

# Speech recognition and synthesis

## 1 Measuring Speech

- Introduction
- Waveforms
- Pitch and F0
- Spectrum
- Spectrograms
- Transcription
- Assignment
- Bibliography

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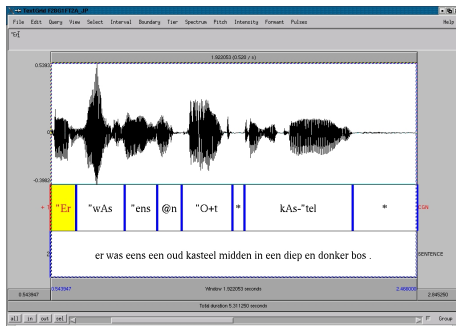
# Introduction

## All technology starts with quantitative modelling

- Speech technology is about speech **sounds**
- Only limited knowledge of human speech production and perception is necessary for modelling speech sounds
- In practice, knowledge about human speech is only used implicitly



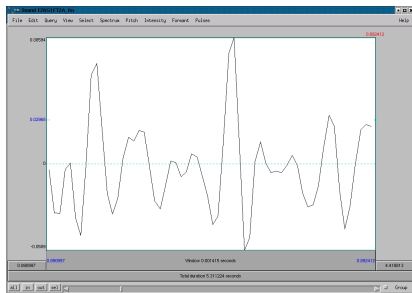
# Waveforms: Oscillogram



## "Er was eens een oud kasteel"

- Display of pressure versus time
- Words are aligned with sound
- Using computer readable (SAMPA) phoneme symbols

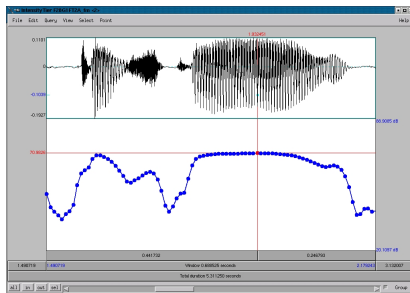
# Waveforms: Digital sound and band-width



## 1.5 ms of an /s/ sound from "was"

- Samples taken at 44.1 kHz (CD audio)
- Quantize at 16 bit ( $\approx 65000$  amplitude levels)
- Maximum audio frequency 22.05 kHz (Nyquist frequency) but generally *much* less
- Dynamic Range  $\approx 96dB$  ( $\approx 6dB/bit$ )

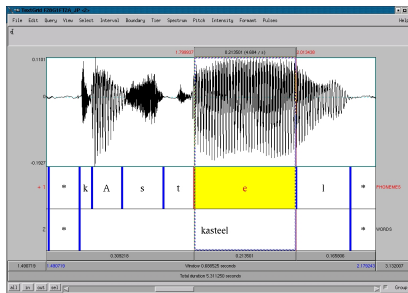
# Waveforms: Amplitude and sound level



## Intensity contour of "Kasteel"

- Intensity versus amplitude
- Intensity in dB ( $10 \cdot \log_{10}(\text{SoundEnergy})$ )
- Intensity you hear is not the intensity you measure  $\Rightarrow$  correct for human perception (*dba*)

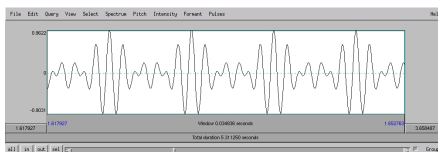
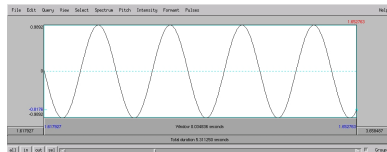
# Waveforms: Durations



## Phoneme segmentation of "Kasteel"

- Determine the boundaries of words, syllables and phonemes
- Use waveform, ear, and spectrum
- Segmentation is ambiguous and laborious
- Start with automatic segmentation (for speed)

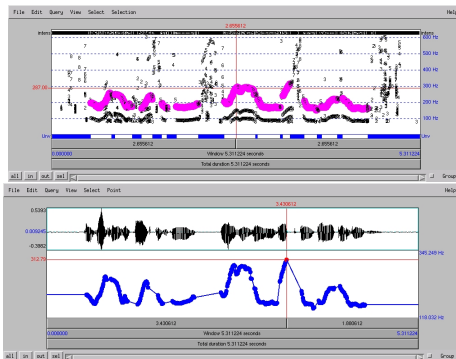
# Pitch and F0: The perception of tones: $F_0$



