Analyzing Human and Machine Performance In Resolving Ambiguous Spoken Sentences

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I'm a linguist.

I love ambiguity more than most people.
Motivation

When an ambiguous sentence is spoken, what information does speech have which text alone doesn’t?

Our goal is to examine this information by analyzing human disambiguation of both text and speech for different types of ambiguities, and developing a model for automatic disambiguation using this information.
Research Summary

- Record sentences containing some ambiguity, with the speaker aware of the correct interpretation
- Subjects hear or read sentences, predict the correct interpretation
- Analyze acoustic features of each utterance, including multiple recordings of the same sentence
- Develop a Machine Learning approach to predict the intended reading given the acoustic features
Types of Ambiguity

- Lexical Ambiguity (I forgot my bag at the bank)
- Syntactic Ambiguity (old men and women)
  - Comma Ambiguity
  - PP-attachment
  - NP-ambiguity
  - Coordination ambiguity ... etc
Comma Ambiguity

A woman without her man is nothing.

A woman: without her, man is nothing.
Comma Ambiguity

- Without punctuation (e.g. out of ASR) text can be ambiguous
- Can the written text be disambiguated by humans?
- Can the spoken sentence be disambiguated by humans?
PP-Attachment

I saw [the boy with the telescope]
I saw the boy [with the telescope]
PP-Attachment

This sentence has two possible interpretations, i.e., a structural ambiguity.
late closure is the principle that new words (or "incoming lexical items") tend to be associated with the phrase or clause currently being processed rather than with structures farther back in the sentence. *

*https://www.thoughtco.com/late-closure-sentence-processing-1691101
Hypotheses

- When there is ambiguity in any sentence and the speaker is aware of the correct reading, they will convey their knowledge of the correct reading using certain prosodic cues.
- Listeners will be able to use these cues to identify the correct reading better than readers will.
- These prosodic cues can be measured and analyzed and used as features for automatic disambiguation system using machine learning.
Previous Research

Psychology - Snedeker and Trueswell, 2003 - Using prosody to avoid ambiguity: Effects of speaker awareness and referential context.

“informative prosodic cues depend upon speaker's knowledge of the situation: speakers provide prosodic cues when needed; listeners use these prosodic cues when present.”

Prosodic cues include pauses and word durations, as shown from the utterances of a speaker who is aware of the intended meaning.

“tap [the frog with the flower]” - modifier

“tap the frog [with the flower]” - instrument
Previous Research

NLP - Levi et al, 2012 - The effect of pitch, intensity and pause duration in punctuation detection

Predicting punctuation from different prosodic cues of speech using neural networks

Cues included: pitch, intensity and pause duration

Achieved a punctuation detection rate of 54%
Data

- We created a collection of 26 constructed sentences (6 pairs of sentences with comma ambiguity and 7 pairs of sentences with PP-attachment ambiguity)
- We recorded the sentences spoken by a native speaker, each sentence recorded five times (total 130 recording files)
Comma Ambiguity - Speaker Tasks

Record 6 pairs of constructed Comma-ambiguous sentences

Example:

3a: John, said Mary, was the nicest person at the party.

3b: John said Mary was the nicest person at the party.
Comma Ambiguity - Listener Tasks

For each Comma-ambiguous sentence, identify the intended meaning:

Task 1 - Using Text only

Task 2 - Using Audio Only

Example:

Sentence: John, said Mary, was the nicest person at the party.

Question: Who was said to be the nicest person at the party? A- John B- Mary
PP-Attachment Ambiguity - Speaker Tasks

Record 7 pairs of sentences with PP-attachment ambiguity, each pair contains a different preceding context supporting one reading of the sentence

Example:

4a: *One of the boys got a telescope.* I saw the boy with the telescope.

4b: *I have a new telescope.* I saw the boy with the telescope.
PP-Attachment Ambiguity - Listener Tasks

For the following settings, identify the correct meaning by answering a question. For the last setting, sentences recordings were trimmed from the previous context.

