Speech Processing And Prosody

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Speech Processing and Prosody

- Prosody conveys various types of information over the linguistic content
  - Prosody structures the utterances
  - May be used to emphasized words
  - Speaker emotional state
  - …

- Speech prosody neglected
  - In automatic speech recognition
  - In manual transcriptions
- But critical for expressive speech synthesis

- Prosody is a suprasegmental information, and is characterized by
  - Duration of the sounds
  - Fundamental frequency
  - Energy of the sounds

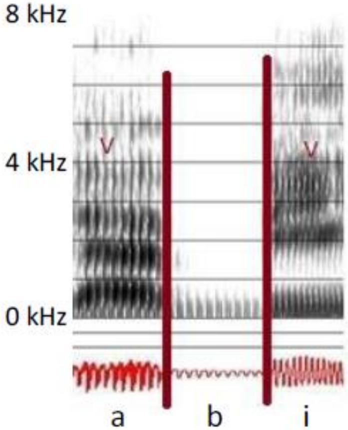
Outline

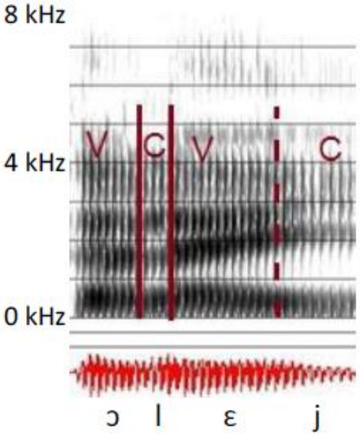
- Prosodic features, computation and reliability
  - Phone duration
  - Fundamental frequency
  - Phone energy
- Prosodic features in automatic speech processing
  - Computer assisted language learning
  - Structuring speech utterances
  - Sentence modality
  - Prosodic correlates of discourse particles
  - Expressive speech
- Conclusion

Phone duration

- Is determined from the phone boundaries that can be set
  - Manually
  - Automatically through forced speech-text alignment

- Some boundaries are clear, some are more ambiguous, for example





  - Clear between vowel and occlusive
  - Ambiguous between vowel and semi-vowel

Automatic speech-text alignment

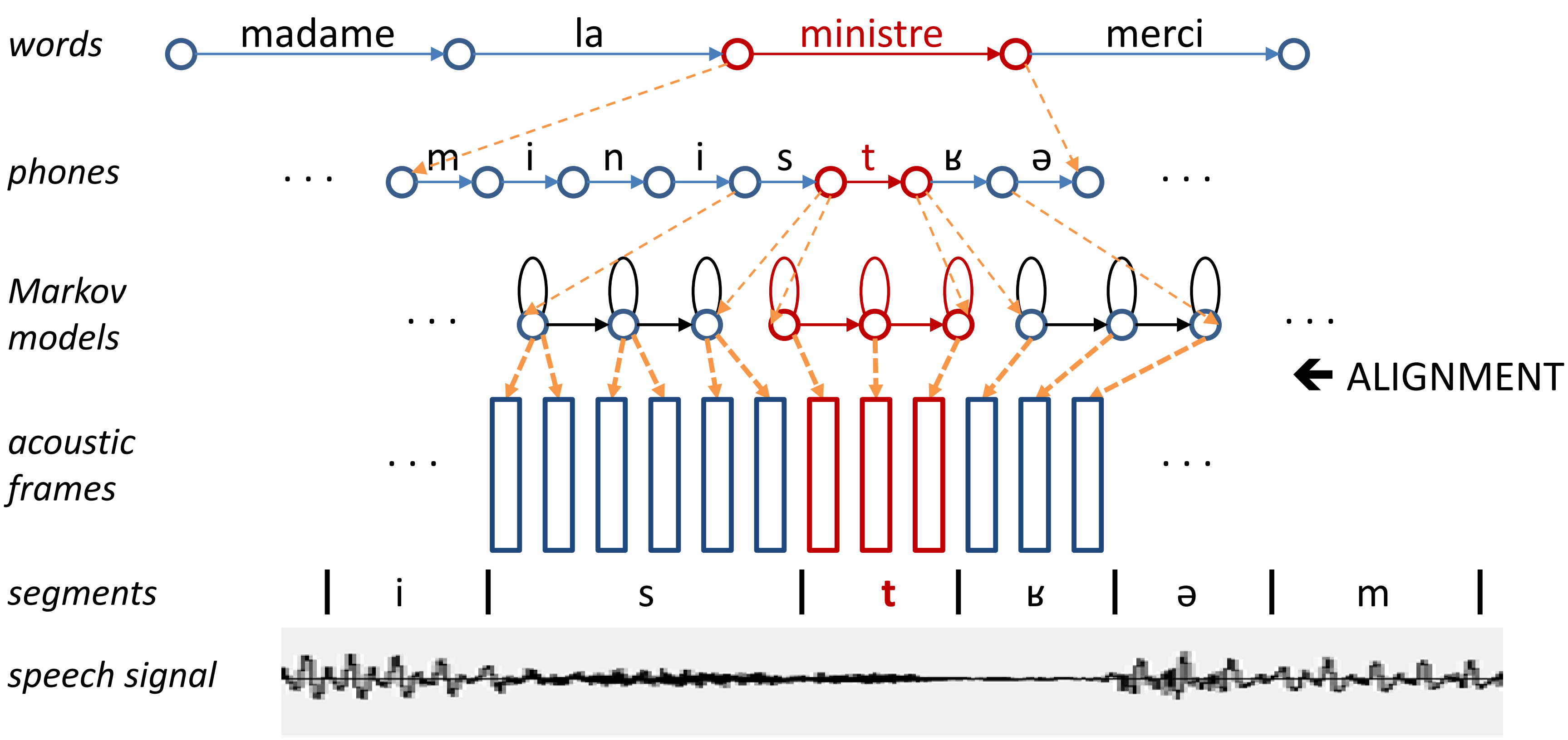
- Needs only a manual transcription of the speech signal into words
  ⇨ sequence of words corresponding to the speech segment
- Uses pronunciation variants for each word (lexicon or grapheme-to-phoneme tools)
- Relies on automatic speech recognition tools
  ⇨ find the sequence of phones that best matches with the speech signal
  (and the associated word and phone boundaries)

- Works well when
  - Good quality speech data and reliable acoustic models
  - Transcription perfectly matches with the actual content
  - Pronunciation variants include the actual pronunciations

- Performance degrades
  - On noisy speech data
  - On non-native speech (difficult to predict every possible pronunciation deviations)

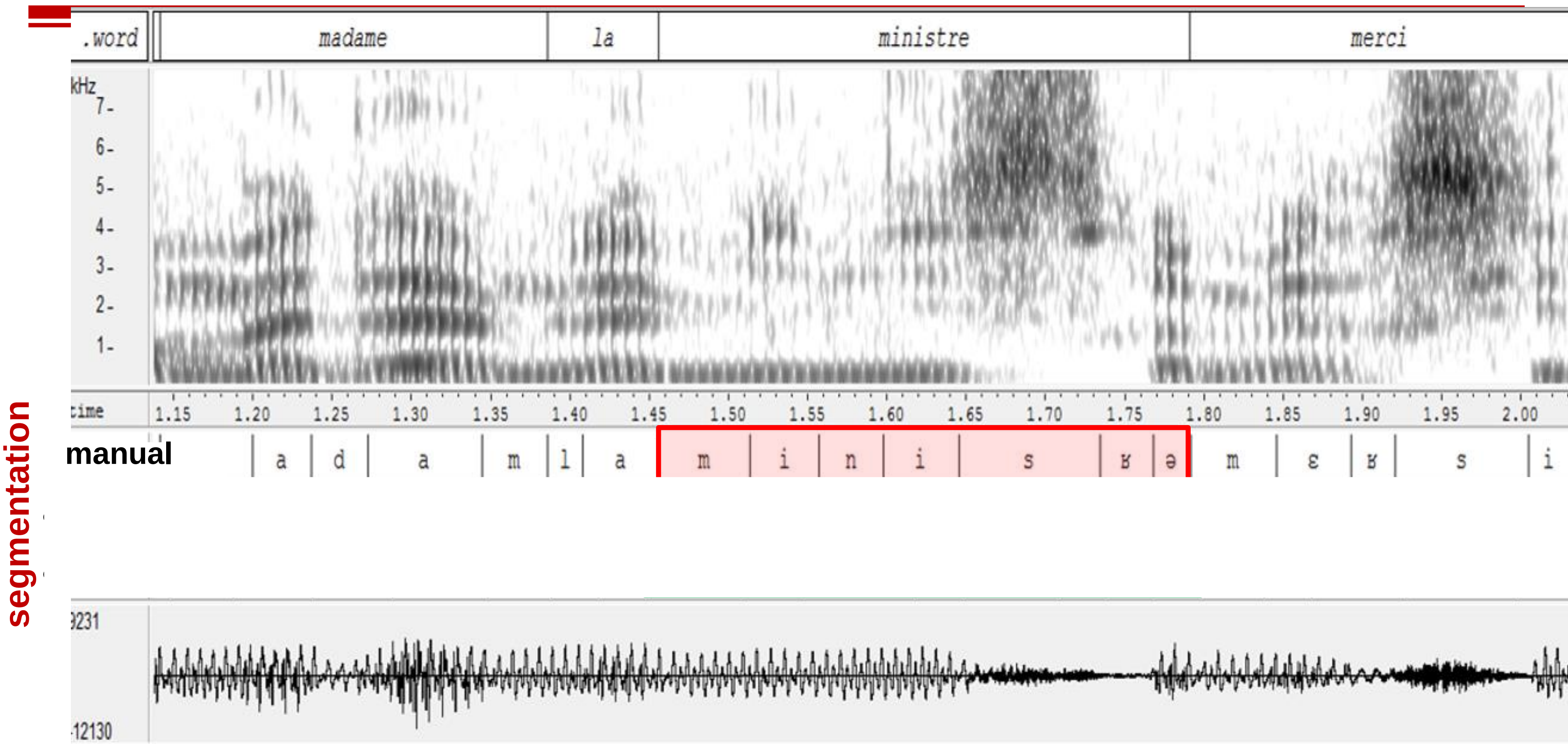
Automatic speech-text alignment

- Example for « *Madame la Ministre, merci* » (⇔ Madame Minister thanks)



- 3 states per phone model * 10 ms per frame ➔ 30 ms minimum duration per phone

Example of speech segmentation



[t]

- absent in manual segmentation
- very short in automatic segmentation with 5 ms frame shift
- 30 ms long in automatic segmentation with 10 ms frame shift

Analysis of final consonantal clusters

- Analysis of a frequent final cluster / t ʁ / as in / m i n i s t ʁ / (*ministre*)

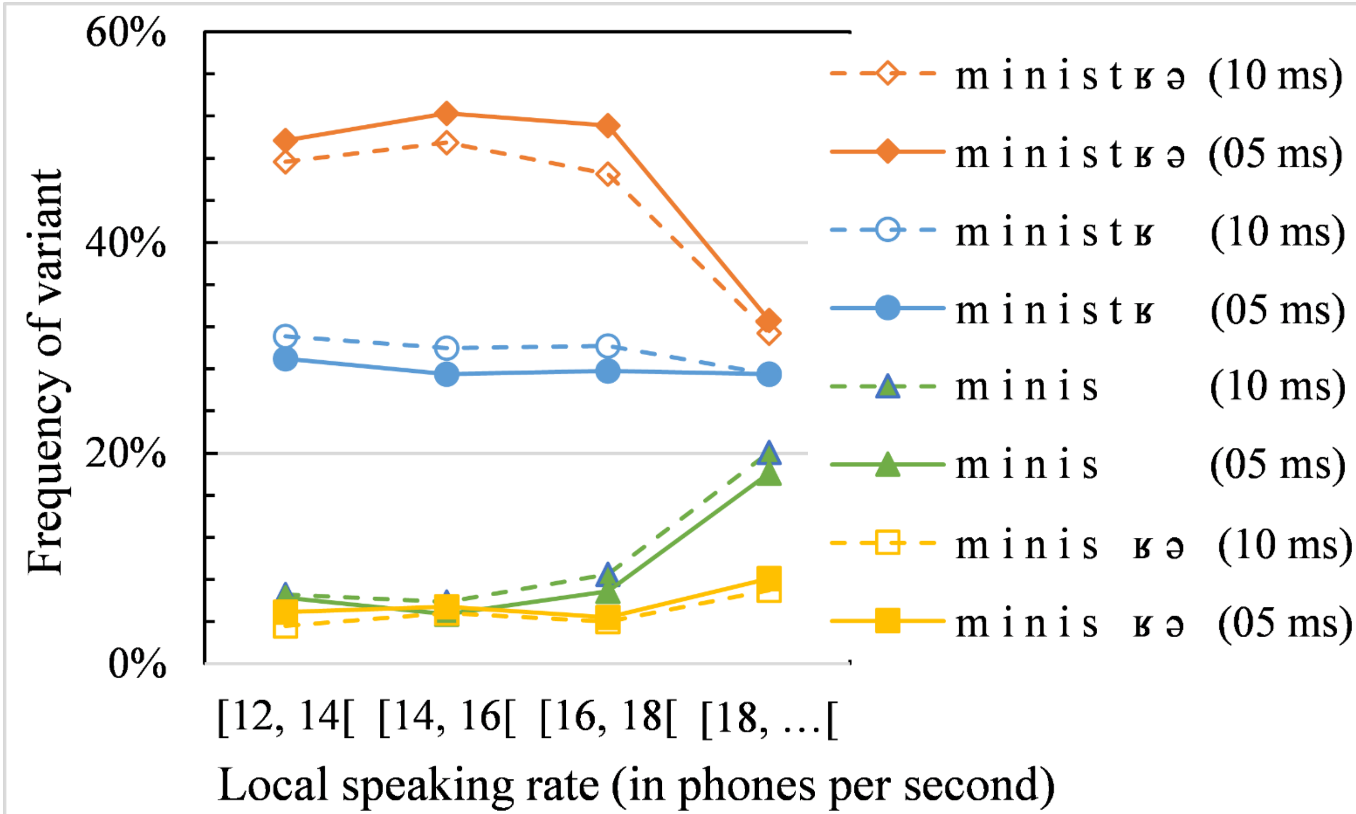
- Extended pronunciation lexicon where all pronunciation variants are allowed
  - Adding final schwa / ə /
  - Eliding consonants / t / or/and / ʁ /

- This leads to an extended set of pronunciation variants
  Example for *ministre*:

/t/ pronounced		/t/ elided		
/ m i n i s t ʁ ə /	[+t][+ʁ][+ə]	/ m i n i s ʁ ə /	[-t][+ʁ][+ə]	/ʁ/ pronounced
/ m i n i s t ʁ /	[+t][+ʁ][-ə]	/ m i n i s ʁ /	[-t][+ʁ][-ə]	/ʁ/ pronounced
/ m i n i s t ə /	[+t][-ʁ][+ə]	/ m i n i s ə /	[-t][-ʁ][+ə]	/ʁ/ elided
/ m i n i s t /	[+t][-ʁ][-ə]	/ m i n i s /	[-t][-ʁ][-ə]	/ʁ/ elided

Comparing frequency estimations

- Word *ministre*
- Comparing frequencies estimated with 5 and 10 ms frame shifts



