Information in Spoken Language

A quantitative approach

Rob van Son

Chair of Phonetic Sciences
ACLC
University of Amsterdam

LOT winterschool 2006

AMSTERDAM CENTER FOR LANGUAGE AND COMMUNICATION ACLC

Introduction

Spoken language is mostly sound: Speech

- To understand speech we must understand speaking and hearing
- Hearing limits the information we can distill from sound
- Articulation limits what we can produce within these limits
- What information can be extracted from speech sounds?
- How can we study this?
- How can we study human speech processing?

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Acoustics of speech

The speech chain constist of articulation, sound, and hearing

- The speech chain is not symbolic
- Articulation is preceeded by formulation
- Hearing is followed by recognition
- Both formulation and recognition center around phonemic segments and words
- However, speech does contain neither, just sound

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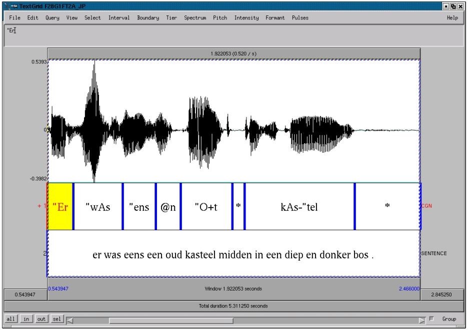
Acoustics of speech: Oscillogram



"Er was eens een oud kasteel"

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

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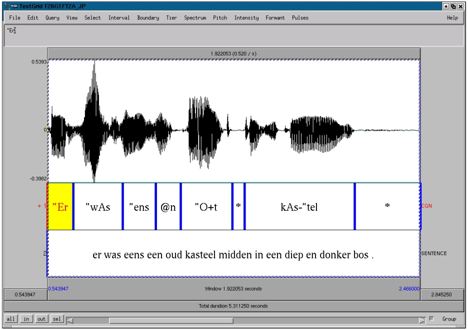

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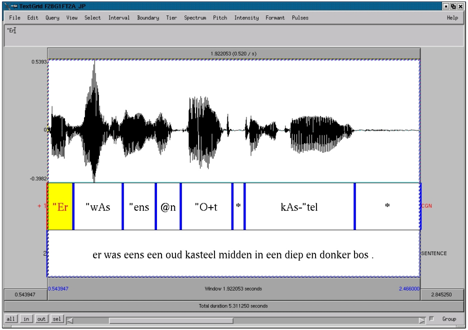

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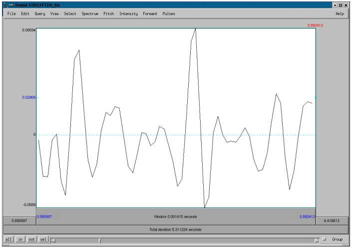
Acoustics of speech: Digital sound and band-width



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

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

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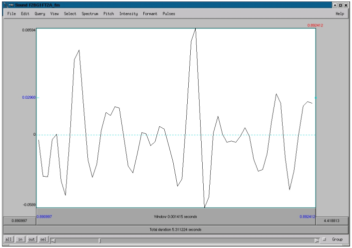

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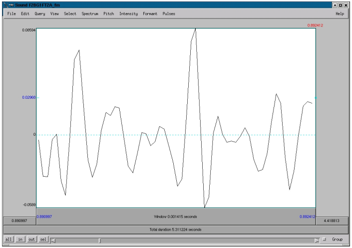

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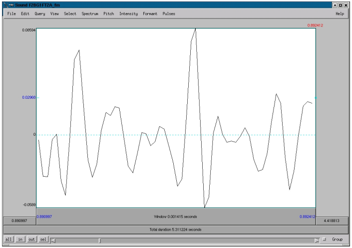

