

CS 224S / LINGUIST 236 Speech Recognition and Synthesis

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Lecture 16: Metadata: disfluencies and boundaries

IP Notice:

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Outline

- Disfluencies
- Characteristics of disfluencies
- Detecting disfluencies
- MDE bakeoff
- Fragments

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Disfluencies

the . [exhale] . . . [inhale] . . . [uh] does American airlines . offer any
one way flights . [uh] one way fares, for one hundred and sixty one
dollars

[mm] i'd like to leave i guess between [um] . [smack] . five o'clock no,
five o'clock and [uh], seven o'clock . P M

around, four, P M

all right, [throat_clear] . . . i'd like to know the . give me the flight . times
in the morning . for September twentieth . nineteen ninety one

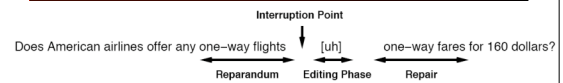
[uh] one way

[uh] seven fifteen, please

on United airlines . . . give me, the . . . time . . . from New York . [smack]
to Boise-, to . I'm sorry . on United airlines . [uh] give me the flight,
numbers, the flight times from . [uh] Boston . to Dallas

Figure 9.5 Some sample spoken utterances from users interacting with the ATIS system.

Disfluencies: standard terminology (Levelt)



- **Reparandum: thing repaired**
- **Interruption point (IP): where speaker breaks off**
- **Editing phase (edit terms): uh, I mean, you know**
- **Repair: fluent continuation**

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Why disfluencies?

- **Need to clean them up to get understanding**
 - Does American airlines offer any ~~one way flights~~ [uh] one-way fares for 160 dollars?
 - Delta leaving Boston ~~seventeen twenty one~~ arriving Fort Worth ~~twenty two~~ twenty one forty
- **Might help in language modeling**
 - Disfluencies might occur at particular positions (boundaries of clauses, phrases)
- **Annotating them helps readability**
- **Disfluencies cause errors in nearby words**

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Counts (from Shriberg, Heeman)

- **Sentence disfluency rate**
 - ATIS: 6% of sentences disfluent (10% long sentences)
 - Levelt human dialogs: 34% of sentences disfluent
 - Swbd: ~50% of multiword sentences disfluent
 - TRAINS: 10% of words are in reparandum or editing phrase
- **Word disfluency rate**
 - SWBD: 6%
 - ATIS: 0.4%
 - AMEX 13%
 - (human-human air travel)

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Prosodic characteristics of disfluencies

- Nakatani and Hirschberg 1994
- Fragments are good cues to disfluencies
- Prosody:
 - Pause duration is shorter in disfluent silence than fluent silence
 - F0 increases from end of reparandum to beginning of repair, but only minor change
 - Repair interval offsets have minor prosodic phrase boundary, even in middle of NP:
 - Show me all n- | round-trip flights | from Pittsburgh | to Atlanta

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Syntactic Characteristics of Disfluencies

- Hindle (1983)
- The repair often has same structure as reparandum
- Both are Noun Phrases (NPs) in this example:



- So if could automatically find IP, could find and correct reparandum!

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Disfluencies and LM

- Clark and Fox Tree
- Looked at "um" and "uh"
 - "uh" includes "er" ("er" is just British non-rhotic dialect spelling for "uh")
- Different meanings
 - Uh: used to announce minor delays
 - Preceded and followed by shorter pauses
 - Um: used to announce major delays
 - Preceded and followed by longer pauses

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Um versus uh: delays (Clark and Fox Tree)

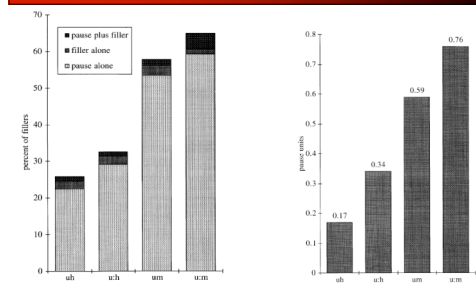


Fig. 1. Percent of fillers followed by delays (LL corpus). S Wint Fig. 2. Mean length of pauses after fillers (LL corpus).

