Informatics 1 Cognitive Science

Lecture 8: Word Segmentation

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Slide credits: Frank Mollica, Chris Lucas, Mirella Lapata

Overview

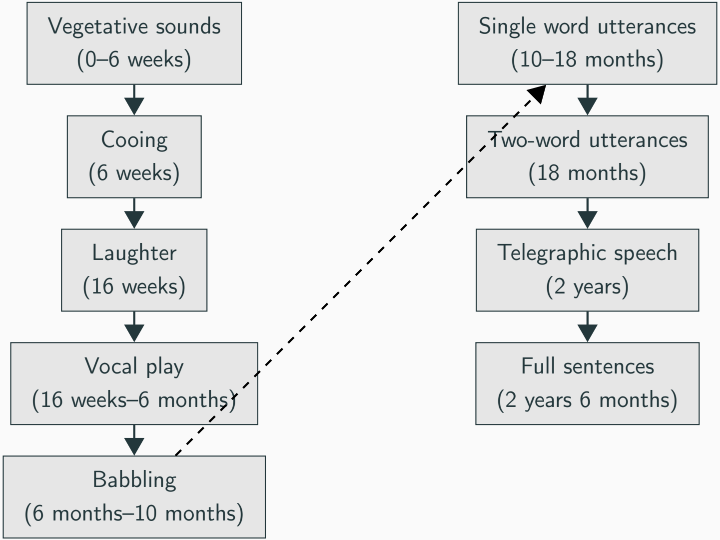
Recap

- So far, we have seen rule-based models and neural network models. These at the extremes of the rationalist–empiricist debate.
- We've also seen how these two modeling frameworks can be applied to capture aspects of language development, such as past tense learning.
- Over the next few lectures, we will introduce a third modeling framework, probabilistic modeling.
- This approach offers a way of combining rules will numerical information (probabilities).
- The rules are pre-existing (maybe innate), while the probabilities are learned. So we combine aspects of rationalism and empiricism.
- Again, we will model aspects of language development: word segmentation (this lecture) and word learning (next week).

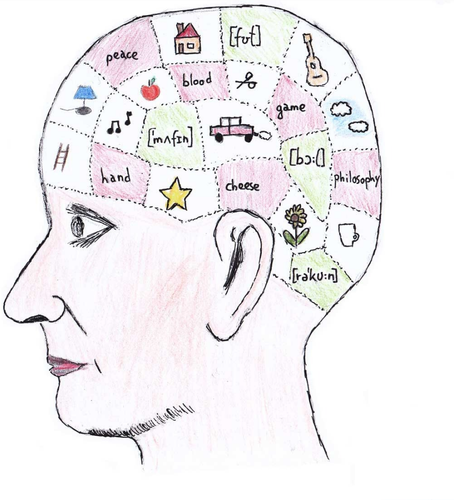
Speech Segmentation and Language Development

The Development of Language

The Development of Language



How Do We Learn Words?



- Knowing a language implies having a mental lexicon.
- Memorized set of associations among sound sequences, their meanings, and their syntax.
- Speech stream lacks any acoustic analog of the blank spaces between printed words.
- Basic units of linguistic input are not words but entire utterances.
- Child's task: to discover the words themselves in addition to meaning and syntax.

What do Infants Hear?

hamuchosañosquebuscoelyermo
hamuchosañosquevivotriste
hamuchosañosqueestoyenfermo
yesporellibroquetúescribiste
okempisantesdeleerteamaba
laluzlasvegaselmarocéano
mastúdijistequetodoacaba
quetodomuerequetodoesvano

What do Infants Hear?