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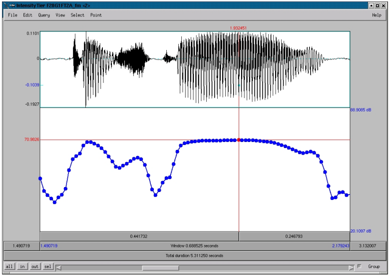
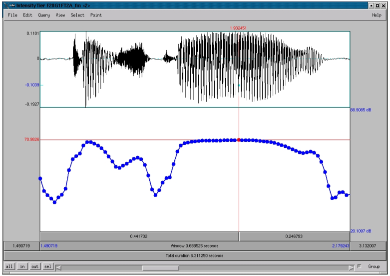


Intensity contour of "Kasteel"

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

Acoustics of speech: Amplitude and sound level



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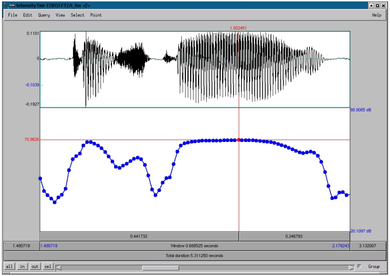

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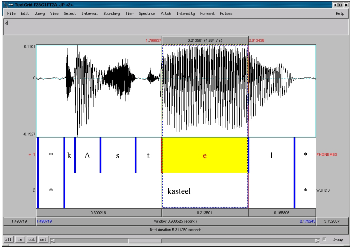

Phoneme segmentation of "Kasteel"

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

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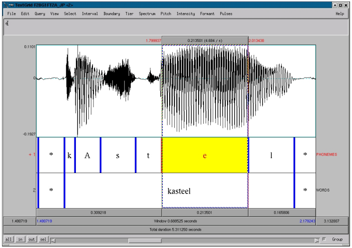

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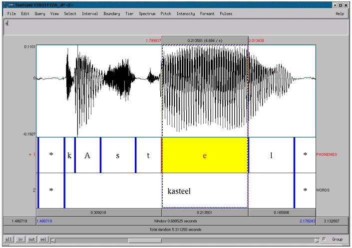

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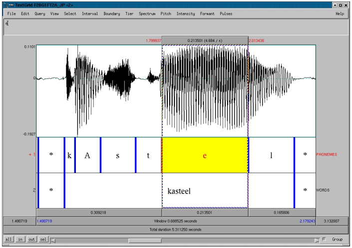

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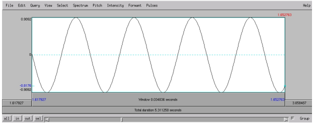
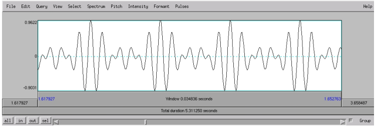
Acoustics of speech: The perception of tones: F_0

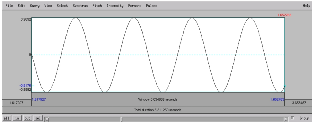


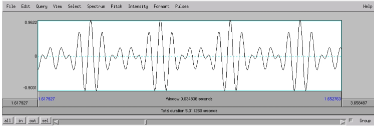


Pitch or F_0 is the *perception* of a harmonic sequence.
Generally, perceived *pitch* is the:

- 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)

Acoustics of speech: The perception of tones: F_0





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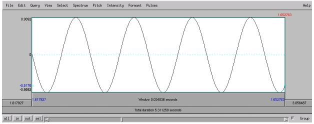

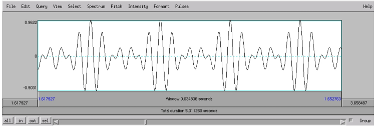

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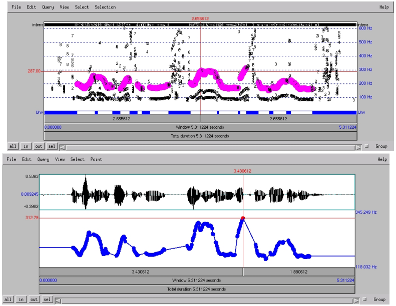
Acoustics of speech: Measuring F_0