Utterance Planning

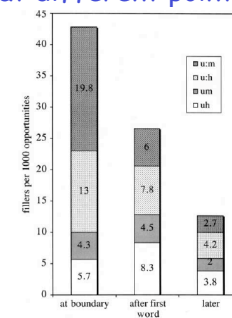
- The more difficulty speakers have in planning, the more delays
- Consider 3 locations:
 - I: before intonation phrase: hardest
 - II: after first word of intonation phrase: easier
 - III: later: easiest
- And then uh somebody said, . [I] but um -- [II] don't you think there's evidence of this, in the twelfth - [III] and thirteenth centuries?

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Delays at different points in phrase



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Fig. 5. Rates of uh and um at three position in tone units (LL corpus).

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Disfluencies in language modeling

- Should we “clean up” disfluencies before training LM (I.e. skip over disfluencies?)
 - Filled pauses
 - Does United offer any [uh] one-way fares?
 - Repetitions
 - What what are the fares?
 - Deletions
 - Fly to Boston from Boston
 - Fragments (we'll come back to these)
 - I want fl- flights to Boston.

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Does deleting disfluencies improve LM perplexity?

- Stolcke and Shriberg (1996)
- Build two LMs
 - Raw
 - Removing disfluencies
- See which has a higher perplexity on the data.
 - Filled Pause
 - Repetition
 - Deletion

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Change in Perplexity when Filled Pauses (FP) are removed

- LM Perplexity goes up at following word:

Position	UH	UH+1	UH+2	UM	UM+1	UM+2	non-FP	overall
Baseline	39.0	223.5	86.8	174.0	96.7	71.9	103.4	101.0
FP model	39.9	281.5	81.4	175.8	73.4	69.2	103.4	103.3
#events	502	502	373	188	188	94		10426

- Removing filled pauses makes LM worse!!
- I.e., filled pauses seem to help to predict next word.
- Why would that be?

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Stolcke and Shriberg 1996

Filled pauses tend to occur at clause boundaries

- Word before FP is end of previous clause; word after is start of new clause;
 - Best not to delete FP
- Some of the different things we're doing [uh] there's not time to do it all
- “there's” is very likely to start a sentence
- So $P(\text{there's}|\text{uh})$ is better estimate than $P(\text{there's}|\text{doing})$

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Suppose we just delete medial FPs

- Experiment 2:
 - Parts of SWBD hand-annotated for clauses
 - Build FP-model by deleting only medial FPs
 - Now prediction of post-FP word (perplexity) improves greatly!
 - Siu and Ostendorf found same with “you know”

Position	UH+1	UM+1
Baseline	849.0	437.4
FP model	606.2	361.7

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What about REP and DEL

- S+S built a model with “cleaned-up” REP and DEL
- Slightly lower perplexity
- But exact same word error rate (49.5%)
- Why?
 - Rare: only 2 words per 100
 - Doesn't help because adjacent words are misrecognized anyhow!

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Stolcke and Shriberg conclusions wrt LM and disfluencies

- Disfluency modeling purely in the LM probably won't vastly improve WER
- But
 - Disfluencies should be considered jointly with sentence segmentation task
 - Need to do better at recognizing disfluent words themselves
 - Need acoustic and prosodic features

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WER reductions from modeling disfluencies+background events

- Rose and Riccardi (1999)

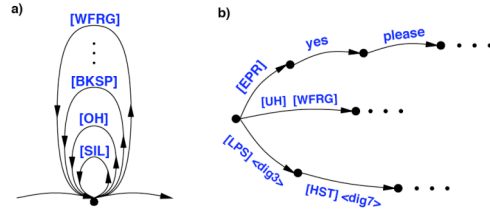


Figure 1: a) Inclusion of all labeled background events (LBEs) in a single "between-word" loop. b) Portion of phrase-based LM trained from LBE annotated text.

HMIHY Background events

- Out of 16,159 utterances:

Filled Pauses	7189
Word Fragments	1265
Hesitations	792
Laughter	163
Lipsmack	2171
Breath	8048
Non-Speech Noise	8834
Background Speech	3585
Operator Utt.	5112
Echoed Prompt	5353

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Phrase-based LM

- "I would like to make a collect call"
- "a [wfrag]"
- <dig3> [brth] <dig3>
- "[brth] and I"

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Rose and Riccardi (1999) Modeling "LBEs" does help in WER

ASR Word Accuracy			
System Configuration		Test Corpora	
HMM	LM	Greeting (HMIHY)	Card Number
Baseline	Baseline	58.7	87.7
LBE	Baseline	60.8	88.1
LBE	LBE	60.8	89.8

