Announcements

HW1 due today by the end of class
HW2 now available (not due till after midterm)
Review questions on word segmentation now available
Midterm review: in class on 4/22/10
Midterm: in class on 4/27/10

Computational Problem

Divide spoken speech into individual words

túðokésalbijándðágáblinsíti

tú dú kæsöll bijáund dó gúblin siti
to the castle beyond the goblin city
Word Segmentation

“One task faced by all language learners is the segmentation of fluent speech into words. This process is particularly difficult because word boundaries in fluent speech are marked inconsistently by discrete acoustic events such as pauses...it is not clear what information is used by infants to discover word boundaries...there is no invariant cue to word boundaries present in all languages.”

- Saffran, Aslin, & Newport (1996)

Pauses between words don’t really happen

Word boundaries are not necessarily evident in the acoustic waveform

Mistakes from children

- Two dults
- [Two adults]
- I don’t want to go to your ami!
- [I don’t want to go to Miami]
- I am being have!
- [I am behaving!] (in response to “Behave!”)
- Oh say can you see by the donzerly light?
- [Oh say can you see by the dawn’s early light?]
Top-down influence

The sky is falling!

or

This guy is falling!

• **Adults** can use top-down information (knowledge of words and the world) to help them with word segmentation.

• What about **infants** who have none or few words in their vocabulary?

**Statistical Information Available**

Maybe infants are sensitive to the statistical patterns contained in sequences of sounds.

“Over a corpus of speech there are measurable statistical regularities that distinguish recurring sound sequences that comprise words from the more accidental sound sequences that occur across word boundaries.” - Saffran, Aslin, & Newport (1996)

- to the castle beyond the goblin city

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Statistical regularity: ca + stle is a common sound sequence to the castle beyond the goblin city
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No regularity: *stle + be* is an accidental sound sequence to the *castle beyond the goblin city* word boundary

Transitional Probability

"Within a language, the transitional probability from one sound to the next will generally be highest when the two sounds follow one another in a word, whereas transitional probabilities spanning a word boundary will be relatively low."

- Saffran, Aslin, & Newport (1996)

Transitional Probability = Conditional Probability

\[ \text{TrProb}(AB) = \text{Prob}(B | A) \]

Transitional probability of sequence AB is the conditional probability of B, given that A has been encountered.

\[ \text{TrProb}(*gob" *lin") = \text{Prob}(*lin" | "gob") \]

Read as "the probability of *lin*, given that *gob* has just been encountered"

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\[ \text{TrProb}(*gob" *lin") = \text{Prob}(*lin" | "gob") \]

Example of how to calculate TrProb:

gob...
...ble...bler...bledygoock...let...lin...stopper
(6 options for what could follow "gob")

\[ \text{TrProb}(*gob" *lin") = \text{Prob}(*lin" | "gob") = 1/6 \]

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\[ \text{TrProb}(*gob" *lin") = \text{Prob}(*lin" | "gob") \]

Idea: \( \text{Prob}(*stle" | "ca") = \) high

Why? "ca" is usually followed by "stle"

to the *castle beyond the goblin city*
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Idea: $\text{Prob}(\text{"be"} \mid \text{"stle"})$ = lower
Why? “stle” is not usually followed by “be”

to the castle beyond the goblin city
word boundary

Transitional Probability

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$\text{Prob}(\text{"be"} \mid \text{"stle"})$ = lower
Why? “stle” is not usually followed by “be”

Transitional Probability Example

$\text{Prob}(\text{"be"} \mid \text{"stle"}) < \text{Prob}(\text{"stle"} \mid \text{"ca"})$
$\text{Prob}(\text{"be"} \mid \text{"stle"}) < \text{Prob}(\text{"yond"} \mid \text{"be"})$

to the castle beyond the goblin city

TrProb learner posits word boundary here, at the minimum of the transitional probabilities

Important: doesn’t matter what the probability actually is, so long as it’s a minimum when compared to the probabilities surrounding it

$\text{Prob}(\text{"be"} \mid \text{"stle"})$ = lower
Why? “stle” is not usually followed by “be”

$\text{Prob}(\text{"be"} \mid \text{"stle"}) < \text{Prob}(\text{"yond"} \mid \text{"be"})$ = higher
Why? “be” is commonly followed by “yond”, among other options

to the castle beyond the goblin city

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$\text{Prob}(\text{"be"} \mid \text{"stle"}) = \text{lower}$
Why? “stle” is not usually followed by “be”

to the castle beyond the goblin city
word boundary
**8-month-old statistical learning**

Saffran, Aslin, & Newport 1996
Familiarization-Preference Procedure (Jusczyk & Aslin 1995)

**Habituation:**
Infants exposed to auditory material that serves as potential learning experience

**Test stimuli (tested immediately after familiarization):**
(familiar) Items contained within auditory material
(novel) Items not contained within auditory material, but which are nonetheless highly similar to that material

**Measure of infants’ response:**
Infants control duration of each test trial by their sustained visual fixation on a blinking light.