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*

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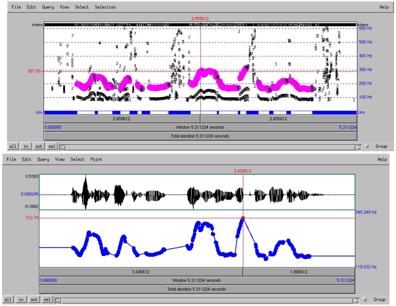

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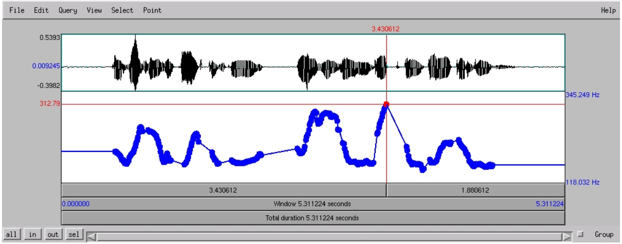
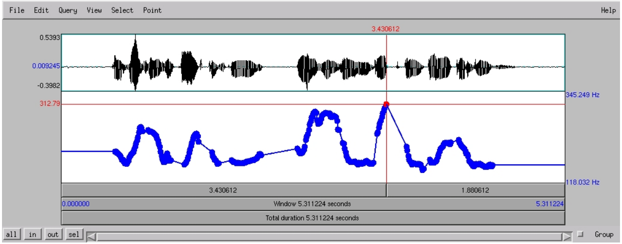


Hummed sound

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

Acoustics of speech: Pitch contours



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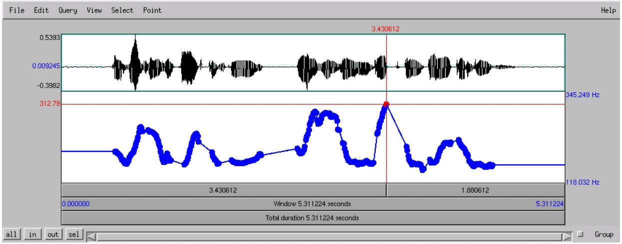

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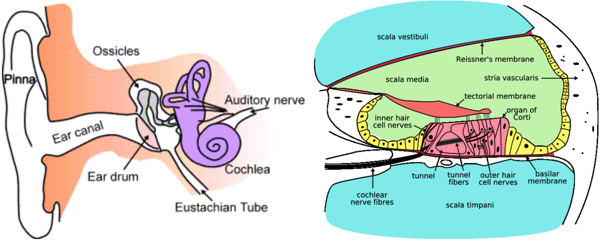

The anatomy of the human ear (l) and cochlea (r)

- Sound enters the ear canal (left)
- The ear drum transfers the sound over the ossicles to the oval window into the cochlea
- The cochlea (right) converts sound into nerve exitations

http://en.wikipedia.org/wiki/Human_ear

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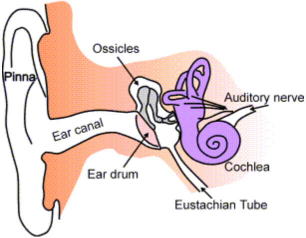

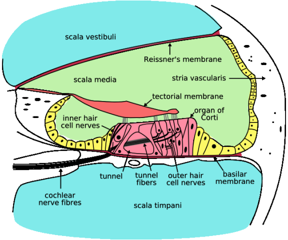

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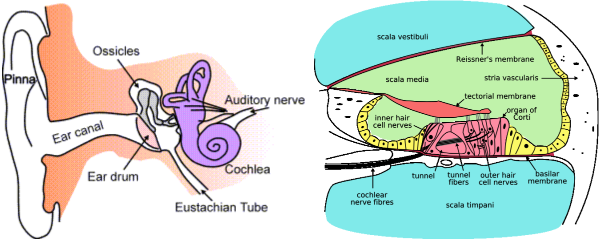

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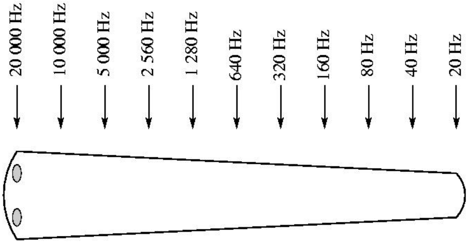