A Kempis by Amado Nervo

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https://www.poemas-del-alma.com/a-kempis.htm

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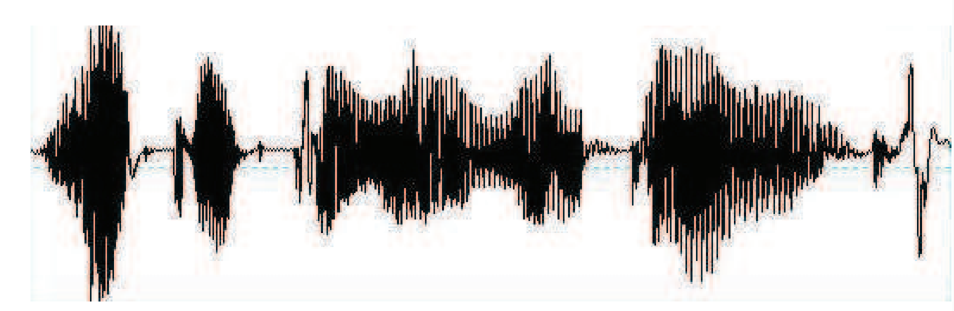
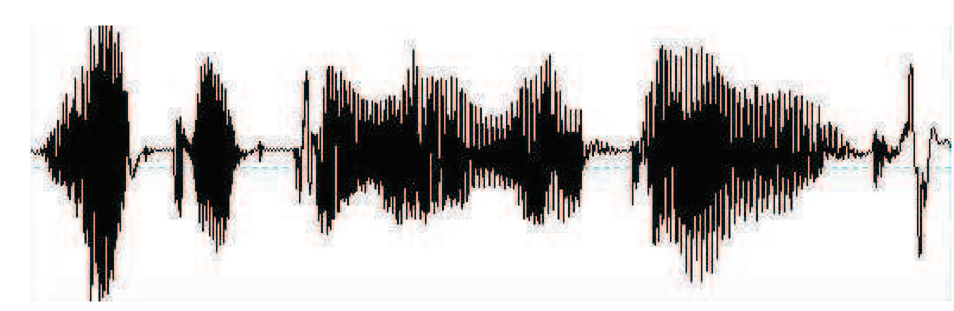
ASL demo: https://youtube.com/playlist?list=PLx1wHz1f-8J_xKVdU7DGa5RWIwWzRWNVt

Where Are the Words?



THEREDONATEAKETTLEOFTENCHIPS

Where Are the Words?



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THE RED ON A TEA KETTLE OFTEN CHIPS

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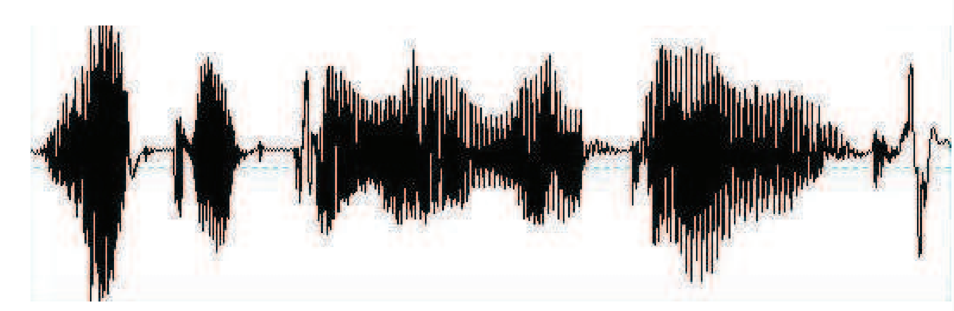
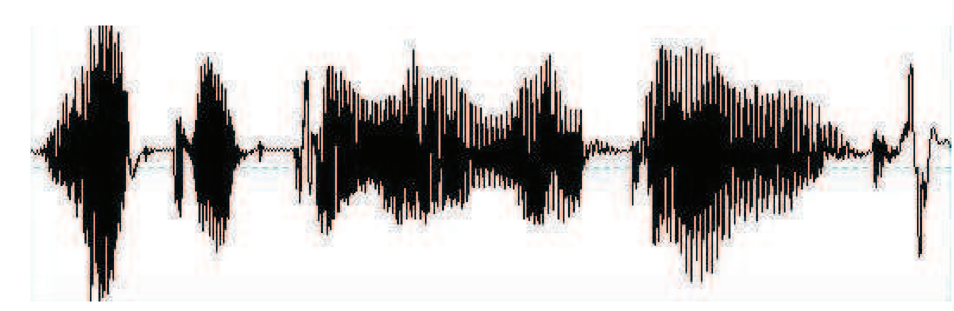


