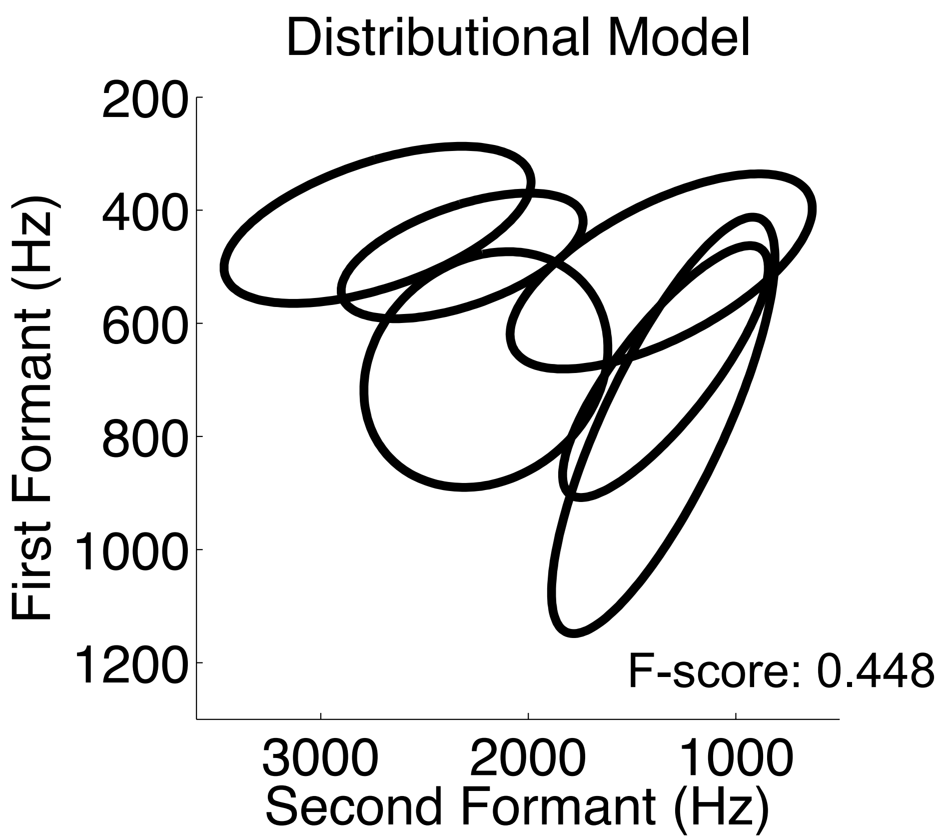


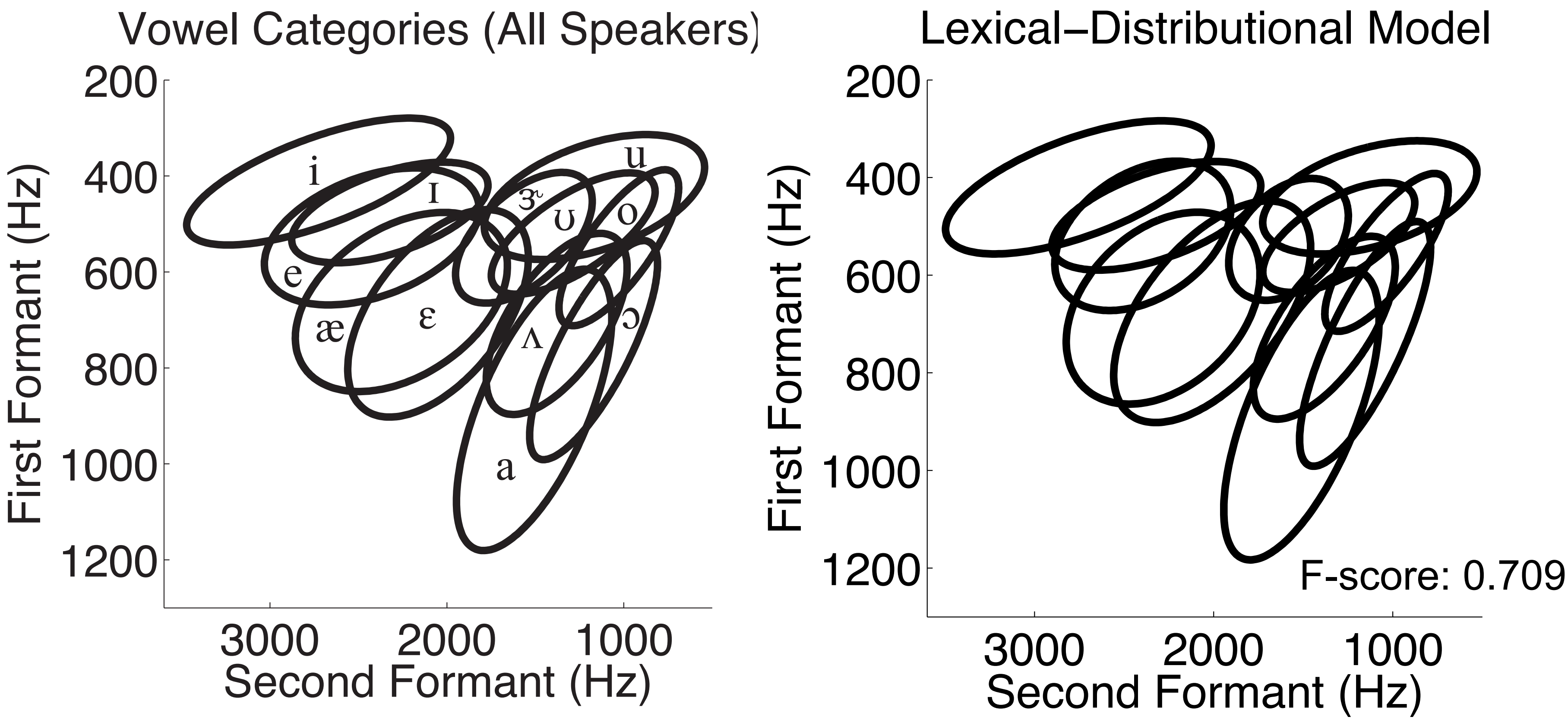
Results: Distributional





(Feldman, Griffiths, Goldwater, & Morgan, in prep)