Frequency map of the basilar membrane from [Moore(2003)]

- The ear analyses sounds roughly into *Log* (*Power* (*Frequency*)) vs. *Log* (*Frequency*)
- Speech is analyzed in the same way
- Use power spectra of sounds

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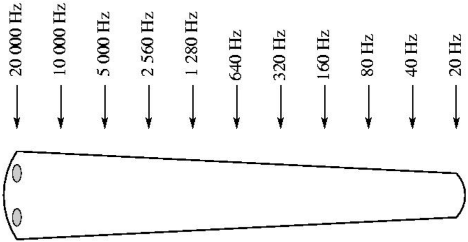

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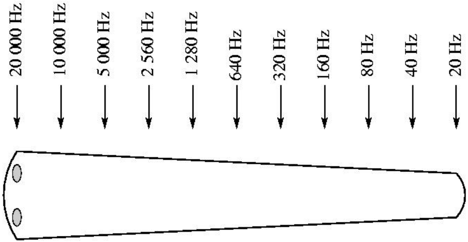

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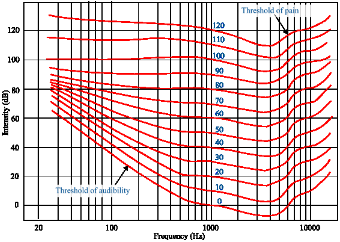

Relation between perceived loudness and frequency

- The absolute threshold varies with frequency
- Best hearing between 800Hz and 6000Hz
- Human speech needs 400Hz - 3400Hz (telephone speech)
- Loudness JND is around 1 dB (soft sounds)

http://en.wikipedia.org/wiki/Threshold_of_hearing

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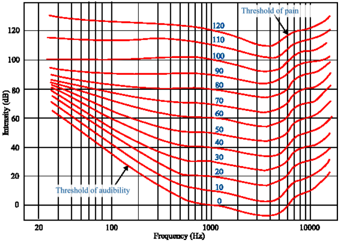

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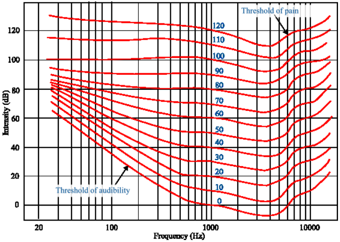

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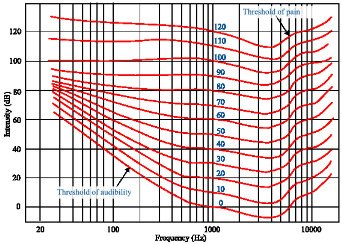

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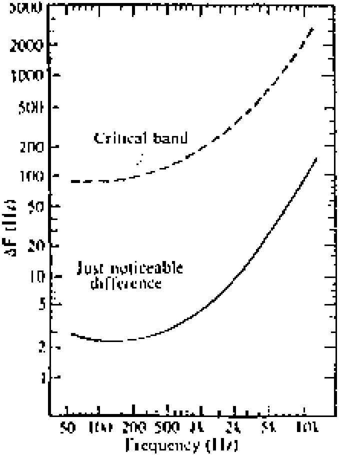

http://www.music.gla.ac.uk/~george/audio/psy/psy.html

- Sounds grouped in *critical bands* (CB)
- CB is around 30 times JND
- One signal per critical band
- 3 CB per Octave
- Time resolution $\approx 25ms$

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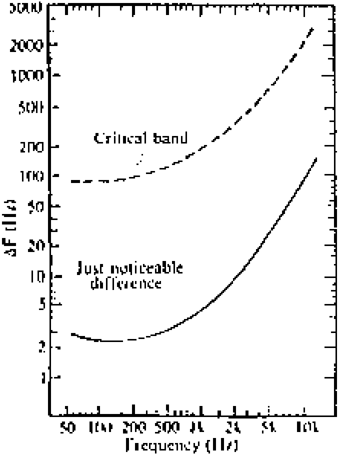