- 5 ms frame shift acoustic analysis leads to higher frequency of occurrences for longest pronunciation variant (here / m i n i s t ʁ ə /)

Speech-text alignment

- Besides correct transcription, adequate pronunciation variants, …
  better to rely on a 2 pass process
  - First, determine the pronunciation variants actually used
    with context-dependent models
  - Then, re-align with context-independent acoustic models
    which leads to a better precision of the boundaries

- To get a better precision
  - Use 5 ms frame shift
    Note, that is what is done in parametric speech synthesis

- Other difficulties stem from
  - Non adequate noise models
  - Annotation conventions for noises, laughing, hesitations, …, that vary among corpora

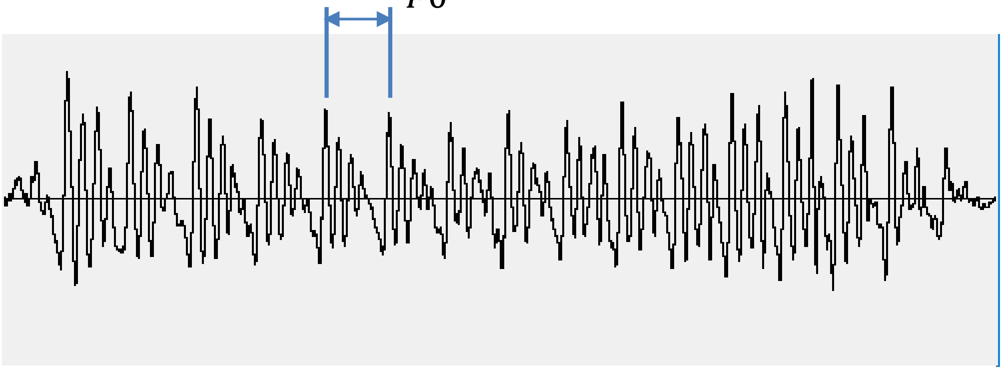
Fundamental frequency (F0)

- Fundamental frequency vs. pitch
  - Pitch is linked to the perception of the frequency
  - F0 is a physical property of the sounds
- However the term ‘pitch’ is often used when talking about the F0

- F0 detection can be done
  - In the time domain
  - In the spectral domain
  - Using both time and spectral domains

F0 detection – time domain

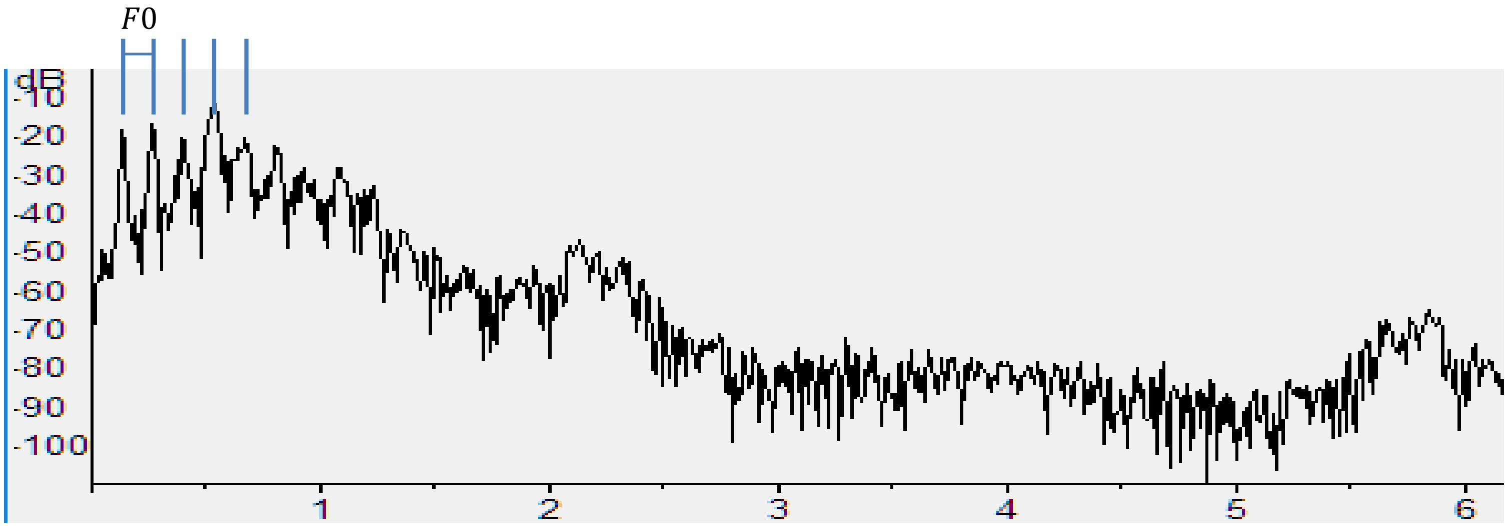
$$T = \frac{1}{F0}$$



- Rely on the time shift at which the signal (almost) repeat itself (in voiced sounds)

ACF	(Praat)	Auto Correlation Function
AMDF	(snack library)	Average Magnitude Difference Function
CCF	(Praat)	Cross Correlation Function
Kaldi	(speech recognition toolkit)	
REAPER	(REAPER)	
RAPT	(SPTK and snack library)	Robust Algorithm for Pitch Tracking
SRPD	(ESTL)	Super Resolution Pitch Determinator
TEMPO	(STRAIGHT)	
YIN	(YIN and JSNOORI)	

F0 detection – frequency domain



- Exploit the harmonic structure of the spectrum for voiced sounds
  - Martin (JSNOORI)
  - SHS (Praat) Sub-Harmonic Summation algorithm
  - SWIPE (SPTK and JSNOORI) Sawtooth Waveform Inspired Pitch Estimator

F0 detection – combined approaches

- Combine time and frequency cues
  - Aurora (ETSI)
  - NDF (STRAIGHT) Nearly Defect-free F0

F0 detection – comments

- Time and frequency approaches provide F0 candidates
  - Main challenge is to select the "good" candidate
    and to avoid pitch halving (F0/2) or doubling (2*F0) estimations
    which lead to the numerous variants

- Voicing decision is a critical step
  [unvoiced sounds and silence ➔ no F0 values;   voiced sounds ➔ F0 values]
  - Usually carried on by applying thresholds on numerical criteria used to compute F0

- Dynamic programming-based post processing in some approaches
  - E.g., RAPT, REAPER, Martin
  - For minimizing jumps in the F0 curve (thus reducing halving and doubling errors, and to improve voicing decision)

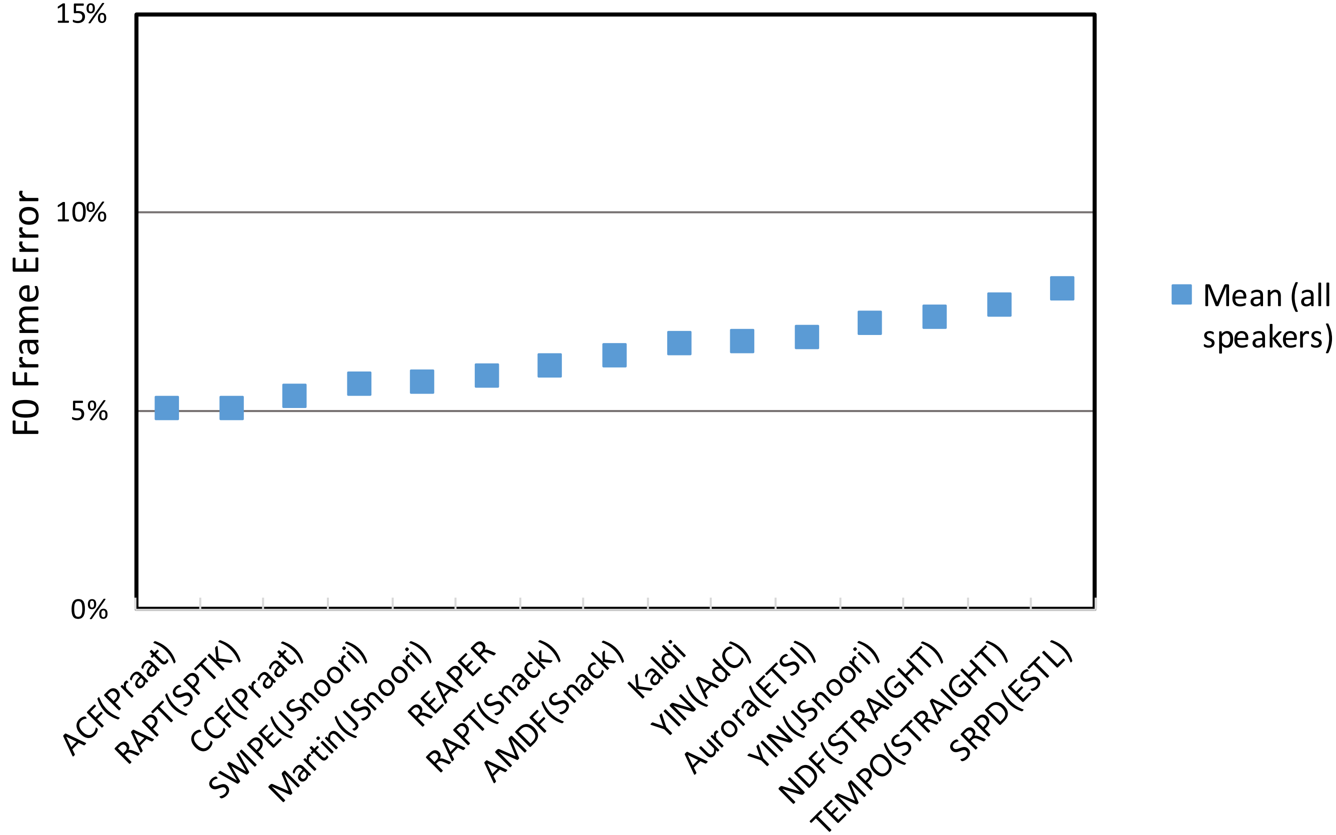
Performance evaluation measures

- VDE: Voicing Decision Error
  - Proportion of frames for which a voicing decision error is made
  - Two types of errors
    - v->uv ⇔ voiced frame classified as unvoiced
    - uv->v ⇔ unvoiced frame classified as voiced

- FFE: F0 Frame Error
  - Provides a global error measure
  - Consider as error
    - Voicing decision error (v->uv and uv->)
    - Gross pitch error (voiced frame classified as voiced, but estimated F0 differs from the reference F0 by more than 20%)

Evaluation on clean data

PTDB-TUG corpus, 20 speakers, 4720 utterances



- Mean (over all speakers) ranges from 5% to 8%

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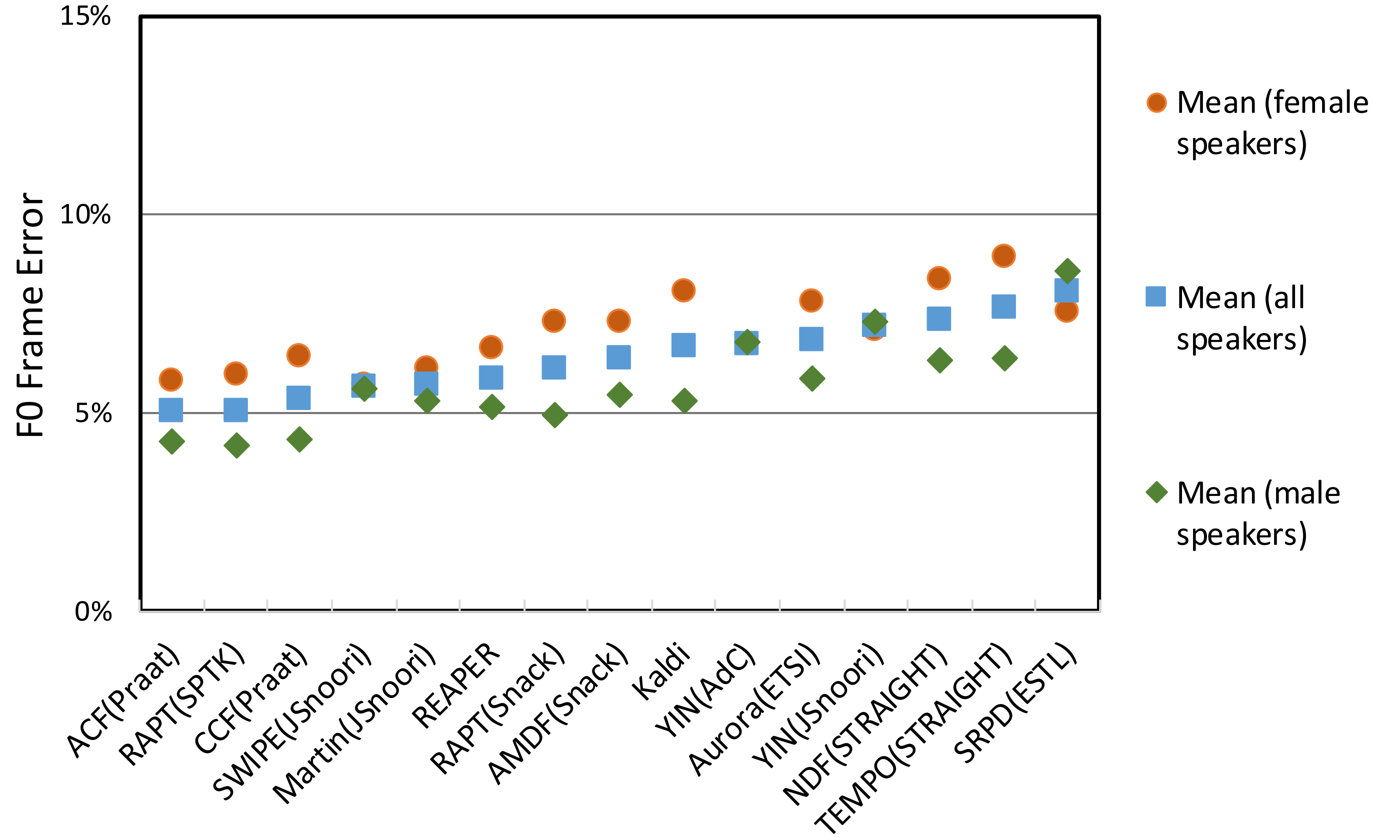