THEREDONATEAKETTLEOFTENCHIPS

THE RED ON A TEA KETTLE OFTEN CHIPS

THERE, DON ATE A KETTLE OF TEN CHIPS



THEREDONATEAKETTLEOFTENCHIPS

THE RED ON A TEA KETTLE OFTEN CHIPS

THERE, DON ATE A KETTLE OF TEN CHIPS

THERE, DONATE A KETTLE OF TEN CHIPS

Important Questions

Things we need to understand before we can even start to study language acquisition:

- How does an infant divide the input into reusable units?
- How does she represent those units?
- What does she know about them and when?

This is not an end in itself: speech segmentation provides useful units (Peters, 1983) for learning a grammar: lexicon, morphology, syntax, phonology.

How do Infants Segment Speech?

Infants make use of multiple cues in the input, most popularly:

- **Stress patterns:** English usually stresses first syllable, French always the last; final syllables of words are longer (*hamster* vs. *ham stir*).
- **Phonotactic constraints:** every word must contain a vowel, finite set of consonant clusters at the beginning of a word, etc. (*gdog* not a possible English word).
- **Bootstrapping** from known words.
- **Statistical regularities:** there is a consistent sequence of elements within words.

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How do Infants Segment Speech?

Time for a short quiz on Wooclap!

https://app.wooclap.com/FQGMXM

Transitional Probability

Transitional Probability

Words create regularities in the sound sequences of a language.

- There is a consistent sequence of elements within words.
- Sequences that don't occur within words can only occur at word boundaries.
- Sequences that don't occur within a word will tend to occur infrequently.
- Thus, we can find word boundaries by looking for unlikely transitions.

Transitional Probability

$$P(y|x) = \frac{p(x,y)}{p(x)} \approx \frac{freq(x,y)}{freq(x)}$$

Transitional Probability

Suppose the phoneme [ð] occurs 200,000 times in a text:

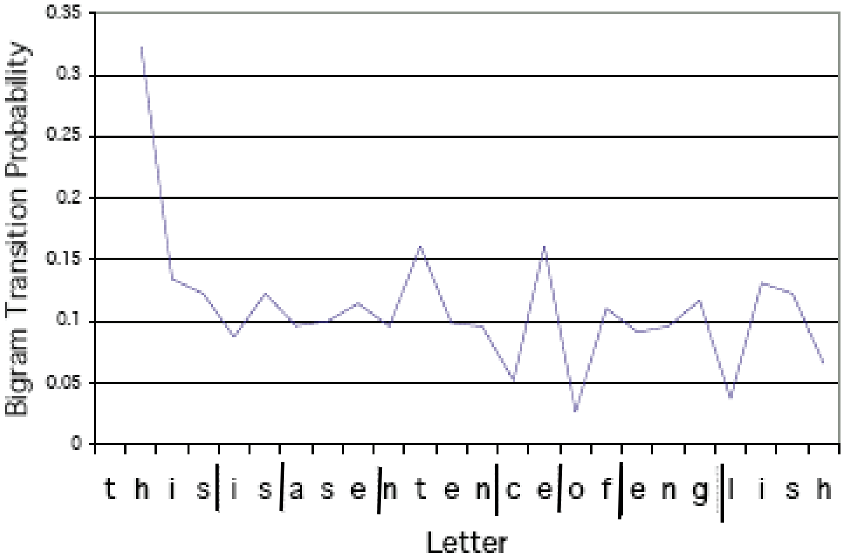
- 190,000 times are before a vowel (as in *the*, *this*);
- 200 times are before [m].

Transitional Probability

$$p(vowel|\text{ð}) = \frac{190{,}000}{200{,}000} = .95$$

$$P(m|\text{ð}) = \frac{200}{200{,}000} = .001$$

Transitional Probability



Word Segmentation Experiments

Do Children Make Use of Such Statistical Information?