Results: Lexical-Distributional



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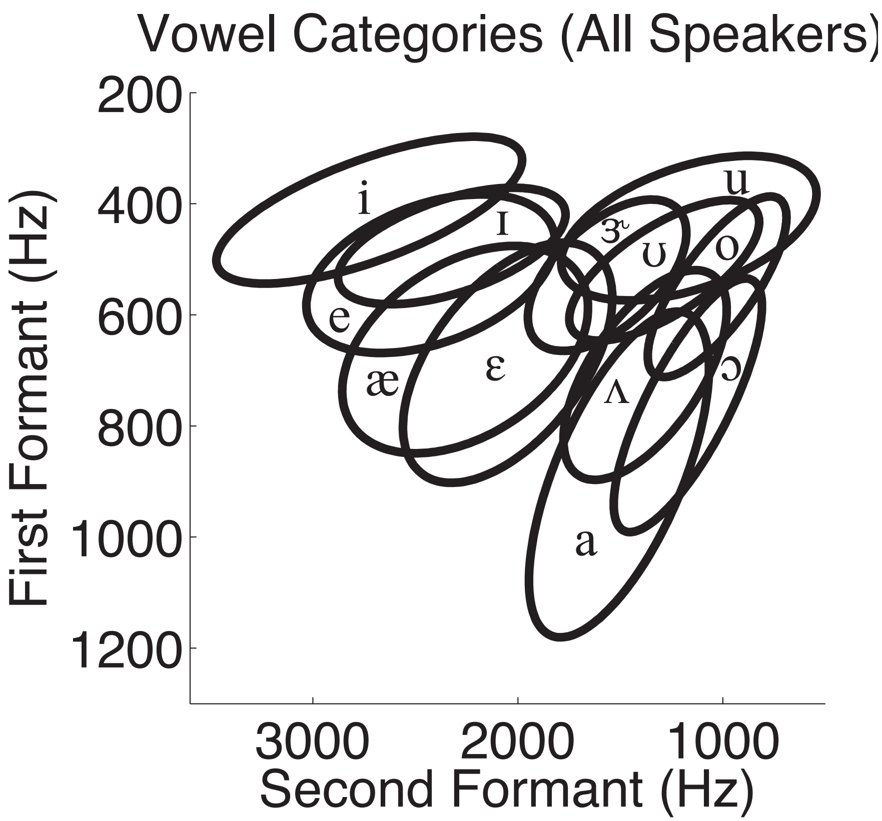