Who has the telescope? A- The boy B- The speaker

<table>
<thead>
<tr>
<th>Setting</th>
<th>Presentation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Text with context</td>
<td>I have a new telescope. I saw the boy with the telescope.</td>
</tr>
<tr>
<td>Audio with context</td>
<td></td>
</tr>
<tr>
<td>Text without context</td>
<td>I saw the boy with the telescope.</td>
</tr>
<tr>
<td>Audio without context</td>
<td></td>
</tr>
</tbody>
</table>
## Results - Human Evaluation

<table>
<thead>
<tr>
<th>Ambiguity</th>
<th>Modality</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Comma</td>
<td>Text</td>
<td>99.3%</td>
</tr>
<tr>
<td>Comma</td>
<td>Audio</td>
<td>94.7%</td>
</tr>
<tr>
<td>PP-attachment with context</td>
<td>Text</td>
<td>93.1%</td>
</tr>
<tr>
<td>PP-attachment with context</td>
<td>Audio</td>
<td>97.1%</td>
</tr>
<tr>
<td>PP-attachment without context</td>
<td>Text</td>
<td>52.0%</td>
</tr>
<tr>
<td>PP-attachment without context</td>
<td>Audio</td>
<td>74.4%</td>
</tr>
</tbody>
</table>
## Results - PP-Attachment - Acoustic Analysis

Acoustic feature values averaged over the 20 productions of the following sentences:

They discussed the mistakes in the second meeting.  
The lawyer contested the proceedings in the third hearing.

<table>
<thead>
<tr>
<th></th>
<th>Late</th>
<th>Early</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preposition Duration (ms)</td>
<td>147</td>
<td>143</td>
</tr>
<tr>
<td>Preceding silent pauses (ms)</td>
<td>0</td>
<td>48</td>
</tr>
<tr>
<td>Intensity (dB)</td>
<td>57.8</td>
<td>56.4</td>
</tr>
<tr>
<td>Following NP duration (ms)</td>
<td>579</td>
<td>640</td>
</tr>
</tbody>
</table>
Acoustic Analysis - Early vs. Late Closure

Early Closure

Late Closure
Results - PP-Attachment - Machine Evaluation

Feature Matrix - Extracted manually from 10 audio files for the sentence “They discussed the mistakes in the second meeting”.

<table>
<thead>
<tr>
<th>duration of preposition (ms)</th>
<th>duration of preceding silence (ms)</th>
<th>duration of following NP (ms)</th>
<th>Preposition Intensity (dB)</th>
<th>Closure Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>160</td>
<td>0</td>
<td>690</td>
<td>56.6</td>
<td>early</td>
</tr>
<tr>
<td>175</td>
<td>0</td>
<td>660</td>
<td>59.0</td>
<td>late</td>
</tr>
<tr>
<td>120</td>
<td>0</td>
<td>470</td>
<td>56.2</td>
<td>late</td>
</tr>
<tr>
<td>140</td>
<td>80</td>
<td>620</td>
<td>55.6</td>
<td>early</td>
</tr>
<tr>
<td>145</td>
<td>0</td>
<td>600</td>
<td>58.7</td>
<td>late</td>
</tr>
<tr>
<td>140</td>
<td>90</td>
<td>635</td>
<td>57.8</td>
<td>early</td>
</tr>
<tr>
<td>135</td>
<td>0</td>
<td>510</td>
<td>61.1</td>
<td>late</td>
</tr>
<tr>
<td>150</td>
<td>110</td>
<td>600</td>
<td>57.9</td>
<td>early</td>
</tr>
<tr>
<td>130</td>
<td>0</td>
<td>620</td>
<td>61.0</td>
<td>late</td>
</tr>
<tr>
<td>140</td>
<td>60</td>
<td>580</td>
<td>58.8</td>
<td>early</td>
</tr>
</tbody>
</table>
Machine Evaluation

Using Decision Trees for 20 data points with 5-fold cross-validation: 80% average accuracy in predicting early vs. late closure

All sentences were using in training and testing each fold
Conclusions

- Humans can disambiguate sentences with comma ambiguity with audio alone almost as well as with text containing punctuation.
- Humans can disambiguate spoken sentences with PP-attachment ambiguity without context, but cannot disambiguate the same sentences as text.
- When speakers are aware of the intended meaning, they can produce sentences in a way that can
  - Be disambiguated by listeners, even without context
  - Be identified through certain acoustic cues
  - Be disambiguated to some extent by machines, initial results are promising.
Thank you!

Questions?