Saffran et al. (1996) asked whether 8-month-old infants can extract information about word boundaries solely on the basis of statistics.

Their experiment proceeded as follows:

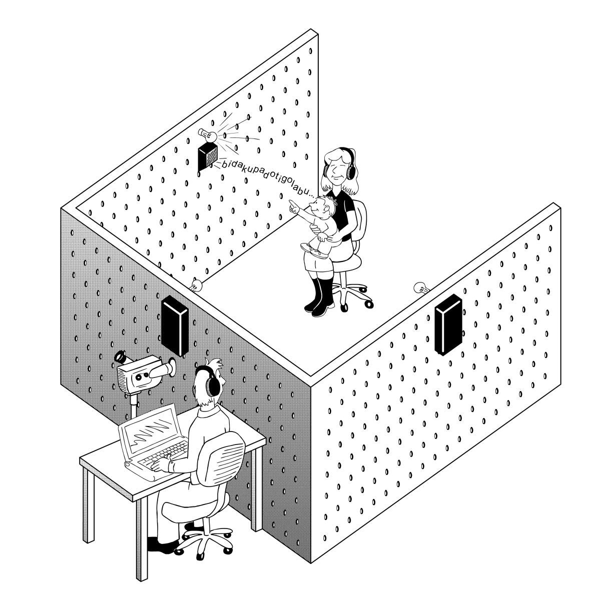
1. Create a “language” from nonsense words.
2. Infants listen to synthesized language (*pabiku*, *tibudo*).
3. Then, test: can infants distinguish words (*pabiku*) from part-words (*dogola*)?

Word Segmentation Experiments

pa bi ku ti bu do go la tu ti bu do da ro pi pa bi ku go la tu ti bu do pa bi ku go la tu da ro pi pa bi ku da ro pi pa bi ku ti bu do go la tu ti bu do

pa bi ku ti bu do go la tu ti bu
do da ro pi pa bi ku go la tu ti
bu do pa bi ku go la tu da ro
pi pa bi ku da ro pi pa bi ku ti
bu do go la tu ti bu do

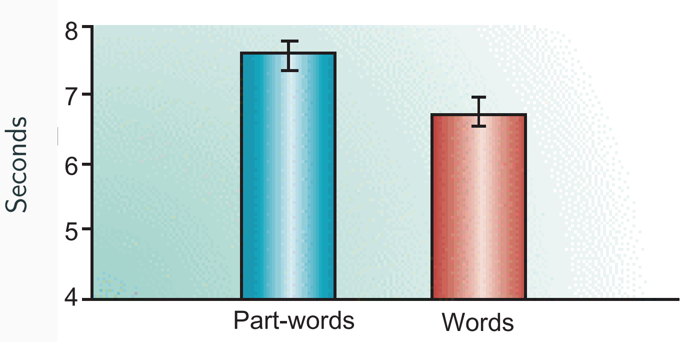
Headturn Preference Procedure



Word Segmentation Experiments

- Infants are exposed for 2 minutes to nonsense language (*pabiku*, *tibudo*, *golatu*)
- Only statistical cues to word boundaries.
- Then record how long they attend to novel sets of stimuli that either do or do not share some property with the familiarization data.
- Discrimination between *words* and *part-words* (sequences spanning word boundaries)
- If there's a difference, there has been some learning during familiarization.

Results



- Infants show longer listening times for part-words
- Infants can extract information about sequential statistics of syllables (input contained no pauses or intonational patterns)

Summary

Saffran's work (and much subsequent research) shows:

- Humans can use statistical information to segment speech.
- But all words were trisyllabic.
- So, transitional probabilities were either 1 or .33
- Will this work with more realistic probabilities?

Patricia Kuhl: The genius of babies
https://www.ted.com/talks/patricia_kuhl_the_linguistic_genius_of_babies

Transitional Probability

Time for a short quiz on Wooclap!