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More on location of FPs

- Peters: Medical dictation task
 - Monologue rather than dialogue
 - In this data, FPs occurred INSIDE clauses
 - Trigram PP after FP: 367
 - Trigram PP after word: 51
- Stolcke and Shriberg (1996b)
 - w_k FP w_{k+1} : looked at $P(w_{k+1}|w_k)$
 - Transition probabilities lower for these transitions than normal ones
- Conclusion:
 - People use FPs when they are planning difficult things, so following words likely to be unexpected/rare/difficult

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Detection of disfluencies

- Nakatani and Hirschberg
- Decision tree at w_i - w_j boundary
 - pause duration
 - Word fragments
 - Filled pause
 - Energy peak within w_i
 - Amplitude difference between w_i and w_j
 - FO of w_i
 - FO differences
 - Whether w_i accented
- Results:
 - 78% recall/89.2% precision

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Detection/Correction

- Bear, Dowding, Shriberg (1992)
- System 1:
- Hand-written pattern matching rules to find repairs
 - Look for identical sequences of words
 - Look for syntactic anomalies ("a the", "to from")
 - 62% precision, 76% recall
 - Rate of accurately correcting: 57%

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Using Natural Language Constraints

- Gemini natural language system
- Based on Core Language Engine
- Full syntax and semantics for ATIS
- Coverage of whole corpus:
 - 70% syntax
 - 50% semantics

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Using Natural Language Constraints

- Gemini natural language system
- Run pattern matcher
- For each sentence it returned
 - Remove fragment sentences
 - Leaving 179 repairs, 176 false positives
 - Parse each sentence
 - If succeed: mark as false positive
 - If fail:
 - run pattern matcher, make corrections
 - Parse again
 - If succeeds, mark as repair
 - If fails, mark no opinion

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NL Constraints

- Syntax Only
 - Precision: 96%
- Syntax and Semantics
 - Correction: 70%

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Recent work: EARS Metadata Evaluation (MDE)

- A recent multiyear DARPA bakeoff
- Sentence-like Unit (SU) detection:
 - find end points of SU
 - Detect subtype (question, statement, backchannel)
- Edit word detection:
 - Find all words in reparandum (words that will be removed)
- Filler word detection
 - Filled pauses (uh, um)
 - Discourse markers (you know, like, so)
 - Editing terms (I mean)
- Interruption point detection

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Liu et al 2003

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Kinds of disfluencies

- **Repetitions**
 - I * I like it
- **Revisions**
 - We * I like it
- **Restarts (false starts)**
 - It's also * I like it

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MDE transcription

- **Conventions:**
 - ./ for statement SU boundaries,
 - <> for fillers,
 - [] for edit words,
 - * for IP (interruption point) inside edits
- **And <uh> <you know> wash your clothes wherever you are ./ and [you] * you really get used to the outdoors ./**

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MDE Labeled Corpora

	CTS	BN
Training set (words)	484K	182K
Test set (words)	35K	45K
STT WER (%)	14.9	11.7
SU %	13.6	8.1
Edit word %	7.4	1.8
Filler word %	6.8	1.8

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MDE Algorithms

- **Use both text and prosodic features**
- **At each interword boundary**
 - Extract Prosodic features (pause length, durations, pitch contours, energy contours)
 - Use N-gram Language model
 - Combine via HMM, Maxent, CRF, or other classifier

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State of the art: SU detection

- **2 stage**
 - Decision tree plus N-gram LM to decide boundary
 - Second maxent classifier to decide subtype
- **Current error rates:**
 - Finding boundaries
 - 40-60% using ASR
 - 26-47% using transcripts

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State of the art: Edit word detection

- **Multi-stage model**
 - HMM combining LM and decision tree finds IP
 - Heuristics rules find onset of reparandum
 - Separate repetition detector for repeated words
- **One-stage model**
 - CRF jointly finds edit region and IP
 - BIO tagging (each word has tag whether is beginning of edit, inside edit, outside edit)
- **Error rates:**
 - 43-50% using transcripts
 - 80-90% using ASR

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Using only lexical cues

- 3-way classification for each word
 - Edit, filler, fluent
- Using TBL
 - Templates: Change
 - Word X from L1 to L2
 - Word sequence X Y to L1
 - Left side of simple repeat to L1
 - Word with POS X from L1 to L2 if followed by word with POS Y

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Rules learned

- Label all fluent filled pauses as fillers
- Label the left side of a simple repeat as an edit
- Label "you know" as fillers
- Label fluent well's as filler
- Label fluent fragments as edits
- Label "I mean" as a filler