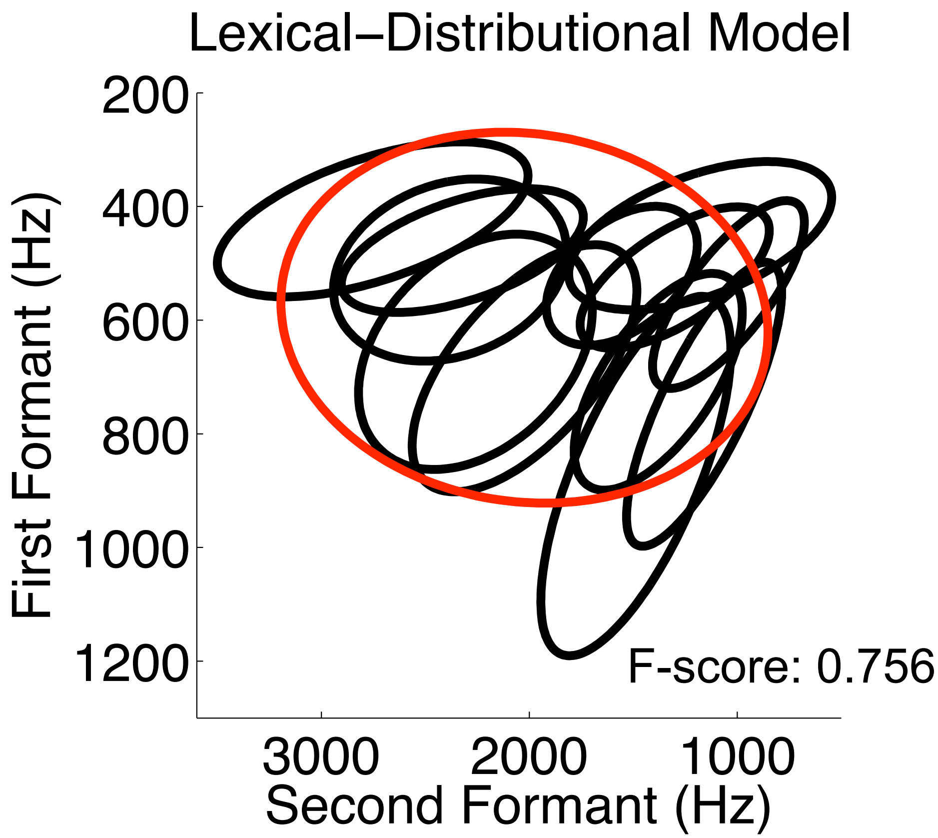

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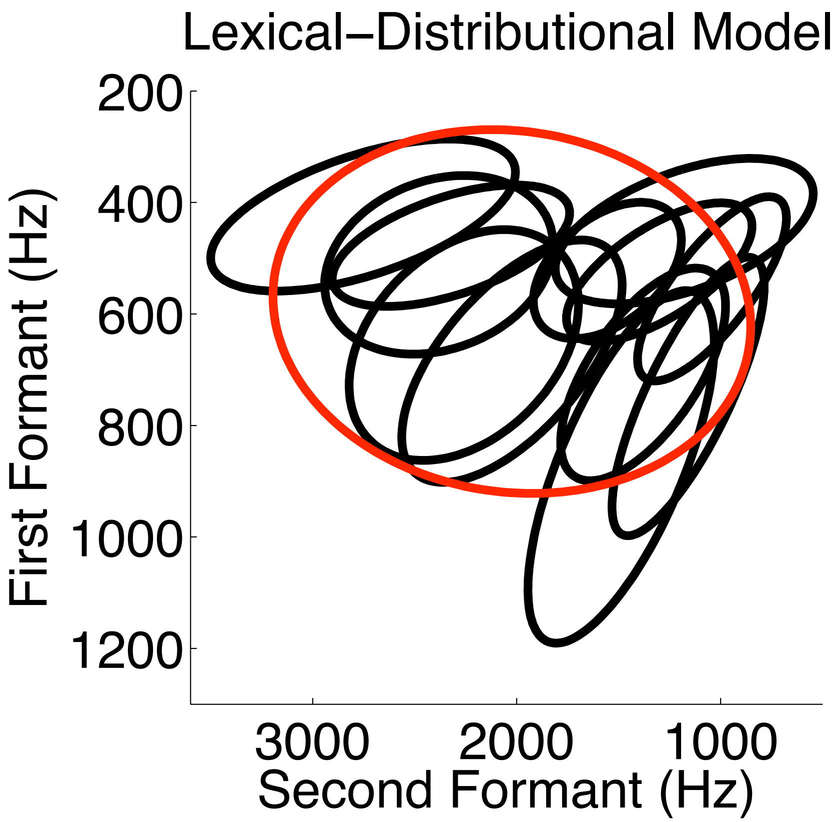