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Minimum Description Length

Lexicons and Segmentation

- The use of transitional probabilities to do word segmentation is not sufficient.
- It ignores the fact that many words are being learned at the same time.
- There are statistical methods for speech segmentation that incorporate the learning of a lexicon as a sub-component.
- Brent and Cartwright (1996): find the lexicon which minimizes the description of the observed data:

Minimum Description Length

$$\text{size(description)} = \text{size(lexicon)} + \text{size(data-encoding)}$$

MDL and Lexicons

Minimum Description Length

size(description) = size(lexicon) + size(data-encoding

- The MDL principle minimizes the length of words:
  shorter words are more plausible
- It minimizes the number of different words:
  try to make use of words you already know
- It maximizes the probability of each word:
  words recur as often as possible

Brent and Cartwright (1996)

Input
doyouseethekitty
seethekitty
doyoulikethekitty

Brent and Cartwright (1996)

Input
doyouseethekitty
seethekitty
doyoulikethekitty

Segmentation 1
do you see thekitty
see thekitty
do you like thekitty

Brent and Cartwright (1996)

Input
doyouseethekitty
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Segmentation 1
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do you like thekitty

Lexicon 1
1 do 2 thekitty 3 you
4 like 5 see

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Lexicon 1
1 do 2 thekitty 3 you
4 like 5 see

Derivation 1
1 3 5 2
5 2
1 3 4 2

Brent and Cartwright (1996)

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do you see thekitty
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Derivation 1
1 3 5 2
5 2
1 3 4 2

Minimum Description Length

size(description) = size(lexicon) + size(data-encoding)

size(lexicon) = number of character
characters = letters and digits

size(data-encoding) = number of characters in derivation

Brent and Cartwright (1996)

Input
doyouseethekitty
seethekitty
doyoulikethekitty

Segmentation 1
do you see thekitty
see thekitty
do you like thekitty

Lexicon 1
1 do 2 thekitty 3 you
4 like 5 see

Derivation 1
1 3 5 2
5 2
1 3 4 2

Minimum Description Length

size(description) = size(lexicon) + size(data-encoding)

size(lexicon) = number of character
characters = letters and digits

size(data-encoding) = number of characters in derivation

Length: 25 + 10 = 35

(Note we don't count spaces, only letters and digits.)

Brent and Cartwright (1996)

Input
doyouseethekitty
seethekitty
doyoulikethekitty

Segmentation 2
do you see the kitty
see the kitty
do you like the kitty

Lexicon 2
1 do 2 the 3 you
4 like 5 see 6 kitty

Derivation 2
1 3 5 2 6
5 2 6
1 3 4 2 6

Minimum Description Length

size(description) = size(lexicon) + size(data-encoding)

size(lexicon) = number of characters
characters = letters and digits

size(data-encoding) = number of characters in derivation

Brent and Cartwright (1996)

Input
doyouseethekitty
seethekitty
doyoulikethekitty

Segmentation 2
do you see the kitty
see the kitty
do you like the kitty

Lexicon 2
1 do 2 the 3 you
4 like 5 see 6 kitty

Derivation 2
1 3 5 2 6
5 2 6
1 3 4 2 6

Minimum Description Length

size(description) = size(lexicon) + size(data-encoding)

size(lexicon) = number of characters
characters = letters and digits

size(data-encoding) = number of characters in derivation
Length: 26 + 13 = 39

(Note we don't count spaces, only letters and digits.)

Brent and Cartwright (1996)

- MDL model is tested on (phonetically) transcribed speech from the CHILDES corpus.
- An idealization of the raw acoustic signal.
- Model searches for segmentation of the input with least MDL.
- Search algorithm is not incremental; it reads in the entire input before segmenting any part of it.
- Approach does not rely on language-specific input!
- Computational simulations systematically explore hypothesis that distributional regularity is useful for word segmentation.

Summary

In order to acquire a lexicon young children segment speech into words using multiple sources of support.

In this lecture, we focused on distributional regularities:

- transitional probability provides cues
- verified by Saffran et al. (1996) experiments
- computational model of word segmentation
- based on Minimum Description Length Principle

Next lecture: Bayesian modeling.