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Error rates using only lexical cues

- CTS, using transcripts
 - Edits: 68%
 - Fillers: 18.1%
- Broadcast News, using transcripts
 - Edits 45%
 - Fillers 6.5%
- Using speech:
 - Broadcast news filler detection from 6.5% error to 57.2%
- Other systems (using prosody) better on CTS, not on Broadcast News

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Conclusions: Lexical Cues Only

- Can do pretty well with only words
 - (As long as the words are correct)
- Much harder to do fillers and fragments from ASR output, since recognition of these is bad

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Fragments

- Incomplete or cut-off words:
 - Leaving at seven *fif-* eight thirty
 - uh, I, I *d-*, don't feel comfortable
 - You know the *fam-*, well, the families
- SWBD: around 0.7% of words are fragments (Liu 2003)
- ATIS: 60.2% of repairs contain fragments (6% of corpus sentences had a least 1 repair) Bear et al (1992)
- Another ATIS corpus: 74% of all reparanda end in word fragments (Nakatani and Hirschberg 194)

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Why fragments are important

- Frequent enough to be a problem:
 - Only 1% of words/3% of sentences
 - But if miss fragment, likely to get surrounding words wrong (word segmentation error).
 - So could be 3 or more times worse (3% words, 9% of sentences): problem!
- Useful for finding other repairs
 - In 40% of SRI-ATIS sentences containing fragments, fragment occurred at right edge of long repair
 - 74% of ATT-ATIS reparanda ended in fragments
- Sometimes are the only cue to repair
 - "leaving at <seven> <fif-> eight thirty"

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How fragments are dealt with in current ASR systems

- In training, throw out any sentences with fragments
- In test, get them wrong
- !!!!!

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Cues for fragment detection

- 49/50 cases examined ended in silence >60msec; average 282ms (Bear et al)
- 24 of 25 vowel-final fragments glottalized (Bear et al)
 - Glottalization: increased time between glottal pulses
- 75% don't even finish the vowel in first syllable (i.e., speaker stopped after first consonant) (O'Shaughnessy)

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Cues for fragment detection

- Nakatani and Hirschberg (1994)
- Word fragments tend to be content words:

Lexical Class	Token	Percent
Content	121	42%
Function	12	4%
Untranscribed	155	54%

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Cues for fragment detection

- Nakatani and Hirschberg (1994)
- 91% are one syllable or less

Syllables	Tokens	Percent
0	113	39%
1	149	52%
2	25	9%
3	1	0.3%

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Cues for fragment detection

- Nakatani and Hirschberg (1994)
- Fricative-initial common; not vowel-initial

Class	% words	% frags	% 1-C frags
Stop	23%	23%	11%
Vowel	25%	13%	0%
Fric	33%	45%	73%

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Liu (2003): Acoustic-Prosodic detection of fragments

- Prosodic features
 - Duration (from alignments)
 - Of word, pause, last-rhyme-in word
 - Normalized in various ways
 - F0 (from pitch tracker)
 - Modified to compute stylized speaker-specific contours
 - Energy
 - Frame-level, modified in various ways

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Liu (2003)

- Use Switchboard 80%/20%
- Downsampled to 50% frags, 50% words
- Generated forced alignments with gold transcripts
- Extract prosodic and voice quality features
- Train decision tree

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Liu (2003) results

- Precision 74.3%, Recall 70.1%

		hypothesis	
		complete	fragment
reference	complete	109	35
	fragment	43	101

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Liu (2003) features

- Features most queried by DT

Feature	%
jitter	.272
Energy slope difference between current and following word	.241
Ratio between F0 before and after boundary	.238
Average OQ	.147
Position of current turn	0.084
Pause duration	0.018

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Liu (2003) conclusion

- Very preliminary work
- Fragment detection is good problem that is understudied!

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Liu (2003): Acoustic-Prosodic detection of fragments

- Voice Quality Features
 - Jitter
 - A measure of perturbation in pitch period
 - Praet computes this
 - Spectral tilt
 - Overall slope of spectrum
 - Speakers modify this when they stress a word
 - Open Quotient
 - Ratio of times in which vocal folds are open to total length of glottal cycle
 - Can be estimated from first and second harmonics
 - Creaky voice (laryngealization) vocal folds held together, so short open quotient

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Summary

- Disfluencies
- Characteristics of disfluencies
- Detecting disfluencies
- MDE bakeoff
- Fragments

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