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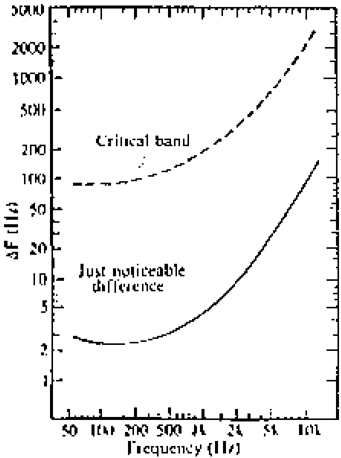

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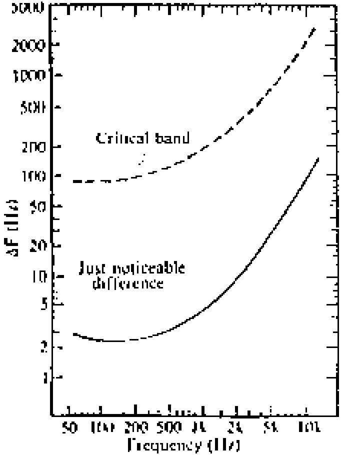

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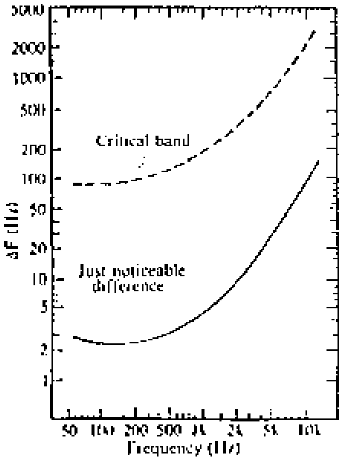

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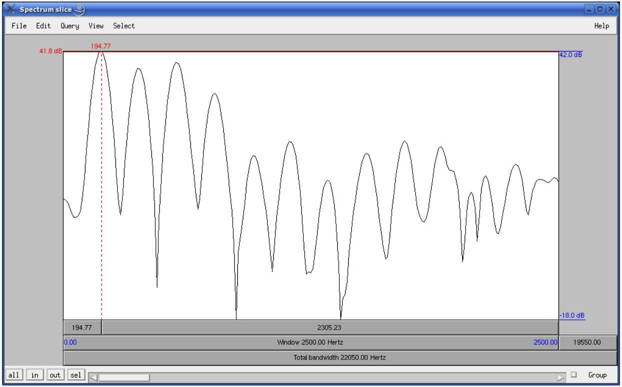
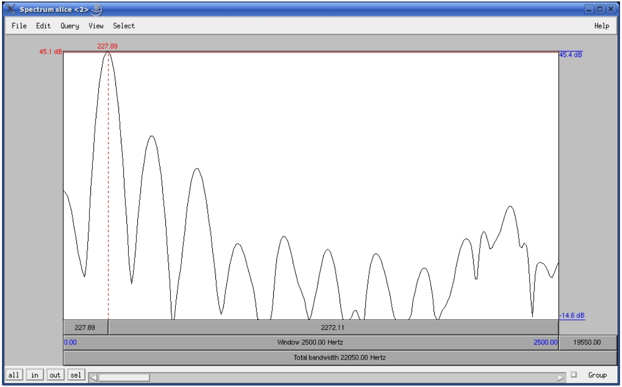
- CB is around 30 times JND
- One signal per critical band
- 3 CB per Octave
- Time resolution $\approx 25ms$

Hearing: Example of /ɛ/



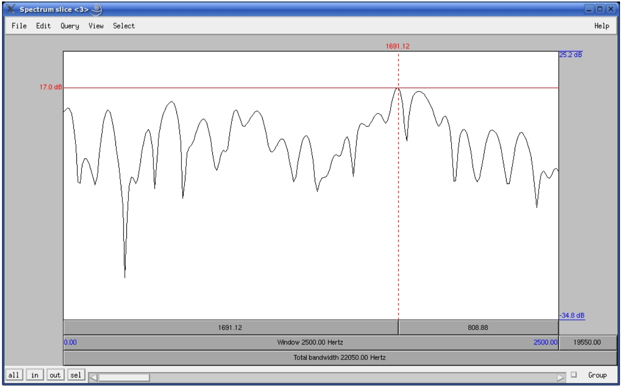
Note the harmonic structure and the "bumps"

Hearing: Example of /n/



Note the harmonic structure and the low level of high frequencies

Hearing: Example of /s/



Note the noisy structure and the broad bandwidth

Hearing

How much information can the ear extract at a minimum from speech?