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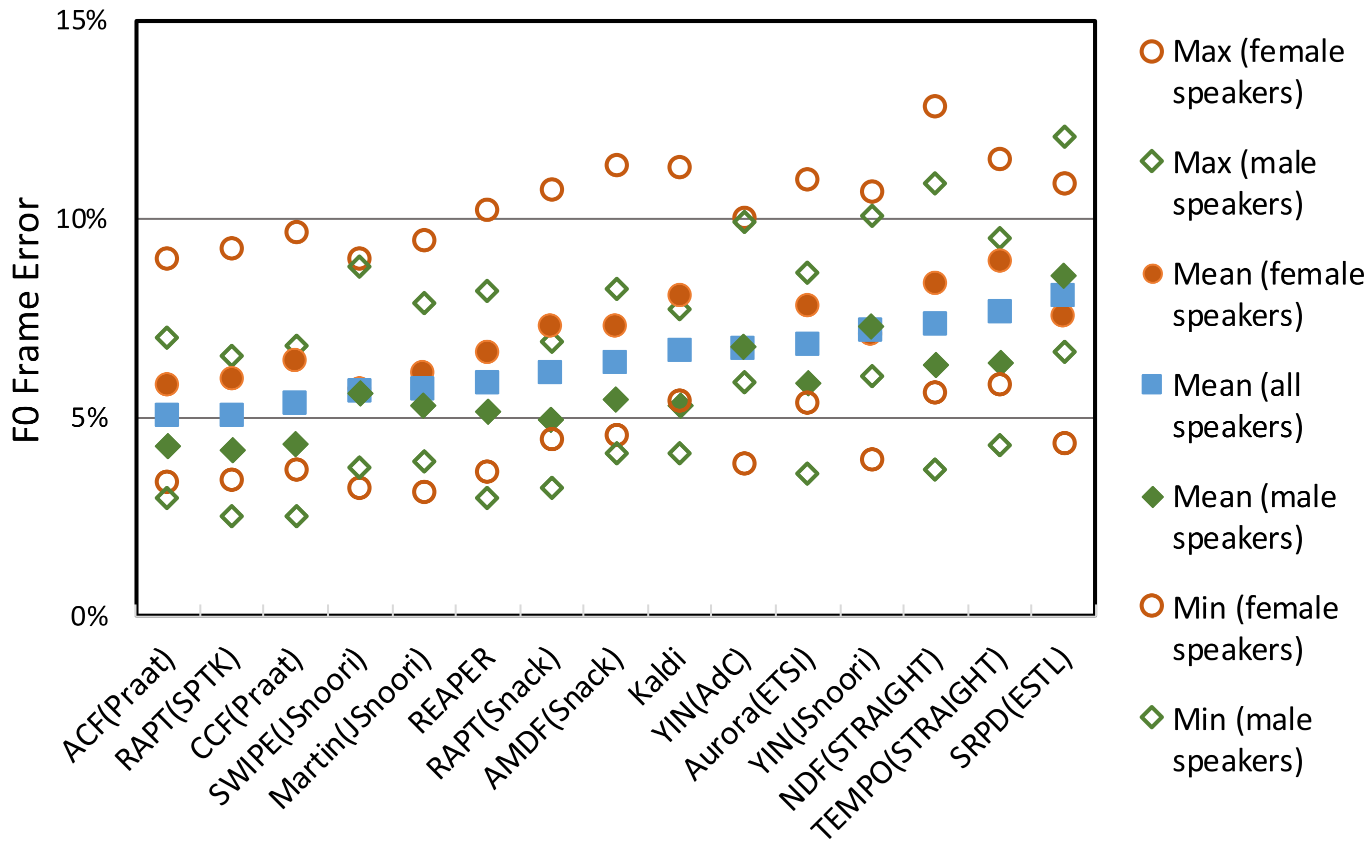
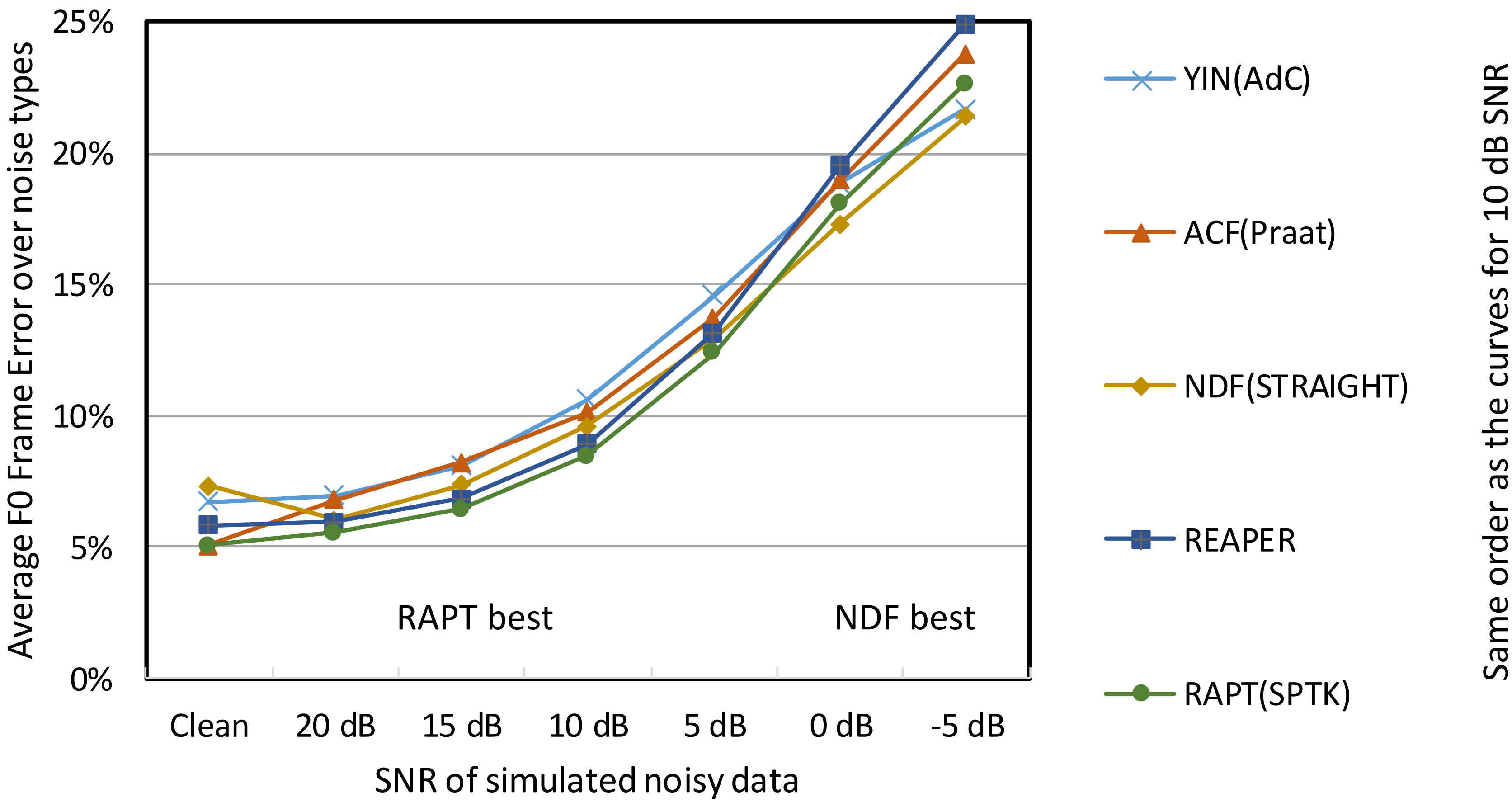


- Mean (over all speakers) ranges from 5% to 8%
- Except SWIPE and YIN, better results on male speakers than on female speakers
- Large gap in performance between best and worst speaker (for all approaches)

Evaluation on simulated noisy data

PTDB-TUG corpus, noises (babble, factory, …) added at various SNR levels



- Most approaches have the same behavior (ending at around 25% FFE for -5 dB SNR)

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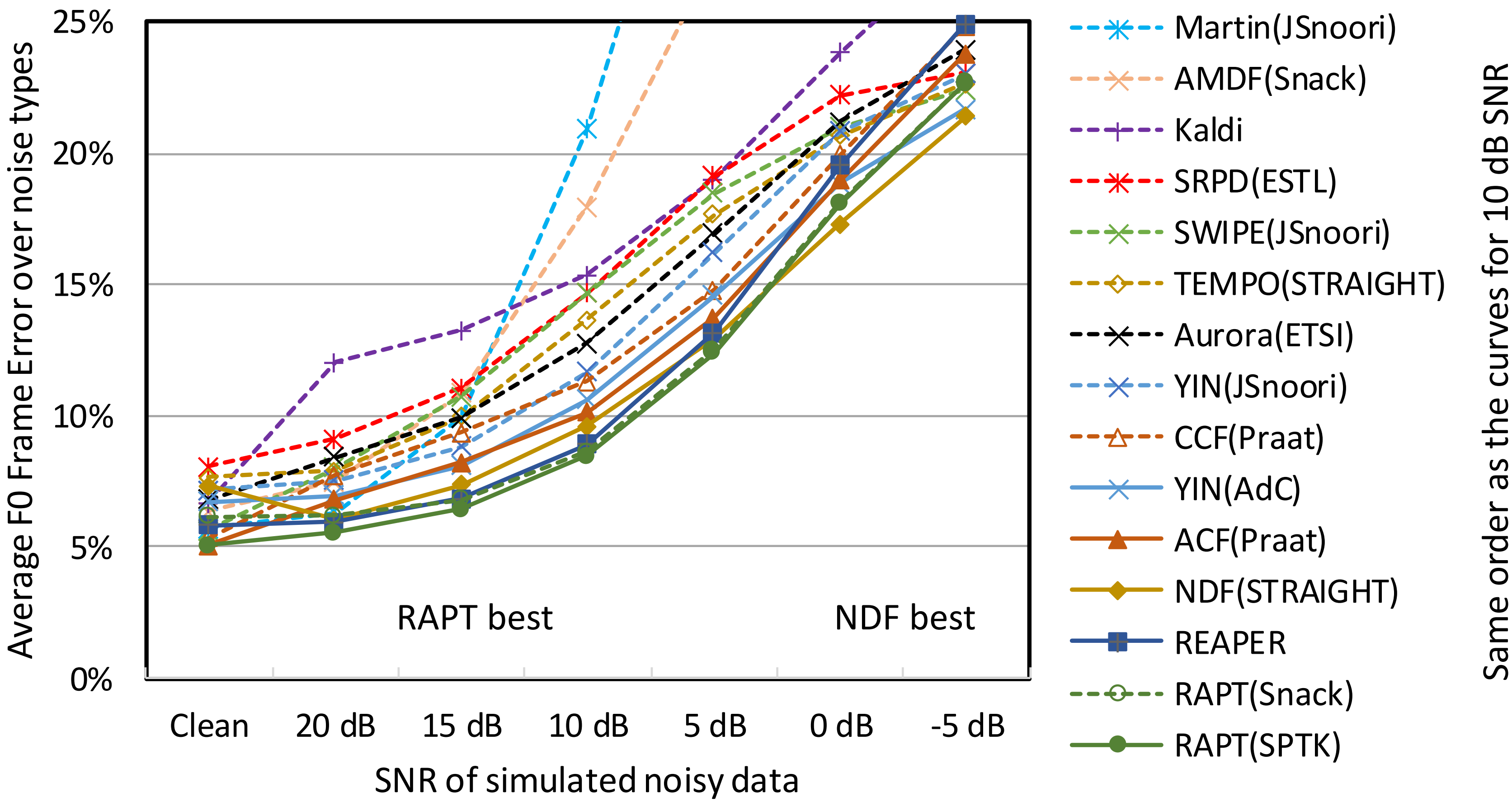
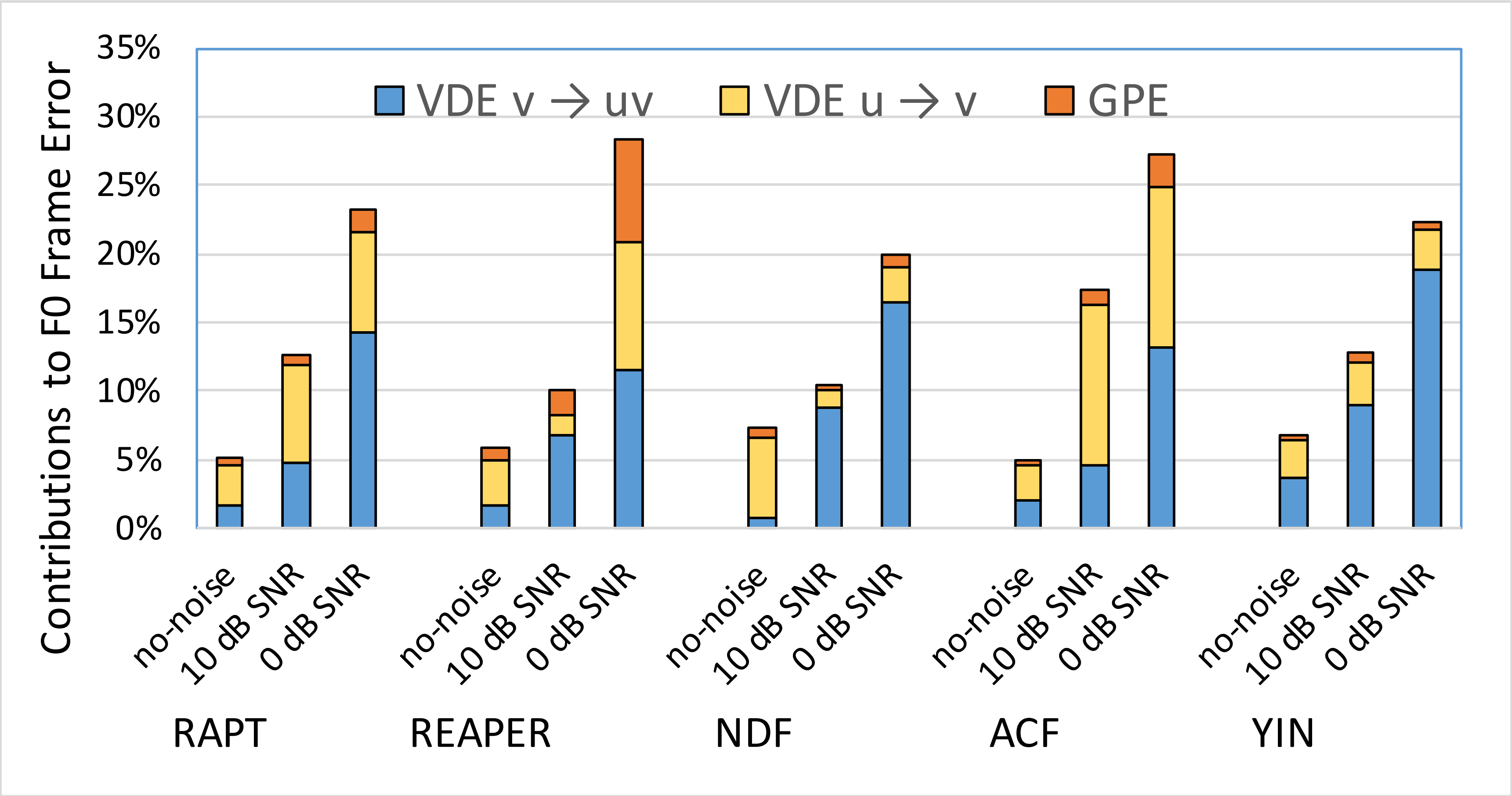


- Most approaches have the same behavior (ending at around 25% FFE for -5 dB SNR)
- A large part of the errors are due to voicing decision errors