Pitch or  $F_0$  is the *perception* of a harmonic sequence. Generally, perceived *pitch* is the:

- frequency of a pure tone (top, 125 Hz)
- distance between the components in a mixture of harmonic tones (eg, 125 Hz)
- closest harmonic fit in complex sounds (bells)

# Pitch and F0: Measuring $F_0$

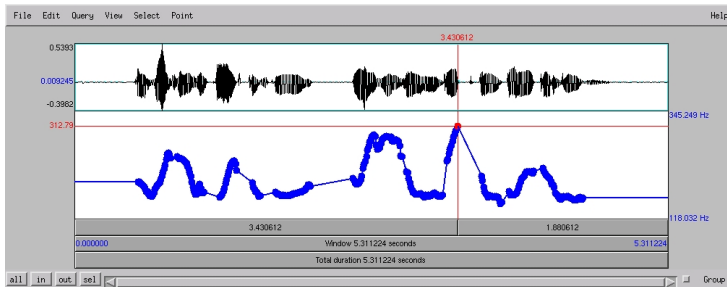


The best  $F_0$  candidates are determined

- from the possible repeat frequencies using an autocorrelation function
- from the best fitting harmonics using a *harmonic sieve*



# Pitch and F0: Pitch contours

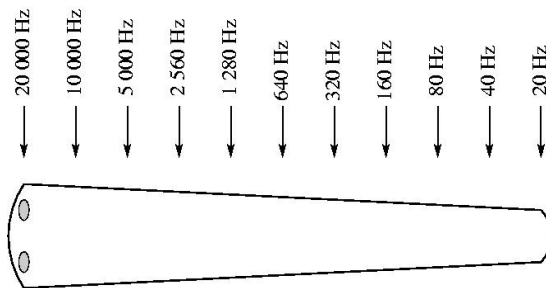


## Hummed sound

$F_0$  makes the melody, or intonation, of an utterance

- There is a general decrease of  $F_0$  over an utterance: The *declination*
- $F_0$  movements indicate emphasized words: *pitch accents*
- $F_0$  movements and *declination resets* indicate boundaries

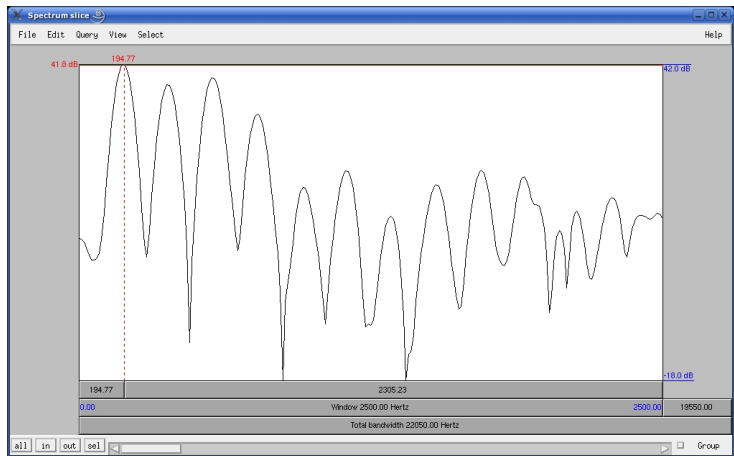
# Spectrum: The Ear (again)