Mistakes from Minimal Pairs



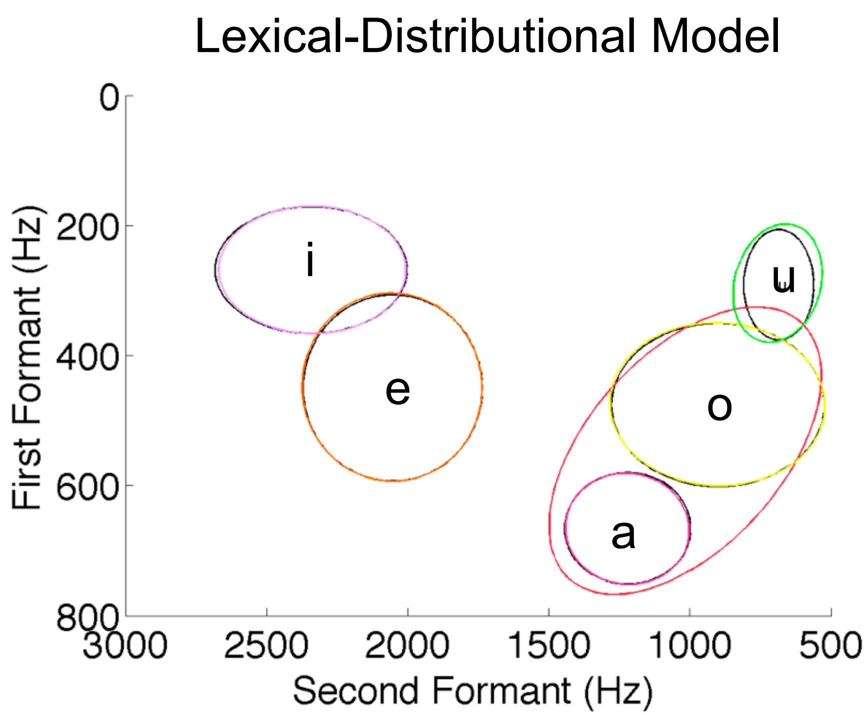
Extra category includes:

- find, found
- think, thank
- will, we'll, well
- give, gave
- made, mad, mid
- big, bag
- way, we

as well as lexical items that were not minimal pairs

(Feldman, Griffiths, Goldwater, & Morgan, in prep)

Mistakes from Minimal Pairs



- Tested on Spanish corpus
  - Categories based on production data
  - Words frequencies from CHILDES
- Model confused by morphological patterns

(Bennett, Kronrod, & Feldman, in progress)

Word and Sound Learning

- A developing lexicon can help an ideal learner separate overlapping categories
- Non-minimal pairs in the lexicon are critical for learning
- Predicts that children should be sensitive to word-level information (non-minimal pairs) during phonetic learning

Hypothesis

Infants use top-down constraints from words when acquiring phonetic categories

1. Formalize a model that can simultaneously learn sounds and words

2. Show that infants are sensitive to words in ways the model would predict

Data from Children

Evidence from 15-month-olds in “switch” task (Stager & Werker, 1997)

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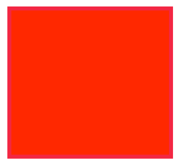
Habituation:



“daw”

(Thiessen, 2011)

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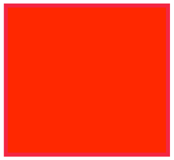
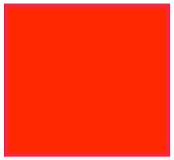


"daw"

Switch trial:



"taw"

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Habituation:

“daw”

Switch trial:

“taw”

✗

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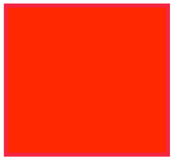
Familiarization: Habituation: Switch trial:



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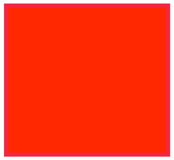

“taw”

✗

“tawgoo”

“dawbow”

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Are infants sensitive to word-level cues during the time when they are first learning phonetic categories?

Data from Children

Test 8-month-olds in a non-referential task

Non-Minimal Pair	**Minimal Pair**
gutah, gutah	gutah, gutaw
litaw, litaw	litah, litaw

(Feldman, Myers, White, Griffiths, & Morgan, submitted)

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Alternating trials (tah-taw-tah-taw)
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Preference Score: Non-alternating - Alternating