Voicing decision errors

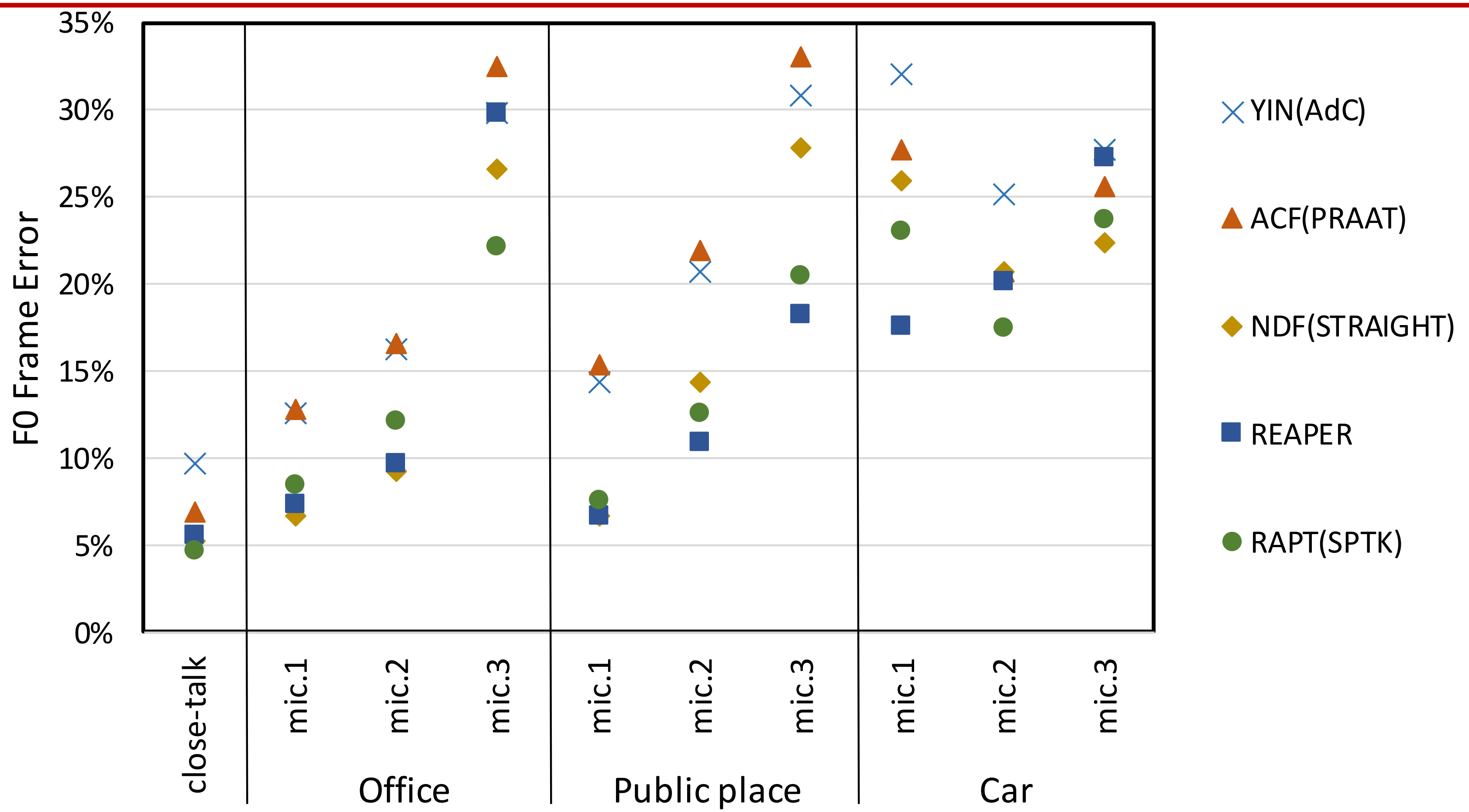
PTDB-TUG corpus, noises (babble, factory, …) added at various SNR levels



- When noise increases, the largest part of the errors comes from v → uv decision errors

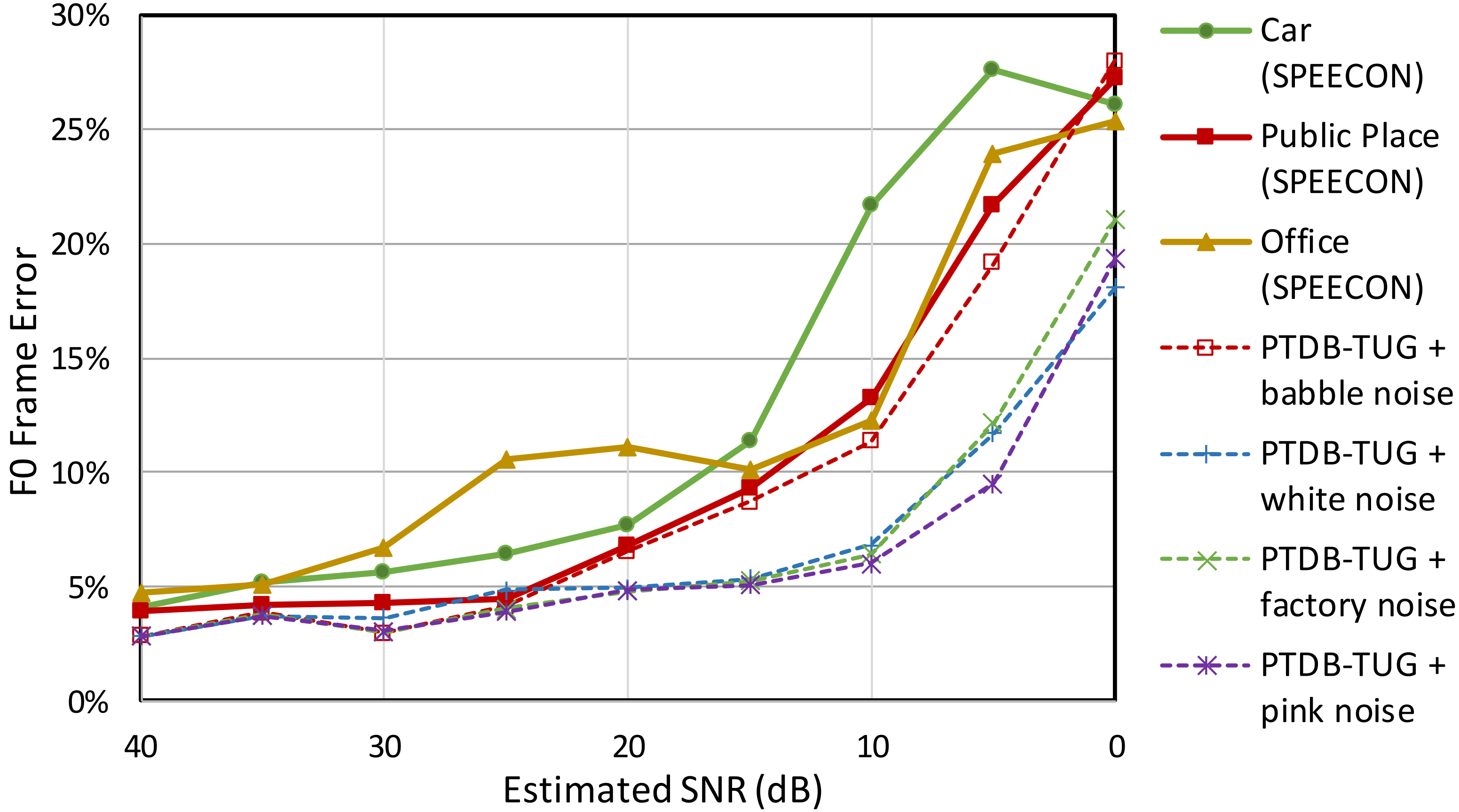
Evaluation on real noisy data

SPEECON corpus, 60 speakers, car, office and public places, close and distant microphones



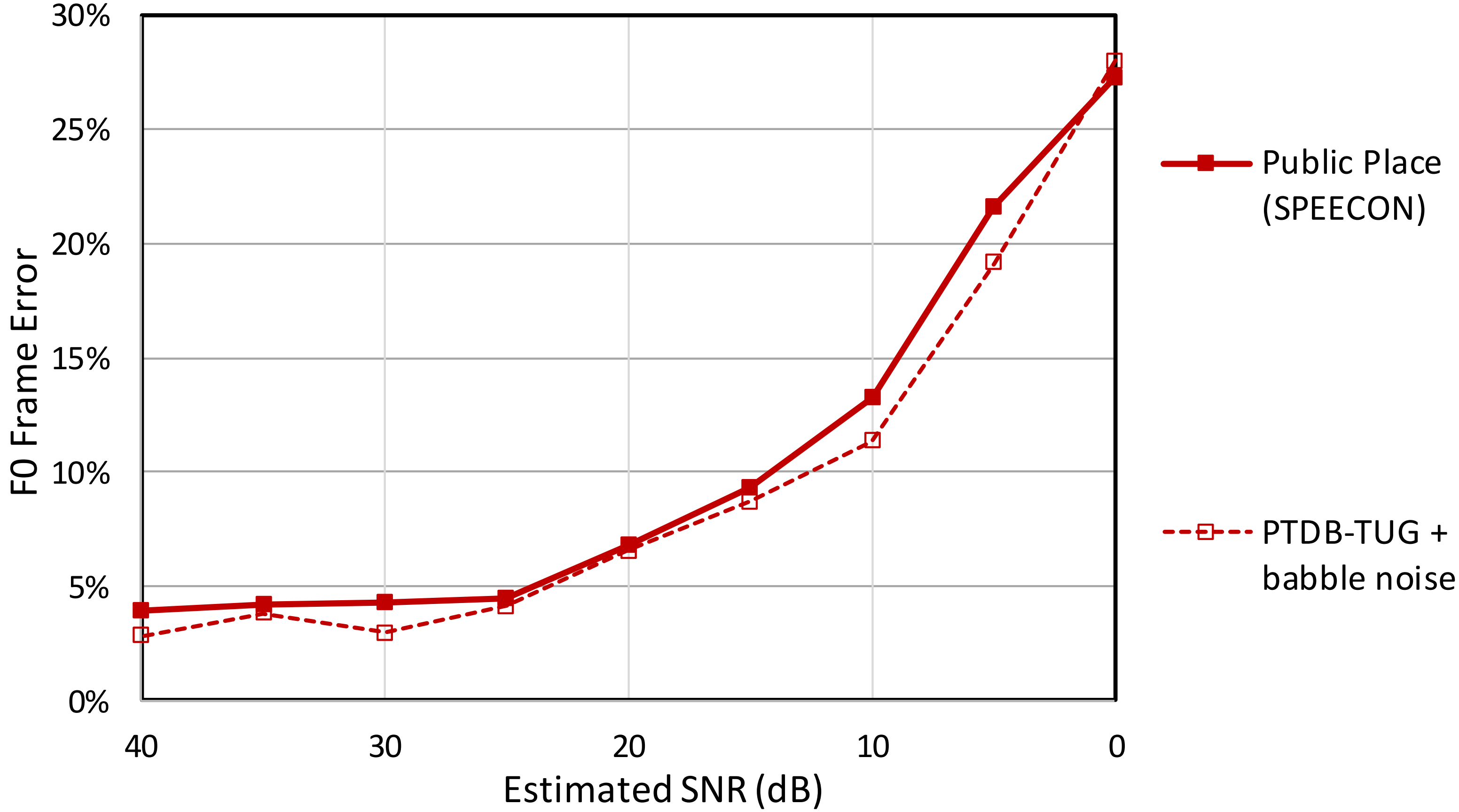
- Degradation with noise (distance to speaker)
- Best algorithm vary depending on condition

Comparing performance on real and simulated noisy data



- Degradation with respect to noise level
- For babble noise (simulated or real public places), results are very similar between simulated noisy data and real noisy data

Comparing performance on real and simulated noisy data



- Degradation with respect to noise level
- For babble noise (simulated or real public places), results are very similar between simulated noisy data and real noisy data

F0 detection

- Most of the algorithms provide good results on clean data (from 5% to 8% FFE)
- But large performance variation across speakers

- Performance degradation when noise is present
- Voicing detection error is the main cause of error
  (in most of the cases, voiced frames are mis-classified as unvoiced)

- Best algorithm vary depending on noise type and level
- RAPT (SPTK), REAPER and NDF (STRAIGHT) are the best approaches
- ACF (Praat), RAPT (SPTK), TEMPO (STRAIGHT), YIN and SWIPE are the most often used
  (according to a recent survey [Strömbergsson, Interspeech 2016])

- Choosing the most adequate algorithm or combining several approaches may be a solution, as well as optimizing the voicing decision

Phone energy

- How to compute it
  - Energy in the middle of the phone segment?
  - Average energy over the whole phone segment?

- Values dependent on many parameters
  - Distance between speaker and microphone
  - Microphone and channel characteristics
  - Signal scaling

- Reasonable feature if comparisons are made inside a given utterance (assuming the speaker does not move to much during an utterance)
- Difficult to have reliable comparisons over different acquisition sessions

Normalizing prosodic features

- Phone duration depends on speaking rate
  - Phone duration ratios are often more relevant
  - Or normalization with respect to speaking rate
- F0 depends on the speaker, and large differences between males and females
  - F0 ratios (when measured in Hz) are more useful
    or delta values in semi-tones
  - Glissando threshold for perception of changing pitch (takes into account pitch variation and duration of the segment)
- Energy depends on many aspects
  - Phone energy ratios (or differences in decibels) are more relevant
  - Or normalization with respect to signal level

Confidence scoring

- Phone boundaries
  - Automatic speech-text alignment provides phone-boundaries but there are no associated confidence score
  - Just very view experiments aiming at computing the posterior probability of the boundary

- F0
  - Algorithms provide F0 values
  - A few of them provide a probability of the voicing feature
  - Some attempts at computing a confidence score on the estimated F0 values

Outline

- Prosodic features, computation and reliability
  - Phone duration
  - Fundamental frequency
  - Phone energy

- **Prosodic features in automatic speech processing**
  - Computer assisted language learning
  - Structuring speech utterances
  - Sentence modality
  - Prosodic correlates of discourse particles
  - Expressive speech