- Frequencies: 400Hz - 3400Hz $\rightarrow$ 3 octaves $\approx$ 9 CBs
- Dynamic range $\approx 30dB$ per CB, $\rightarrow$ 5 bit / CB
- Time resolution $\approx 25ms$
- Information available: $\frac{9CB \cdot 5bit}{0.025sec} \approx 1800$ bit/second
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How much information is actually needed?

- Concatenated phoneme transitions (diphones) are perfectly intelligble
- There are ≈ 1600 diphones ($40 \cdot 40$ allophones)
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- Articulation rate ≤ 15 phones/second
- Information needed for recognition: $11 \cdot 15 = 165$ bits/second
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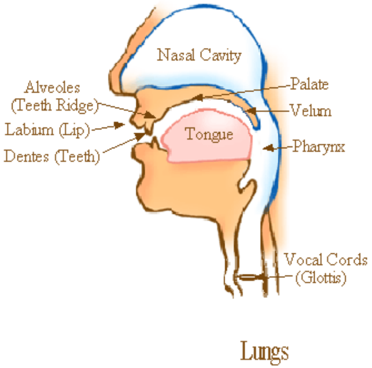
Speaking: Articulators



Vocal trackt and primary articulators

- The lungs pump air through the glottal folds
- The glottal folds can vibrate (or not)
- The oral cavity can be constricted at many points
- Alternatively, air can flow through the nasal cavity

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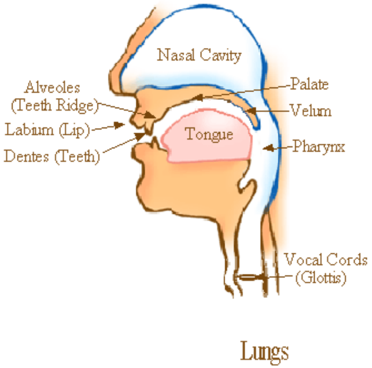

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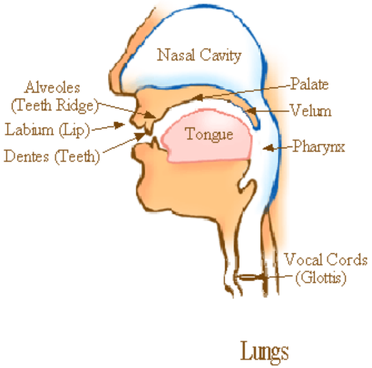

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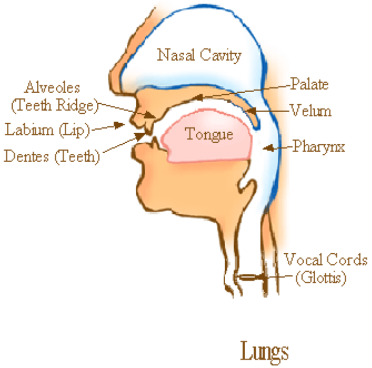