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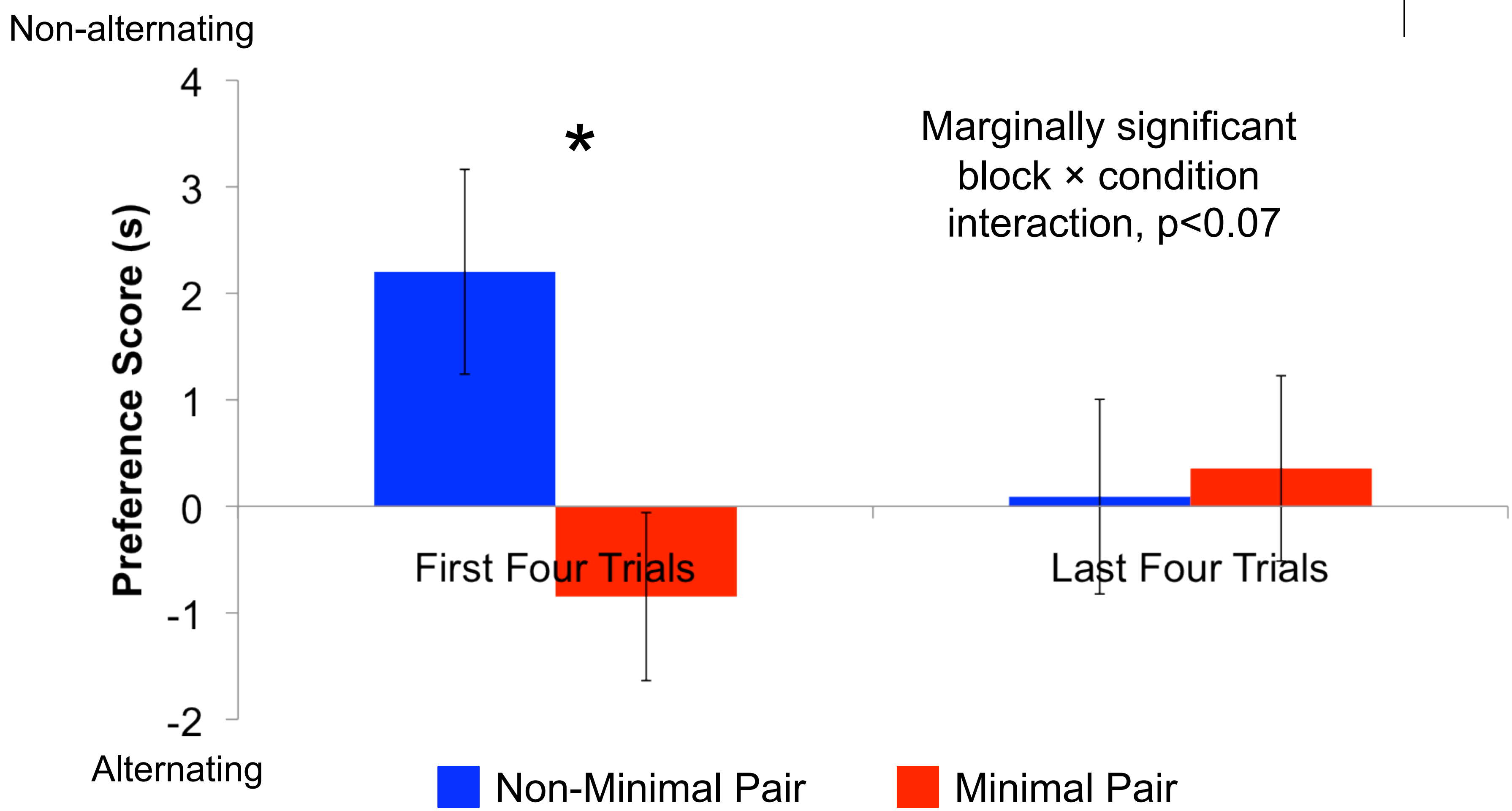

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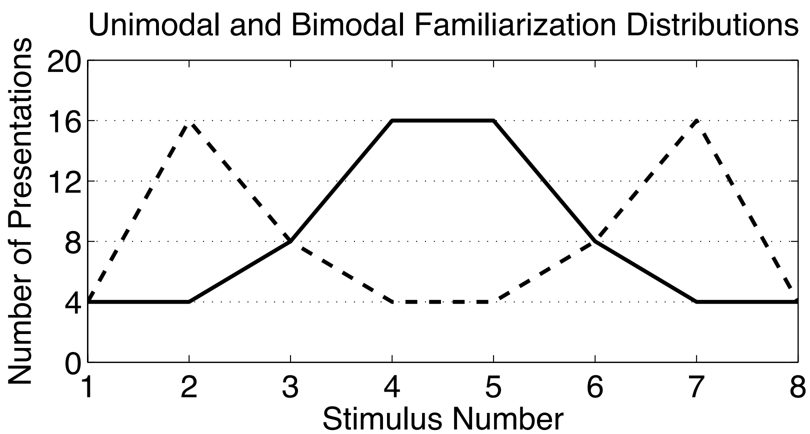
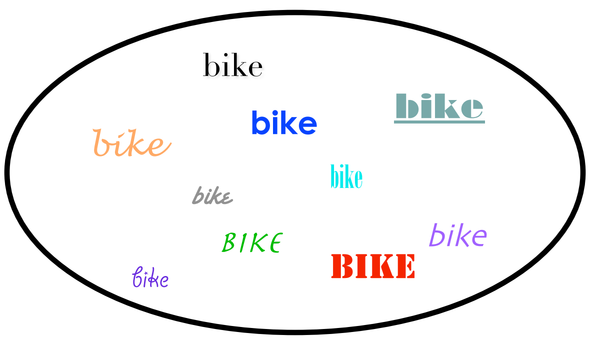
Language Acquisition