- Conclusion

Computer assisted language learning

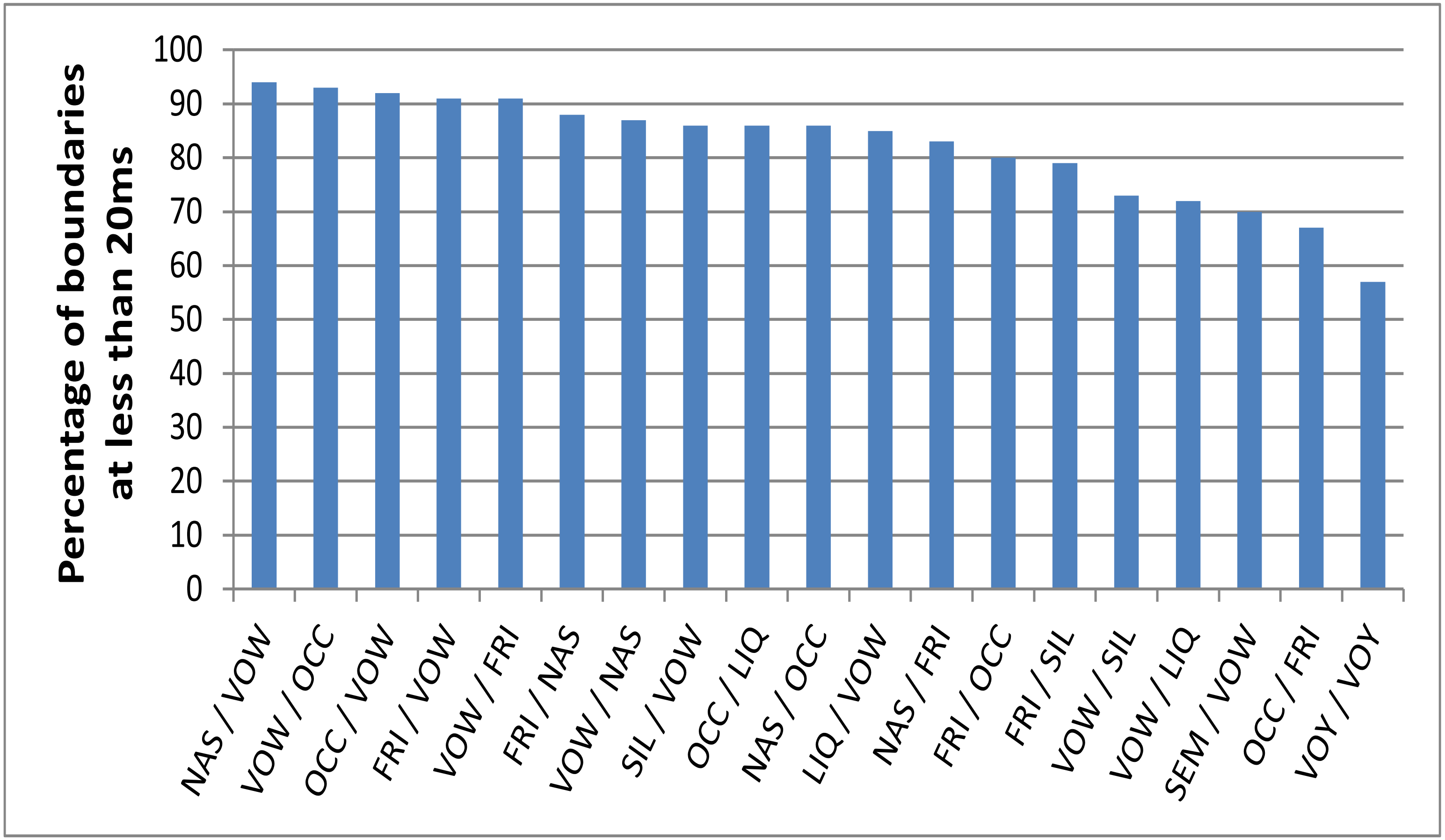
- Providing automatic feedback to language learners, on various aspects
  - Implies detecting pronunciation defects
  - Providing reliable feedback

- Detecting pronunciations defects
  - Requires an alignment of the speech signal with the expected pronunciation
    - Pronunciation defects, such as phone insertions and deletions affect the alignment accuracy
    - If mother tongue known, some frequent pronunciation defects may be taken into account to enrich the pronunciation lexicon
  - Scoring pronunciation
    - Phoneme quality (i.e., is it the expected phoneme?) based on GOP (goodness of pronunciation) score
    - Lexical stress requires prosodic features (phone duration, fundamental frequency)

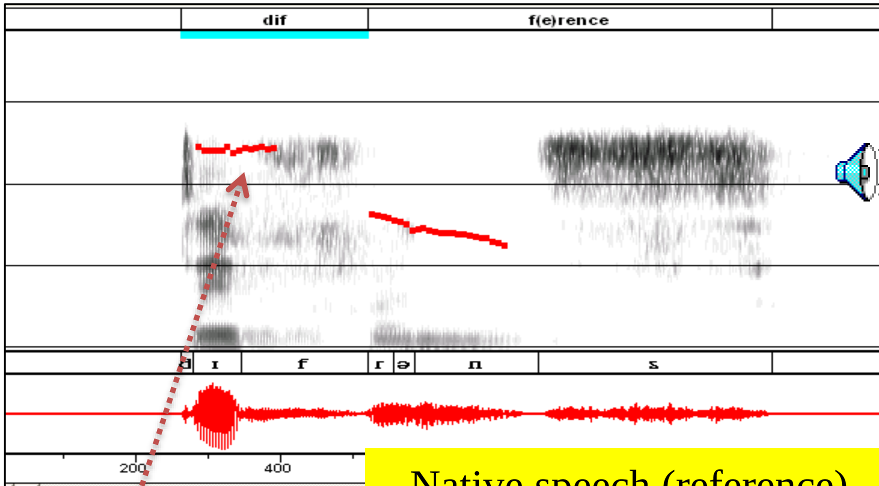
Precision of phone boundaries

on non-native speech

- Percentage of boundaries that are less than 20 ms of the reference boundary



Example of audio & textual prosodic feedback



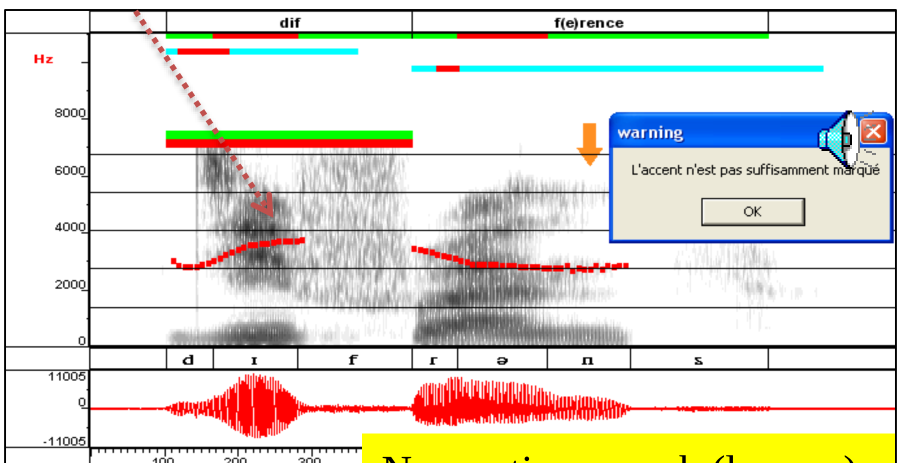
Native speech (reference)

Example for the word "*difference*" pronounced by a native speaker (reference) and by a learner

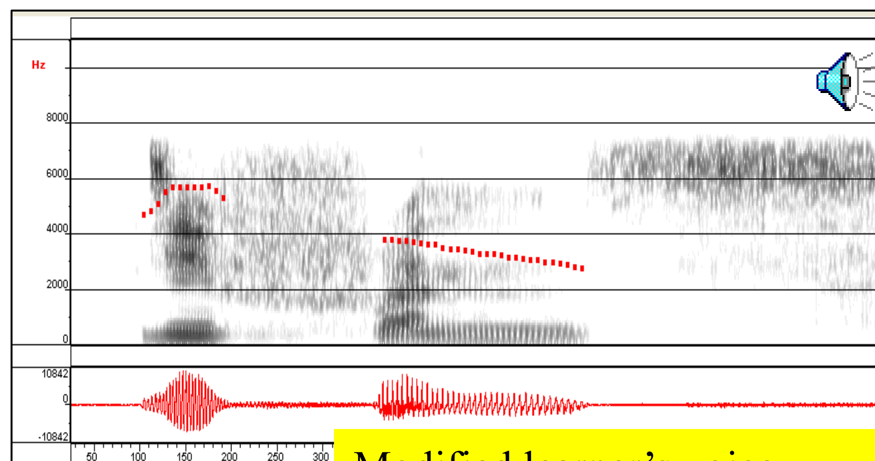
- Leaner: syllable S2 is too long, and syllable S1 is not stressed enough

- After analyzing the pronunciation, a textual diagnosis is provided to the learned, as well as a audio feedback

Melodic curve (in red)



Non-native speech (learner)



Modified learner's voice

Structuring speech utterances

- Prosody structures speech utterances
  - Prosodic groups
  - Organization of prosodic groups
- Automatic approach for prosodic structure in French based on [Martin, 1987] mainly relies on
  - Amplitude of the F0 slopes
  - Inversion of F0 slopes

  at the end of the potentially stressed groups

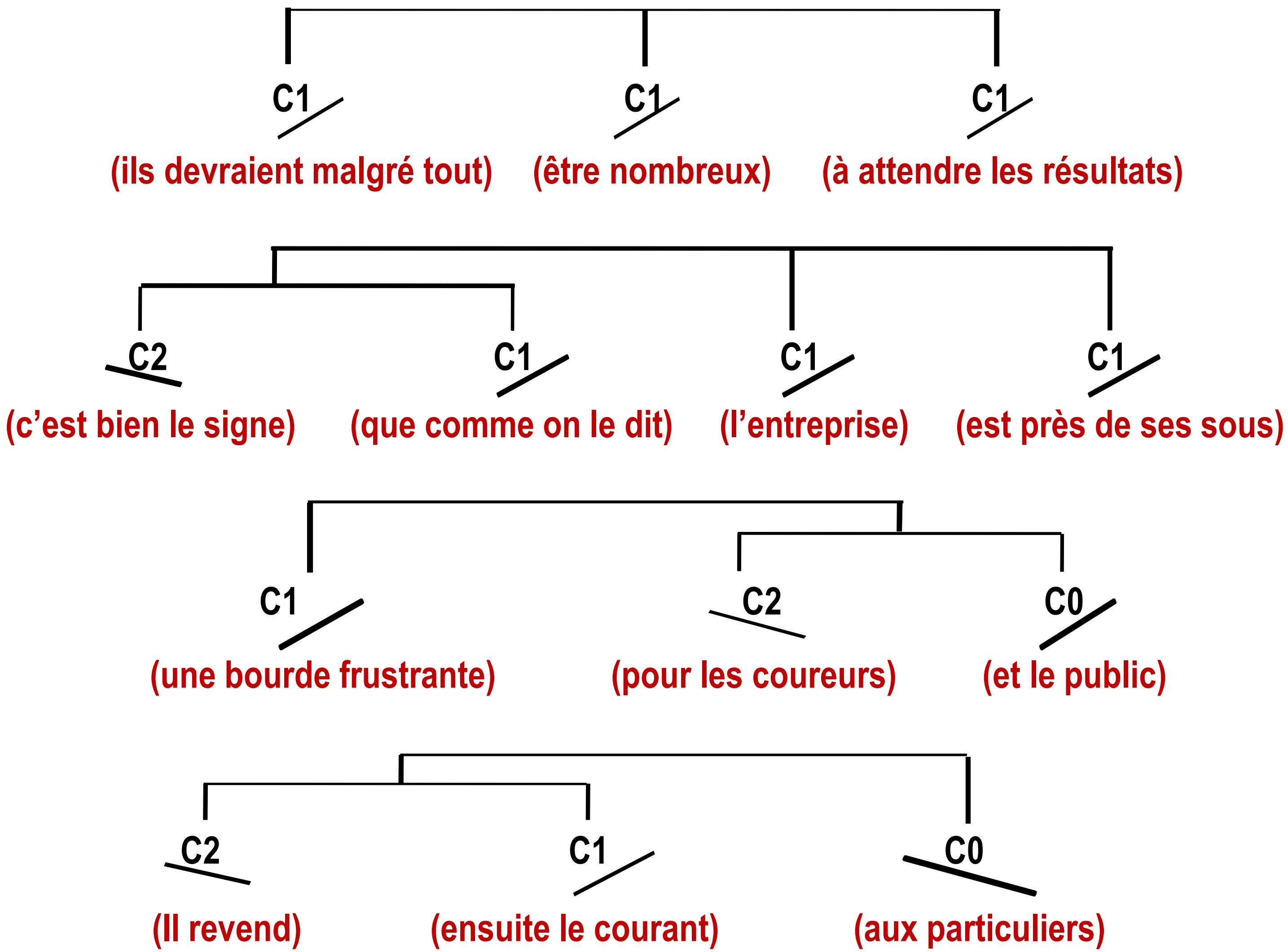
Detection of prosodic boundaries

- Subset of ESTER and ETAPE (broadcast news) have been manually segmented in prosodic groups

- Analysis of automatic prosodic boundary detection

Speech data	Number of boundaries in reference data	Percentage		
		Found	Omitted	Inserted
ESTER subset	1405	83%	17%	20%
ETAPE subset	1167	77%	23%	13%

Examples of prosodic trees



Prosodic groups and punctuation

- Using ESTER data that was manually transcribed with punctuation marks
- 96% of dots match with end of automatically detected prosodic groups
- 80% of commas match with end of automatically detected prosodic groups

Sentence modality

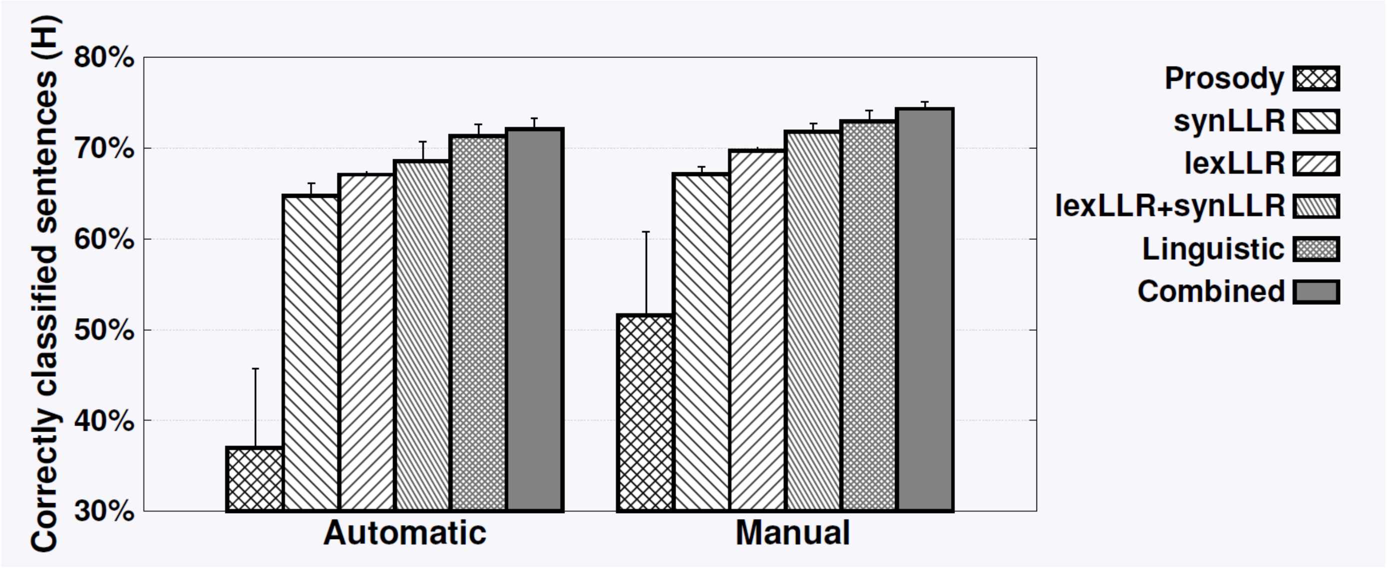
- Focus on statement vs. question
- Questions can be
  - Expressed with interrogative forms
  - Perceived as questions only through a rising intonation

- Classification based on
  - Linguistic features (words)
  - Prosodic features
  - Both linguistic and prosodic features

- Evaluations on speech data from ESTER and ETAPE (broadcast news) using
  - Manual transcriptions
  - Automatic speech recognition output

Detection of sentence modality

- Comparison of classification results using an MLP classifier



- The most important linguistic feature is the lexical log likelihood ratio (lexLLR) using two language models (one for questions, one for statements)
- The best results are obtained when combining all features

Discourse particles

- Words of expressions such as « well », « then », « you see », « you know », …
- That lose their usual lexical meaning
- But have a function at the discourse level
  - For utterance interpretation
  - For the management of the interaction
  - …

- Focus on a few French words that are frequently used as discourse particles (DP)
  - *alors* (so)
  - *bon* (well)
  - *donc* (thus, therefore)
  - *enfin* (finally, anyway)
  - *quoi* (what)
  - *voilà* (there you go)

Examples

Label	Example
Non-DP	*… la question que tout le monde se posait **alors** était les ventes de ces nains de jardin reflèteraient elles …* … the question that everyone was asking **then** was would the sales of these garden dwarves reflect …
DP	*… la les forces régulières les forces loyalistes vont mettre le paquet sur bouaké* [pause] ***alors** la question qui qui se pose à la mi journée c'est de savoir qui …* … the regular forces the loyalist forces will provide full backing on bouaké [pause] **then** the question arising at midday is to know …
DP	*… en achetant tout simplement des produits vous savez étiquetés satisfait ou remboursé **alors** c'est une gestion mais ça marche il l'a prouvé il a rempli son frigo …* ... by simply buying products you know labeled satisfied or refunded **then** it is a management but it works he proved it he has filled its fridge ...