Idea: If infants have extracted information (based on transitional probabilities), then they will have different looking times for the different test stimuli.

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**Artificial Language**

Saffran, Aslin, & Newport 1996
4 made-up words with 3 syllables each

**Condition A:**
tupiro, golabu, bidaku, padoti

**Condition B:**
dapiku, tilado, burobi, pagotu

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**Artificial Language**

Saffran, Aslin, & Newport 1996
Infants were familiarized with a sequence of these words generated by speech synthesizer for 2 minutes. Speaker’s voice was female and intonation was monotone. There were no acoustic indicators of word boundaries.

Sample monotone speech: 
http://whyfiles.org/058language/images/baby_stream.aiff
tu pi ro go la bu bi da ku pa do ti go la bu tu pi ro pa do ti...
Artificial Language

Saffran, Aslin, & Newport 1996
The only cues to word boundaries were the transitional probabilities between syllables.

Within words, transitional probability of syllables = 1.0
Across word boundaries, transitional probability of syllables = 0.33

\( \text{TrProb}(\text{"tu"} \rightarrow \text{"pi"}) = 1.0 = \text{TrProb}(\text{"go"} \rightarrow \text{"la"}), \text{TrProb}(\text{"pa"} \rightarrow \text{"do"}) \)

\( \text{tu pi ro go la bu bi da ku pa do ti go la bu tu pi ro pa do ti...} \)
Artificial Language
Saffran, Aslin, & Newport 1996
The only cues to word boundaries were the transitional probabilities between syllables.
Within words, transitional probability of syllables = 1.0
Across word boundaries, transitional probability of syllables = 0.33
TrProb("ro" "go"), TrProb("ro" "pa") = 0.3333 <
1.0 = TrProb("pi" "ro"), TrProb("go" "la"), TrProb("pa" "do")
tu pi go la bu bi da ku pa do ti go la bu tu pi ro pa do ti...
word boundary

Testing Infant Sensitivity
Saffran, Aslin, & Newport 1996
Expt 1, test trial:
Each infant presented with repetitions of 1 of 4 words
2 were “real” words
(ex: tupiro, golabu)
2 were “fake” words whose syllables were jumbled up
(ex: ropitu, bulago)
tu pi ro go la bu bi da ku pa do ti go la bu tu pi ro pa do ti...

Testing Infant Sensitivity
Saffran, Aslin, & Newport 1996
Expt 1, results:
Infants listened longer to novel items (non-words)
(7.97 seconds for real words, 8.85 seconds for non-words)
Implication: Infants noticed the difference between real words and non-words from the artificial language after only 2 minutes of listening time!
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But why?
Could be that they just noticed a familiar sequence of sounds ("tupiro" familiar while "ropilu" never appeared), and didn’t notice the differences in transitional probabilities.

Testing Infant Sensitivity
Saffran, Aslin, & Newport 1996
Expt 2, test trial:
Each infant presented with repetitions of 1 of 4 words
2 were "real" words
(ex: tupiro, golabu)
2 were "part" words whose syllables came from two different words in order
(ex: pirogo, bubida)

"tu pi ro go la bu bi da ku pa do ti go la bu tu pi ro pa do ti..."
Testing Infant Sensitivity
Saffran, Aslin, & Newport 1996

Expt 2, results:
- Infants listened longer to novel items (part-words)
  - (6.77 seconds for real words, 7.60 seconds for part-words)

Implication: Infants noticed the difference between real words and part-words from the artificial language after only 2 minutes of listening time! They are sensitive to the transitional probability information.


Experimental evidence suggests that 8-month-old infants can track statistical information such as the transitional probability between syllables. This can help them solve the task of word segmentation.

Evidence comes from testing children in an artificial language paradigm, with very short exposure time.

Questions?
Use the remaining time to work on HW2 and look over the relevant review questions for word segmentation