Infants have a machine learning problem to solve…



Phonetic Categories



Words

Language Acquisition

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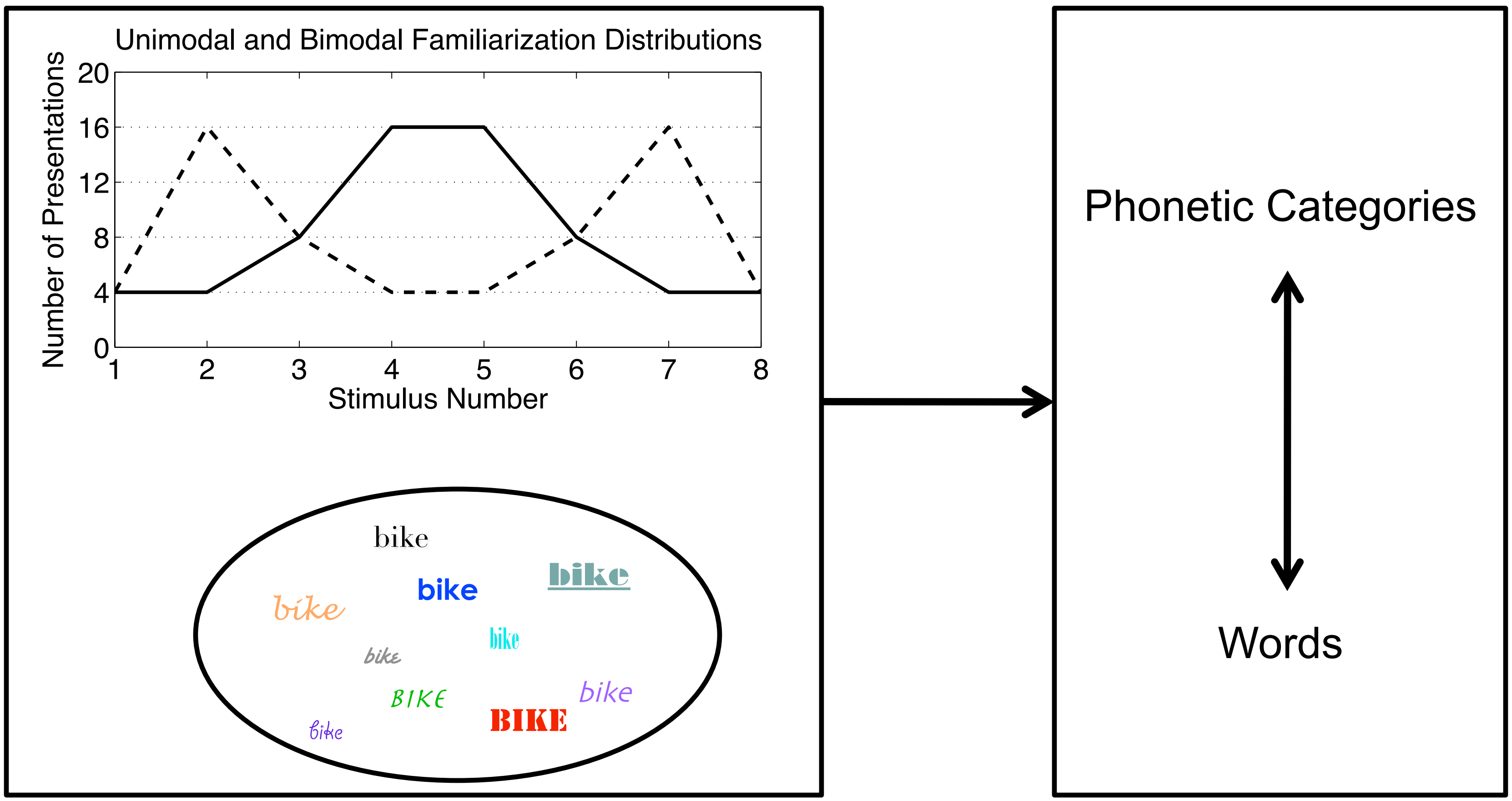