Speech corpora

- Large set of speech corpora (13 subsets)
  - that were manually transcribed (by respective corpora developers)
  - And text-speech aligned (in house, or in the ORFEO project)

- French language

- Variety of speaking styles with various degrees of speech spontaneity
  - Storytelling [0.14 million words]
  - Prepared speech [1.82 million words]
    - Broadcast news
  - Spontaneous speech
    - Conversations, interviews, … [1.84 million words]
    - Interactions [1.52 million words]

- About 1000 occurrences randomly selected for each word

Data annotation

- Annotation of speech data
  - Speech segments with about 15 words before and 15 words after the selected word
  - Using praat
    - Speech signal available (for listening)
    - Speech transcription also available
  - Annotation as DP or non-DP
  - If DP, further annotation with pragmatic function

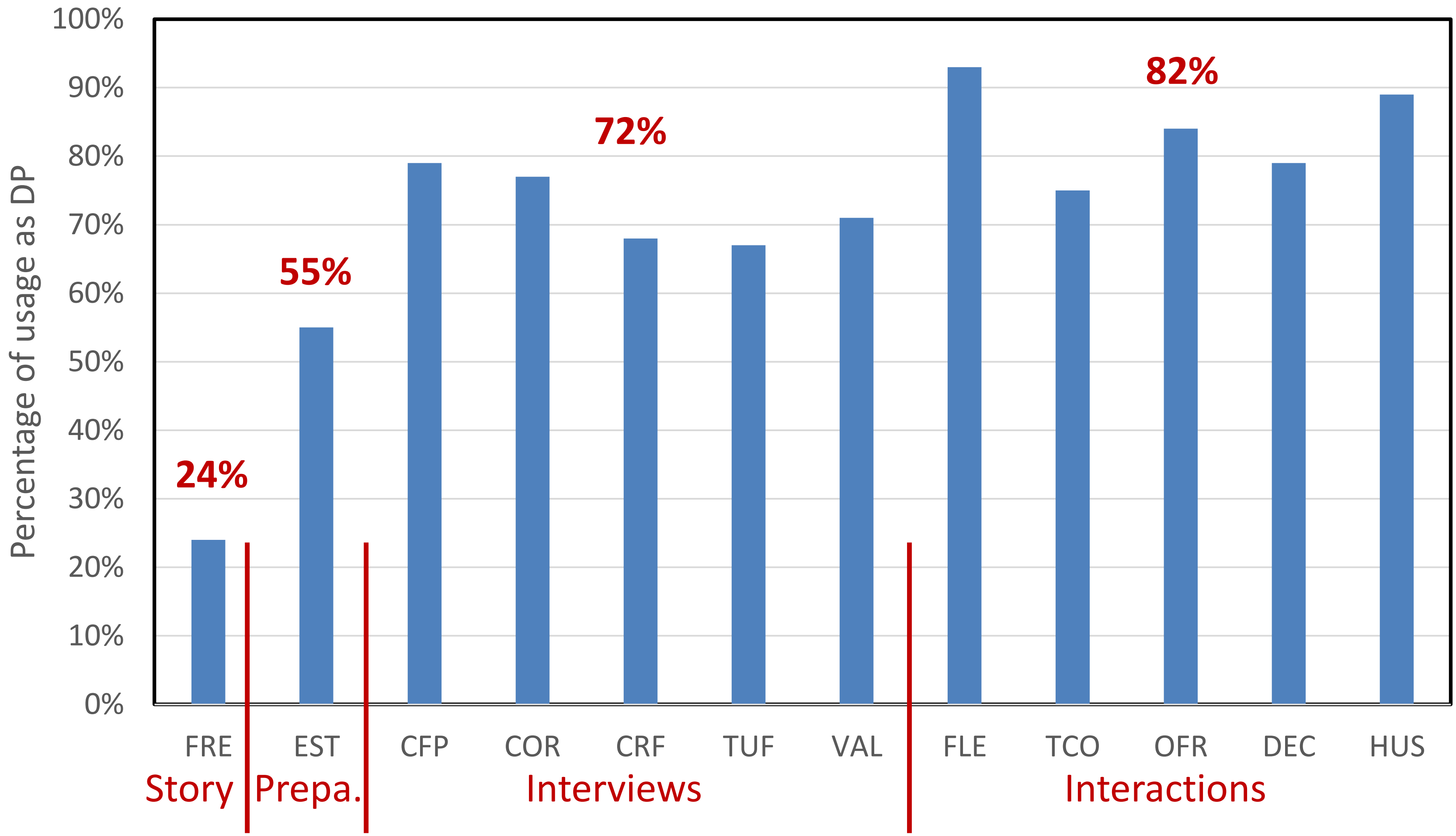
- Pragmatic functions depend on discourse particles
- Examples of pragmatic functions are
  - Introduction
  - Conclusion
  - Addition
  - Confirmation
  - …

Examples

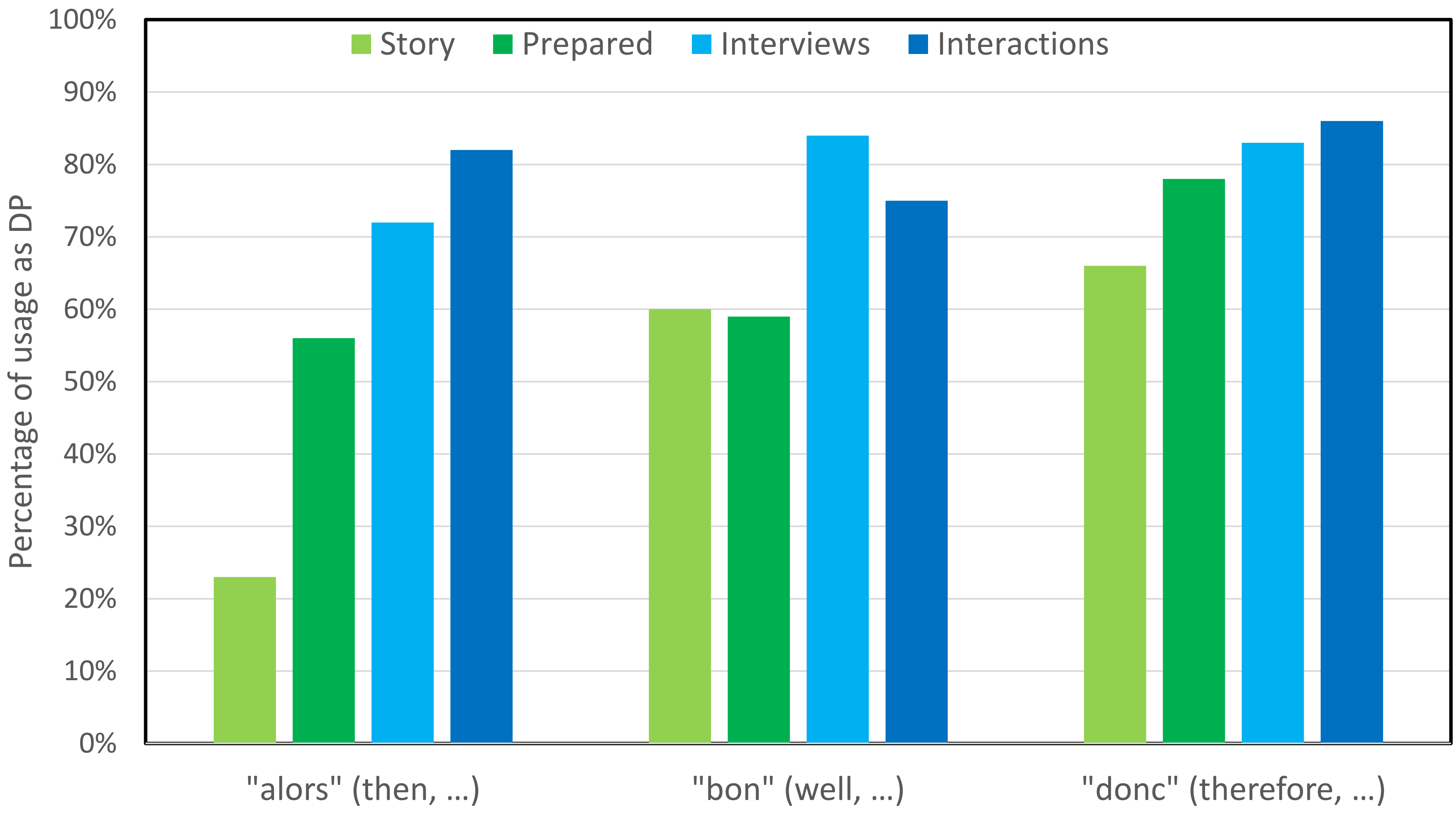
Label	Example
Non-DP	*… la question que tout le monde se posait **alors** était les ventes de ces nains de jardin refléteraient elles …* … the question that everyone was asking **then** was would the sales of these garden dwarves reflect …
DP – **introduction**	*… la les forces régulières les forces loyalistes vont mettre le paquet sur bouaké* [pause] ***alors*** *la question qui qui se pose à la mi journée c'est de savoir qui …* … the regular forces the loyalist forces will provide full backing on bouaké [pause] **then** the question arising at midday is to know …
DP – **conclusion**	*… en achetant tout simplement des produits vous savez étiquetés satisfait ou remboursé **alors** c'est une gestion mais ça marche il l'a prouvé il a rempli son frigo …* ... by simply buying products you know labeled satisfied or refunded **then** it is a management but it works he proved it he has filled its fridge ...

DP / non-DP analysis for word "*alors*"

with respect to spontaneity of speech data



DP / non-DP with respect to speech type

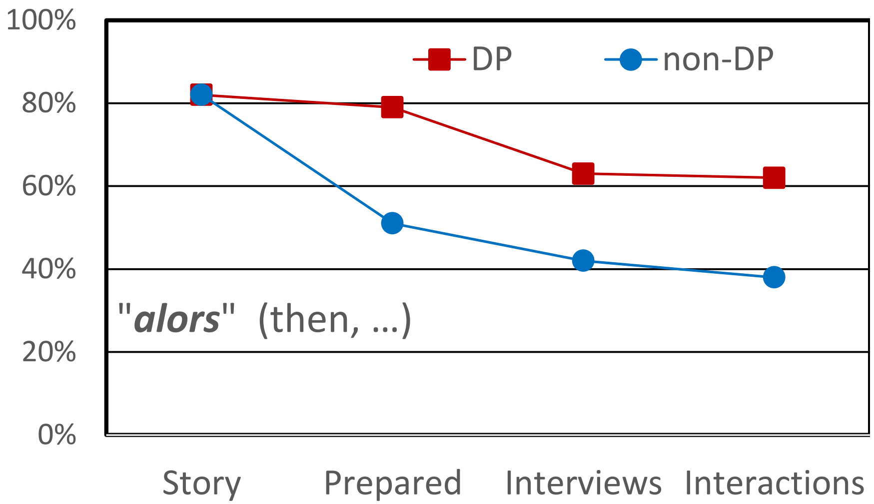


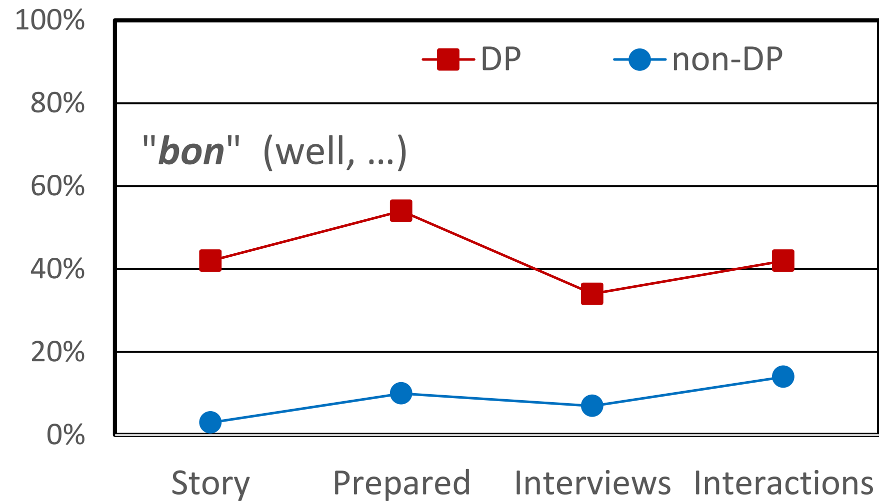
Analysis of a few prosodic correlates

- Different prosodic correlates have been analyzed
  - Pauses before and after the word
  - Position in intonation group
    (segmentation in intonation groups relies on F0 slope inversion, pitch level and vowel duration)
  - Pitch level and slope at end of words
  - Vowel duration, and lengthening
  - …

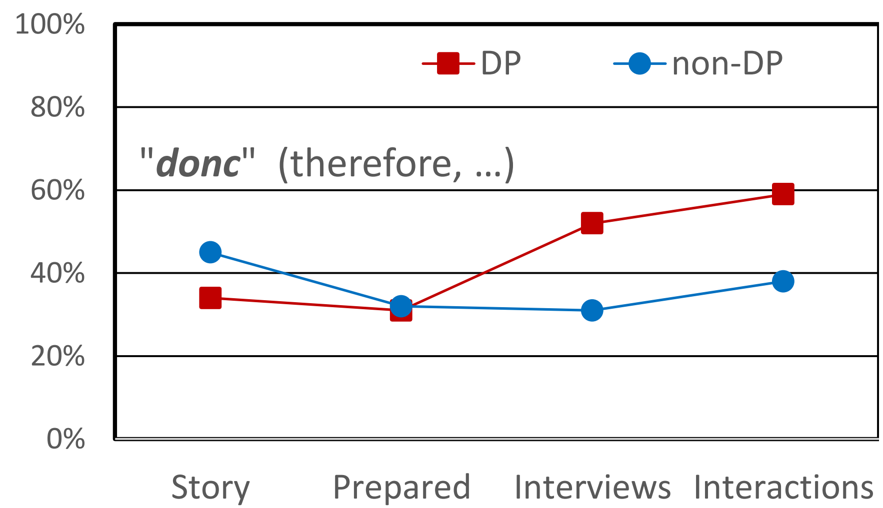
- Here, analysis is focused on
  - Pauses before and after the word
  - Position in intonation group