## Frequency map of the cochlea from [Moore(2003)]

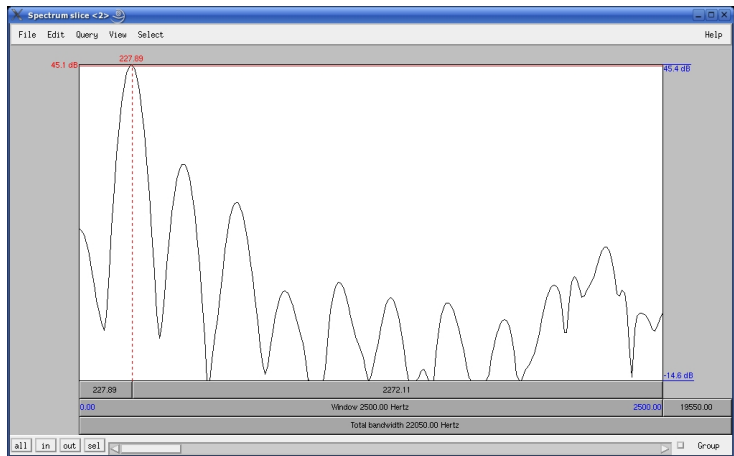
- The ear analysis sounds roughly into  $\text{Log}(\text{Power}(\text{Frequency}))$  vs.  $\text{Log}(\text{Frequency})$
- Speech is analyzed in the same way
- Use power spectra of sounds

# Spectrum: Example of /ε/



Note the harmonic structure and the "bumps"

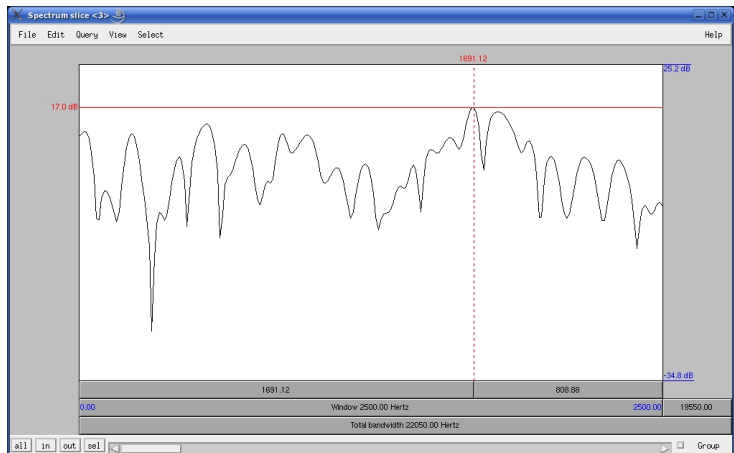
# Spectrum: Example of /n/



Note the harmonic structure and the low level of high frequencies



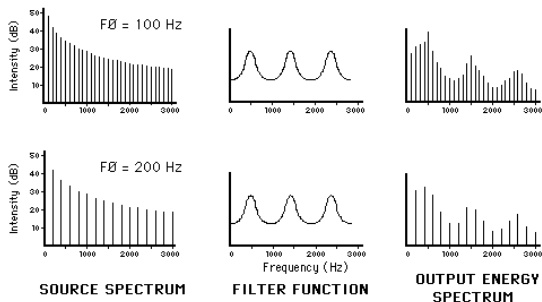
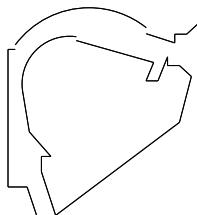
# Spectrum: Example of /s/



Note the noisy structure and the broad bandwidth



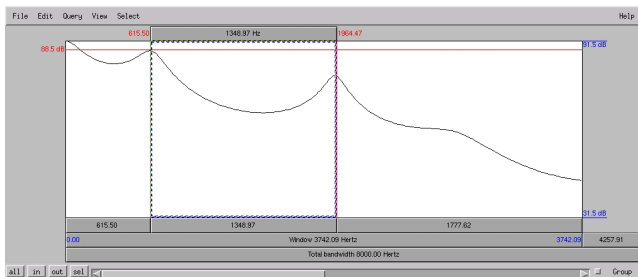
# Spectrum: Source Filter model of speech



Sound enters the oral cavity (vocal tract) from below and is filtered by the resonances of the cavity



# Spectrum: Resonances and formants



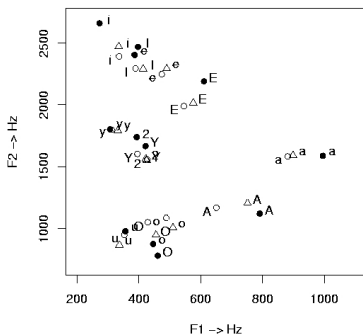
Oral cavity filter function of / $\epsilon$ / (LPC model).

Peaks are formants  $F_1$  and  $F_2$ .