Scaling Up to Real Speech

Just defining the phonetic emission model more realistically won't work

- No way of accounting for predictable phonological variability
- Can't even do speaker normalization (not interchangeable; every sound in a word is uttered by the same speaker)
- What can we draw from this work?

Phonetic Categories

↓

Lexicon

↓

Corpus

The Right Generative Model

Distributional Model

Phonetic Categories

↓

Corpus

Lexical-Distributional Model

Phonetic Categories

↓

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Corpus

Mixture of Linear Models

Phonemes

↓

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(Dillon, Dunbar, & Idsardi, in press)

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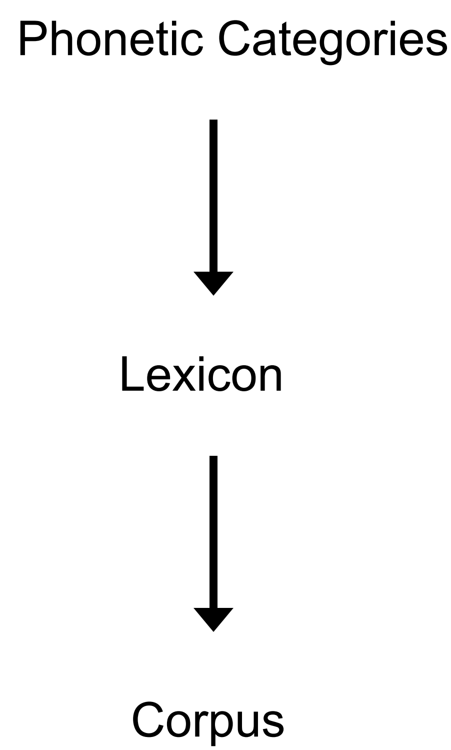
?

(Dillon, Dunbar, & Idsardi, in press)

The Right Generative Model

- Phonetic categories are part of the prior distribution over lexical items
  - Can be learned by computing statistics over the developing lexicon
  - Knowledge of phonetic categories allows rapid learning of new words, without re-estimating parameters each time
- Many other parts of this prior distribution
  - Anything that can best be learned by computing statistics over the lexicon
  - Phonological alternations, phonotactics, morphology



Evidence from Bilinguals

- Catalan-Spanish bilinguals' vowel discrimination shows a surprising pattern (Bosch & Sebastián-Gallés, 2003; Sebastián-Gallés & Bosch, 2009):

Contrast	4 months	8 months	12 months
[e]-[ɛ] (Catalan only)	✔	✘	✔
[o]-[u] (both languages)	✔	✘	✔

- S&B (2009) suggested 8-month-olds might be confused because of high number of cognates e.g., 'boat' [barko]~[barku]

- Preliminary results: Need a way to represent parallels across languages

Erin Bennett
Yakov Kronrod

Prior Distribution Over Words

- What is the form of this prior distribution?
- Can we learn the form of the prior distribution, rather than specifying it in advance?
- How can we define a prior distribution that represents parallels across multiple languages?

Acknowledgments

Lexical-distributional model
Joint work with Tom Griffiths, Sharon Goldwater, James Morgan

Infant experiment
Joint work with Emily Myers, Katherine White, Tom Griffiths, James Morgan

Bilingual learning
Joint work with Erin Bennett, Yakov Kronrod

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