Frequency of occurrence of pauses **before** the word

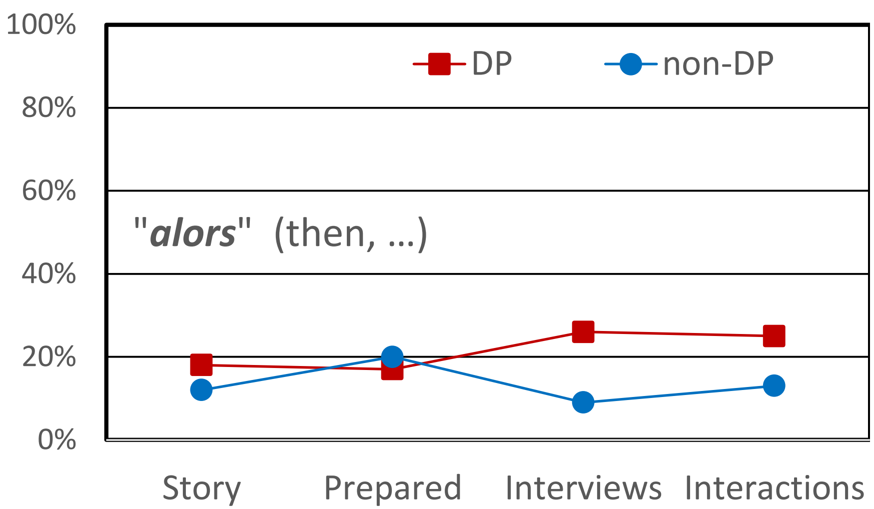


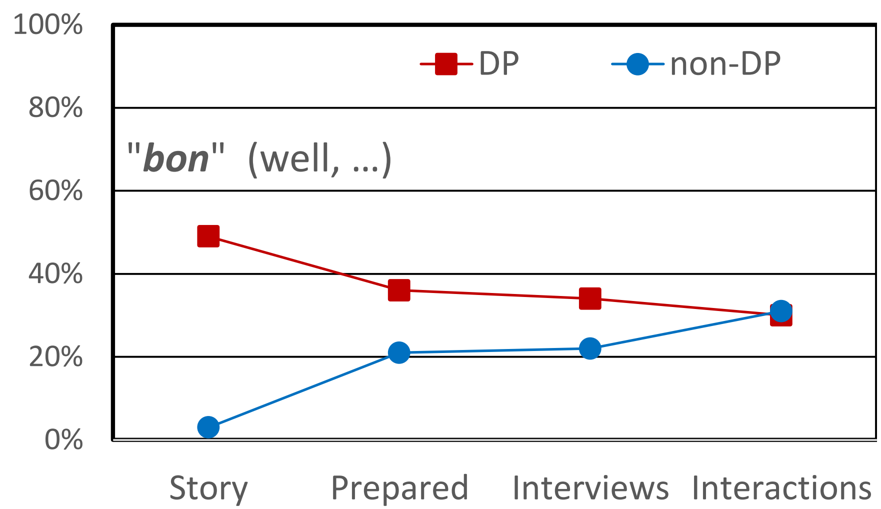


- Word "*bon*"
  - Very few pauses before when non-DP
  - Pause before much more frequent when DP
- Words "*alors*" and "*donc*"
  - More pauses before when DP than when non-DP, in spontaneous styles

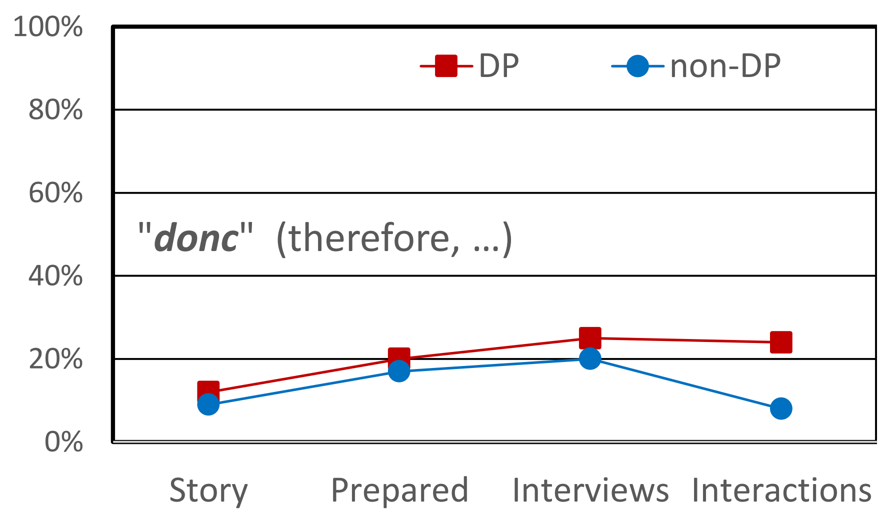


Frequency of occurrence of pauses **after** the word

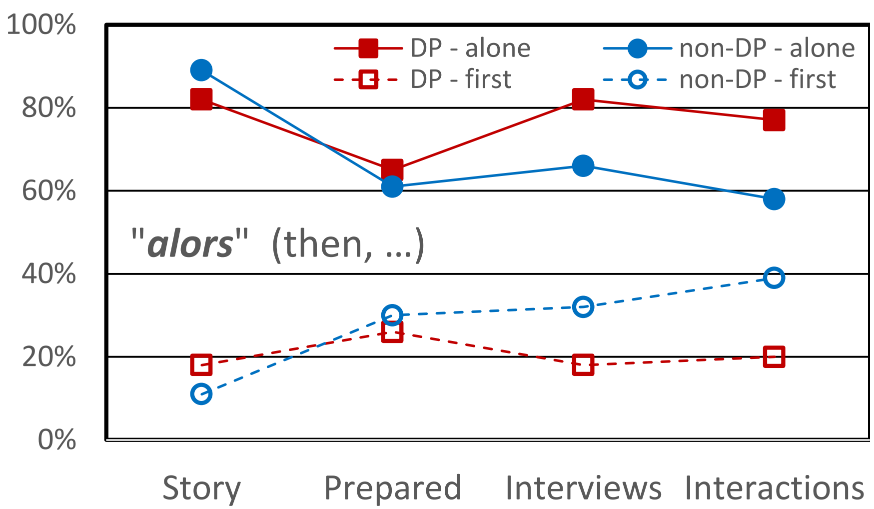


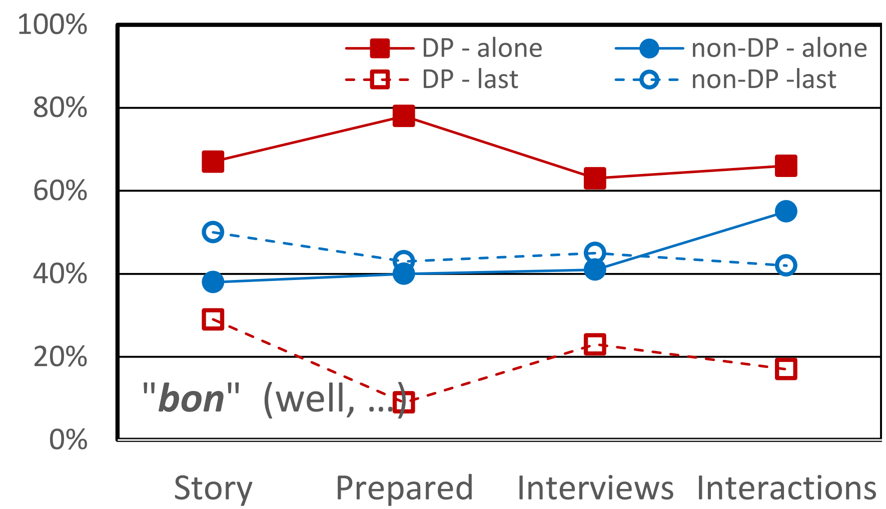


- No large differences between DP and non-DP functions, except for "*bon*"
- Word "*bon*" (well, ...)
  - Largest difference for storytelling

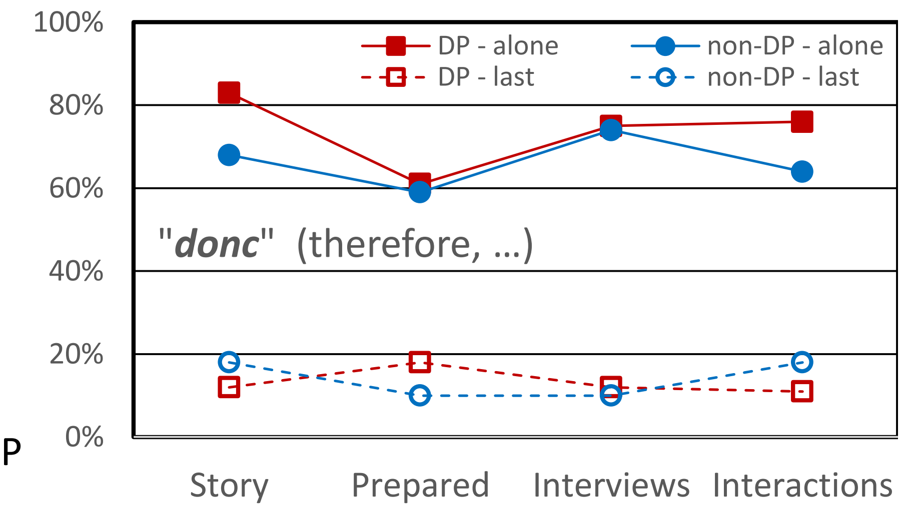


Position of the word in the intonation group





- Alone in intonation group
  - More often when DP than when non-DP
  - Largest difference for "*bon*"
- *"alors"* non-DP
  - Is getting more frequent in first position when spontaneous speech
- *"bon"* non-DP
  - More frequent in last position than when DP



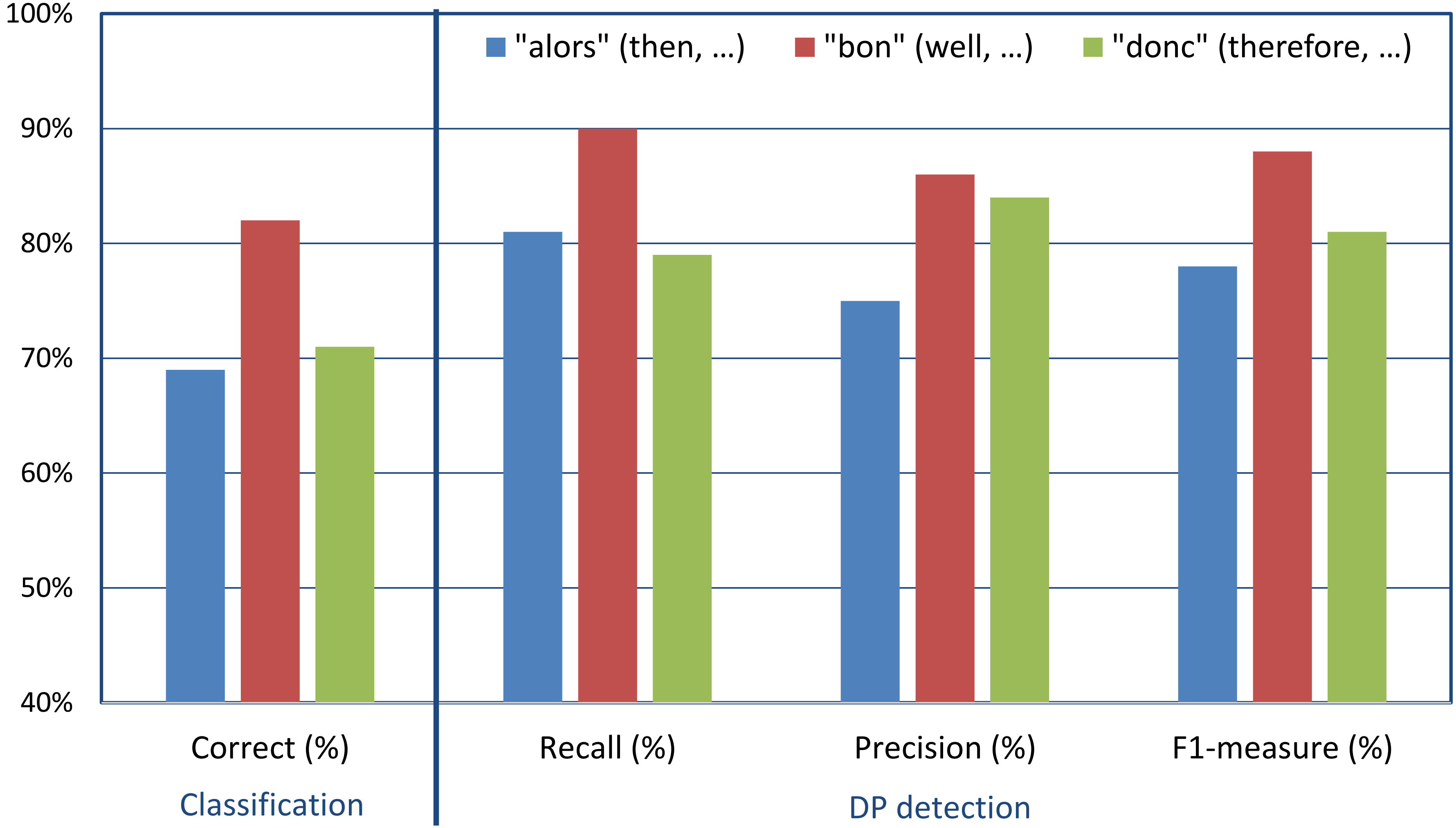
Automatic classification and detection experiments

- Data subsets
  - 60% for training, 10% for validation, 30% for performance evaluation