The resonances of the vocal tract are called Formants, and numbered from below, i.e.,  $F_1$ ,  $F_2$ ,  $F_3$ ,  $\dots$ . Normally, the first three are sufficient to describe (voiced) speech.



# Spectrum: Vowel Formant space



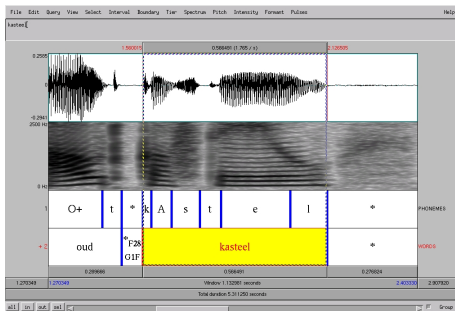
Vowel formant space of Dutch.

Only two formant values,  $F_1$  and  $F_2$ , suffice to identify a vowel (in the ideal case). However, in normal speech, there is so much overlap and variation that it remains almost impossible.





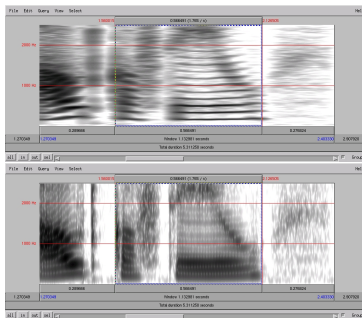
# Spectrograms



A spectrogram shows the development of the spectrum in time (darker is more power)

- A spectrogram shows the harmonics
- Vowels, fricatives, and plosives are visible

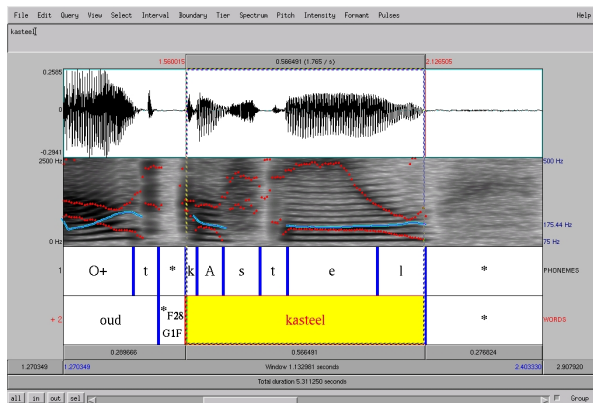
# Spectrograms: Narrow versus Wide band



## Two views on spectrograms

- Narrow-band (top): High frequency resolution, low time resolution
- Wide-band (bottom): Low frequency resolution, high time resolution

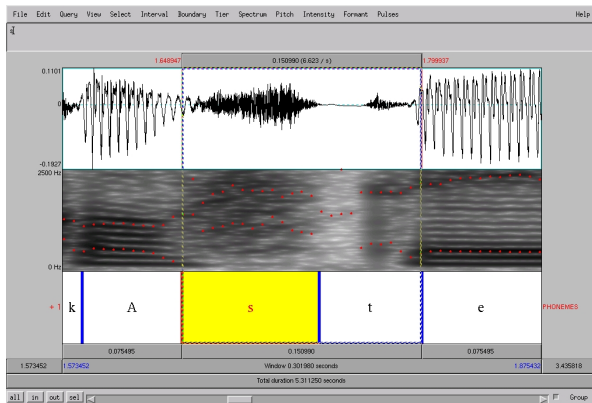
# Spectrograms: Formant and Pitch tracking



Formants (red dots) and Pitch (blue line) can be automatically determined and plotted into a spectrogram.



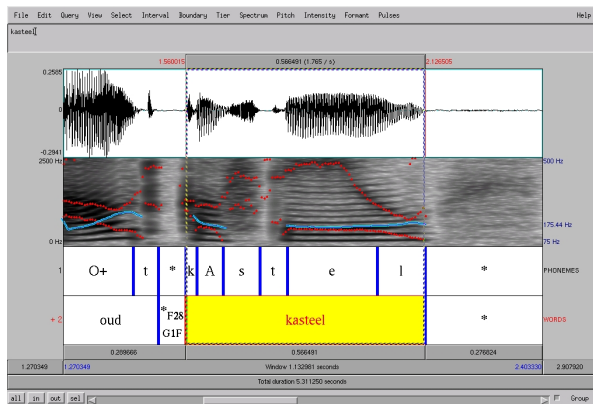
# Spectrograms: Noise and bursts



Fricatives are visible as gray noise patches. Plosives as a silent part followed by a noisy burst.