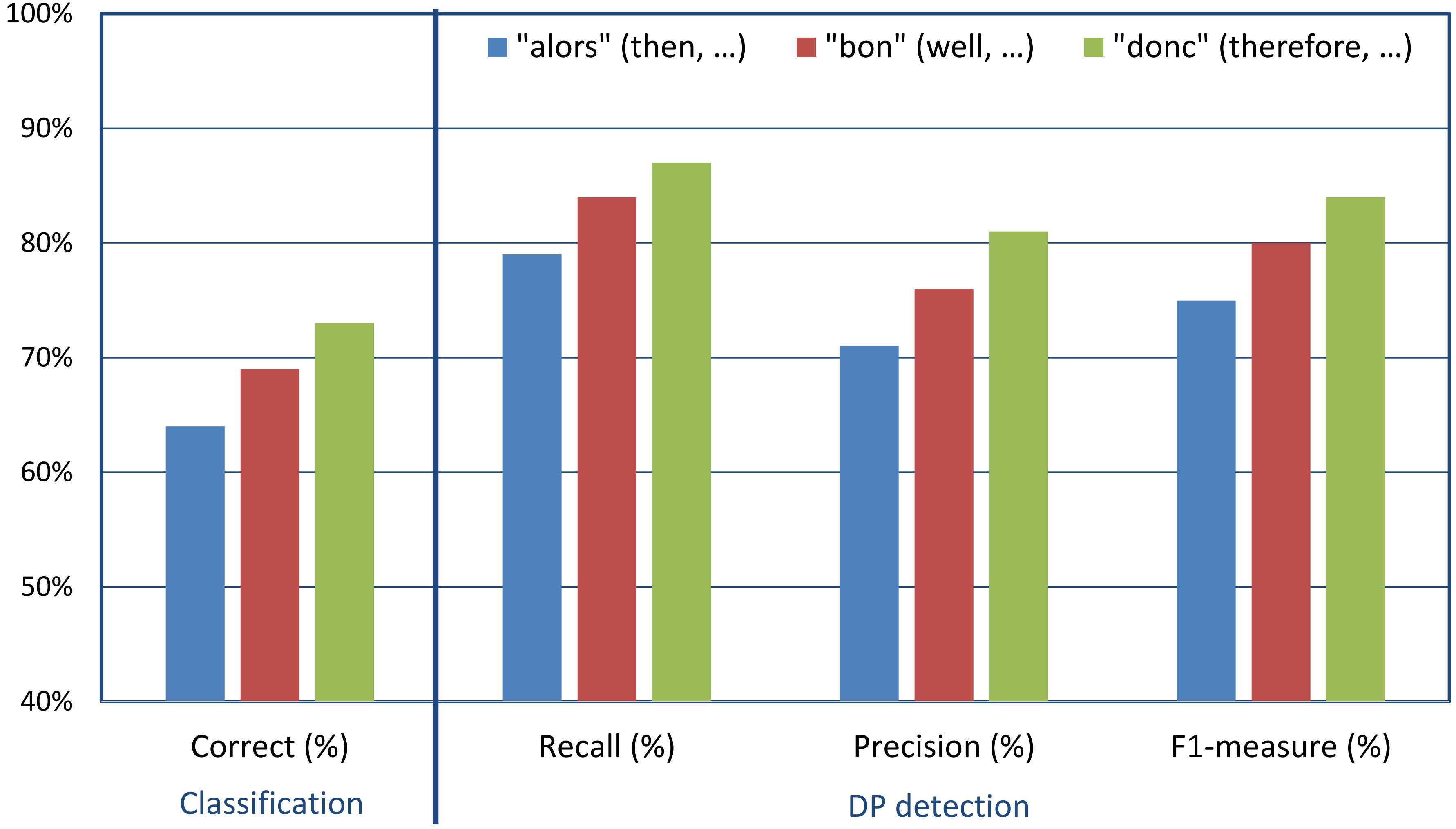
- Classifiers
  - Word dependent classifier
  - Neural network approach (Keras toolkit)

- Two sets of features
  - Prosodic features over a few word window
    - duration and energy of last vowel of the word
    - absolute F0 value at end of the word, and its slope
    - pause before and/or after the word
    - …
  - Fundamental frequency values over a few second window
    - F0 values computed every 10 ms

Automatic classification and detection **using prosodic features**

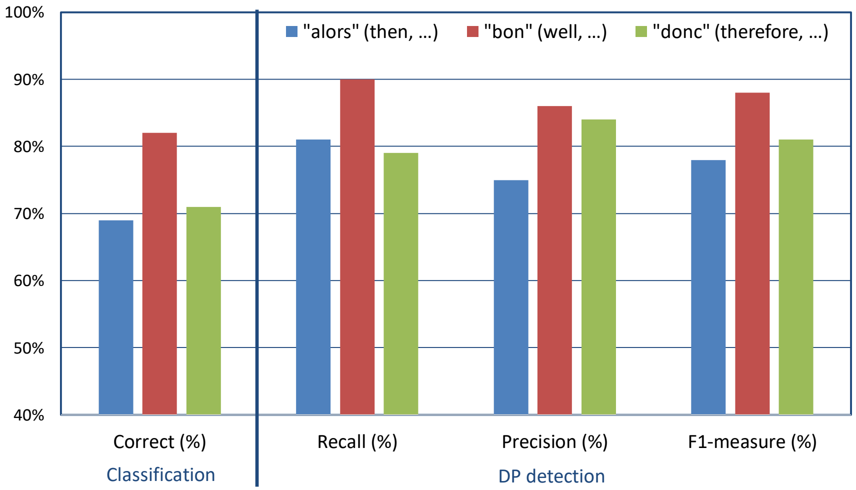


Automatic classification and detection **using fundamental frequency values**

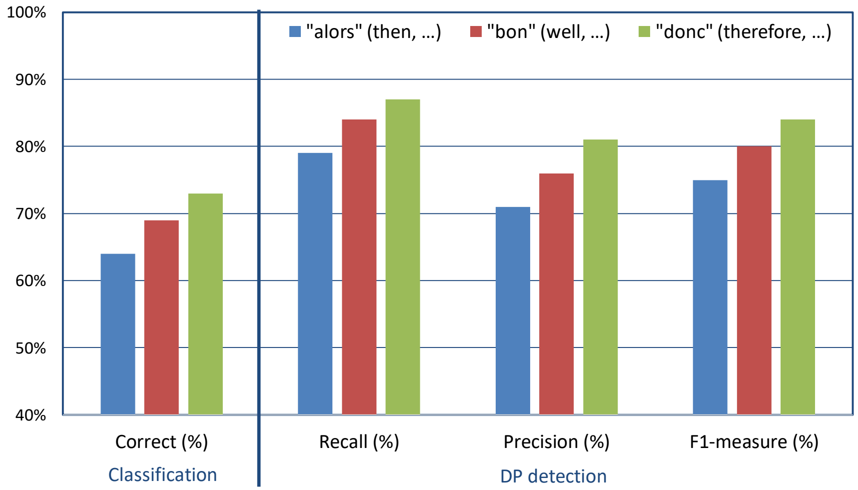


Automatic classification and detection

Prosodic features



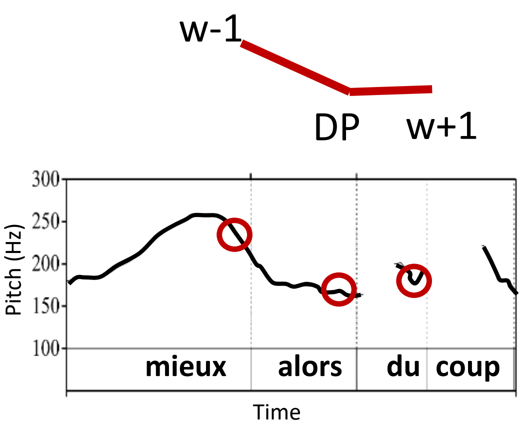
Fundamental frequency



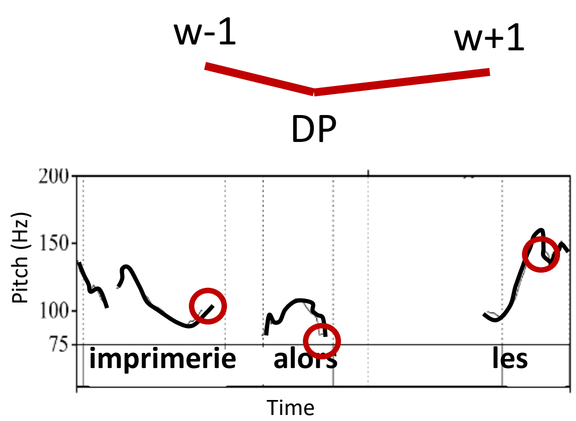
- *"alors"* (then, …) & *"bon"* (well, …) ➔ Prosodic features more relevant than F0
- *"donc"* (therefore, …) ➔ F0 slightly more relevant than prosodic features
- It might be interesting to combine these two sets of features

F0 patterns

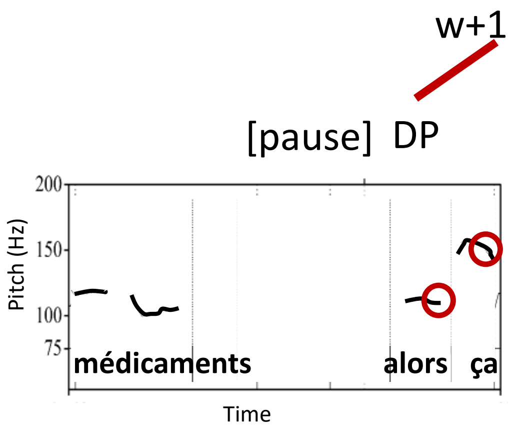
- F0 movements with respect to
  - Last syllable of previous word
  - First syllable of next word



falling_plateau



falling_rising



rising_w+1

F0 patterns

Most frequent F0 patterns with respect to discourse particle and pragmatic function

Discourse Particle	Pragmatic function	F0 patterns	
alors	conclusion	falling-rising	falling-plateau
	introduction	rising	rising-plateau
	reintroduction	falling-plateau	plateau
donc	conclusion	falling-plateau	plateau
	reintroduction	rising-plateau	plateau
	addition	falling-plateau	plateau
bon	conclusion	falling-rising	falling-plateau
	interruption	plateau	
	confirmation	falling-rising	plateau
	incident	falling-plateau	

F0 patterns

addition and incident ➔ add an information or a comment

Discourse Particle	Pragmatic function	F0 patterns	
alors	conclusion	falling-rising	falling-plateau
	introduction	rising	rising-plateau
	reintroduction	falling-plateau	plateau
donc	conclusion	falling-plateau	plateau
	reintroduction	rising-plateau	plateau
	addition	**falling-plateau**	plateau
bon	conclusion	falling-rising	falling-plateau
	interruption	plateau	
	confirmation	falling-rising	plateau
	incident	**falling-plateau**	

F0 patterns

Conclusion and confirmation ➔ expression of look-back; semantic action of finality

Falling-rising and falling-plateau highlight a strong semantic break

Discourse Particle	Pragmatic function	F0 patterns	
alors	**conclusion**	**falling-rising**	**falling-plateau**
	introduction	rising	rising-plateau
	reintroduction	falling-plateau	plateau
donc	**conclusion**	**falling-plateau**	plateau
	reintroduction	rising-plateau	plateau
	addition	falling-plateau	plateau
bon	**conclusion**	**falling-rising**	**falling-plateau**
	interruption	plateau	
	confirmation	falling-rising	plateau
	incident	falling-plateau	

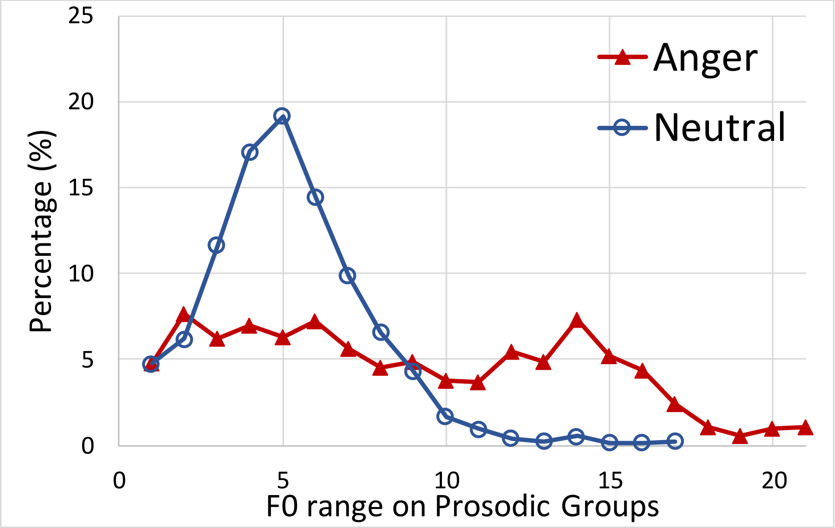
Expressive speech

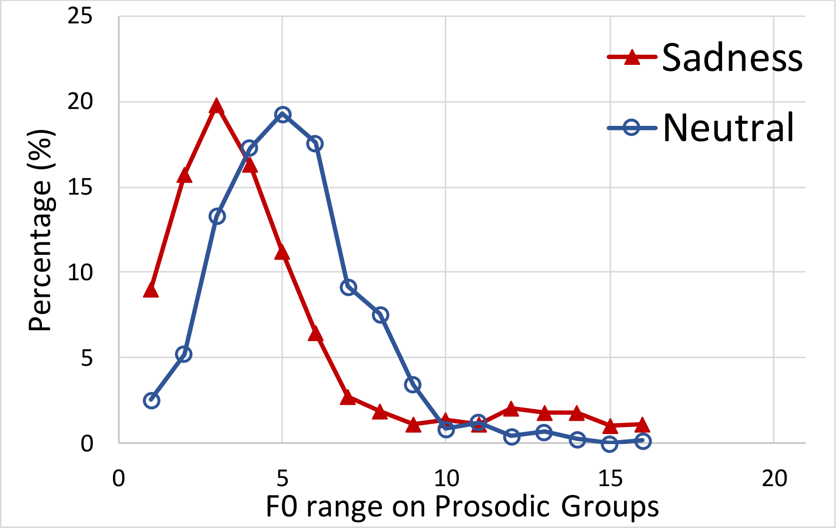
- Expressive speech is now attracting a lot of interest
  - Expressive text-to-speech synthesis
  - Recognition of emotions

- Emotional speech can be collected
  - Recording of spontaneous speech – then annotation of the emotion
  - Recording through induced situations
  - Recording of acted speech from professional actors

Prosody of emotional speech

- Considering for example the F0 range, in comparison with neutral speech





- Larger F0 ranges are much more frequent for anger
- And, slightly more frequent for fear, surprise and joy
- Smaller F0 ranges are more frequently observed for sadness.

Segmental level analysis

- Compared to neutral speech, pronunciation of emotional speech is often modified

- Many omissions of the schwa like vowel
- Omissions are more frequently observed In the first and last breathing groups
- Slightly vary with emotions – highest percentage was observed for disgust, fear and joy

- There exist also some other modifications, as for example
  the omission of liquid consonants in consonantal clusters

Expressive speech synthesis

- Currently relies on an expressive speech synthesis corpus
- Recent approaches are based on deep learning approaches
- This opens research tracts for
  - Adjusting the level of the emotions
  - Investigating mixing of emotions
  - Investigating transfer learning approaches
  - …

Outline

- Prosodic features, computation and reliability
  - Phone duration
  - Fundamental frequency
  - Phone energy
- Prosodic features in automatic speech processing
  - Computer assisted language learning
  - Structuring speech utterances
  - Sentence modality
  - Prosodic correlates of discourse particles
  - Expressive speech
- **Conclusion**

Conclusion

- Computation of prosodic features
  - Forced speech-text alignment is used for phone duration
  - Many algorithms exists for fundamental frequency

- Approaches work well on clean and good quality speech
- However performance degrades on noisy speech

- Missing of reliable confidence estimators

- Prosody features are involved in many speech processing tasks