# Spectrograms: Spectrogram reading



It is actually possible, after a few weeks training, to read spectrograms. All the information needed to "understand" the speech is in the spectrogram [Lander and Carmell(1997)].



# Transcription: Transliteration

Before anything can be done with speech, it has to be written down and transcribed

- Write out orthographically what was said (and check it)
- Align chunks of text roughly with the stretches of speech
- Transcribe the text automatically into phonemes using a lexicon
- Split the orthographic/phonemic text into words
- Align the words/phonemes automatically with the speech
- Add automatic Part-of-Speech tags and Syntax



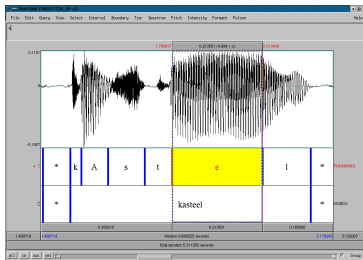
# Transcription: Transcription

## Human annotator transcriptions: Difficult and expensive

- Accents, stress, and boundaries (always ambiguous)
- Handcorrected word-boundaries
- Handcorrected phoneme-boundaries (always ambiguous)
- Check Part-of-Speech tags
- Check Syntax



# Transcription: Identifying and annotating phonemes

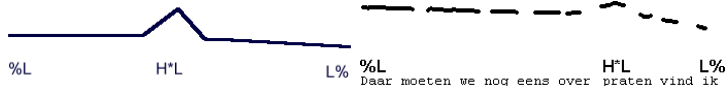


## Phonemes are not pearls on a string

- Phonemes always overlap and are extremely variable
- A phoneme you hear can appear absent in the waveform
- It is often unclear what phonemes were uttered
- Sometimes, even the order is unclear



# Transcription: ToBI systems for intonation transcription



## ToBI symbols (IP: Intonational Phrase)

High	Low	description
H*	L*	high/low accent
H	L	upward/downward movement after L*/H*
H%	L%	rising/low ending of IP
%H	%L	high/low beginning of IP
%HL		Initial falling pitch not marking accent
%		half-completed fall/rise at end of IP
!H*		downstepped H*

[Gussenhoven et al.(2003)Gussenhoven, Rietveld, Kerkhoff, and Terken]

# Assignment- Week 2 Spectrogram and spectrum

See BlackBoard for full description

- Use a recorded sentence (assignment 1)
- Determine pitch maxima and minima. On which words do you find the maxima? Where inside the word?
- Determine the spectrum of a (monophthong) vowel and draw it
- Compare the formant frequencies of this vowel with the spectrum
- Determine the formants at the center of all (at most 10) monophthong vowels
- Using the formant values, where do these vowels fit into the vowel triangle? ( $F_1/F_2$  space)
- Hand in your report as a PDF



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*Glot International*, 5:341–345, 2001.

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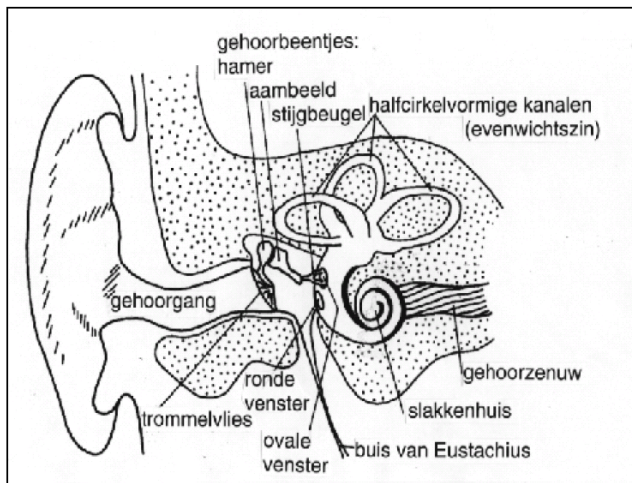
Lecture 6.



# Appendix A



# The inner ear



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