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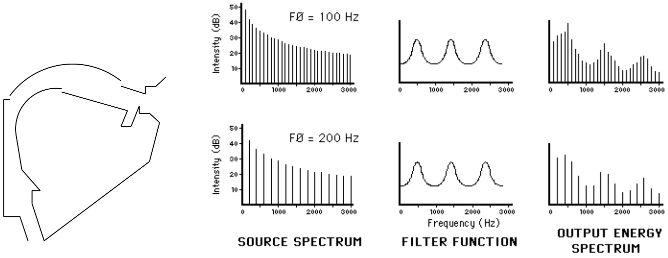
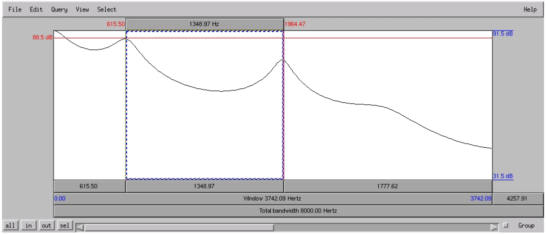
Speaking: Source Filter model of speech



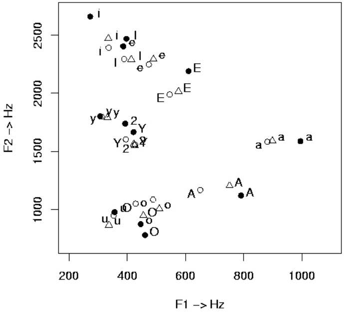
Sound enters the oral cavity (vocal tract) from below and is filtered by the resonances of the cavity

Speaking: Resonances and formants



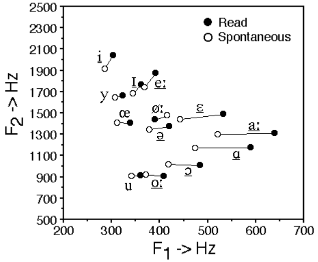
Oral cavity filter function of /ɛ/ (LPC model). Peaks are formants F_1 and $F2$.
The resonances of the vocal tract are called Formants, and numbered from below, i.e., F_1, F_2, F_3, $\cdots$. Normally, the first three are sufficient to describe (voiced) speech.

Speaking: 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.

Speaking: Reduction



Articulation takes effort and humans are "lazy"

- Unimportant, unstressed, items are articulated "less well"
- Leads to less distinctive sound segments
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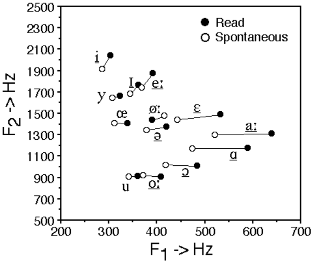

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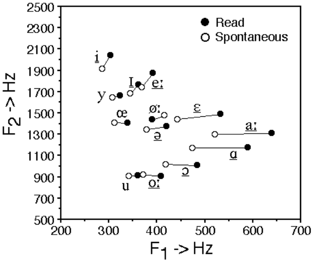

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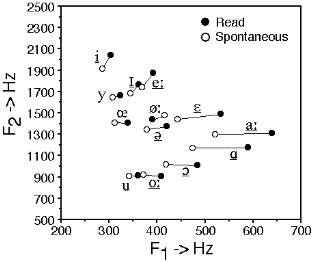

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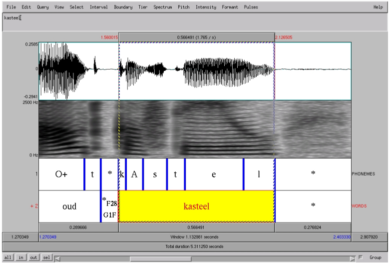
Spectrograms



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

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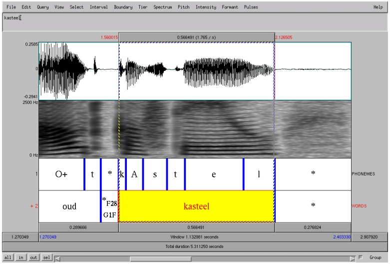

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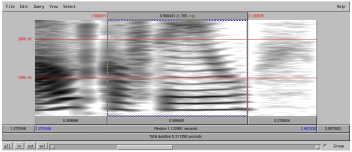
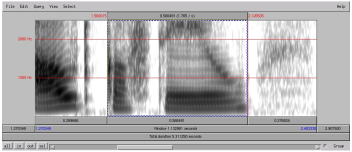
Spectrograms: Narrow versus Wide band

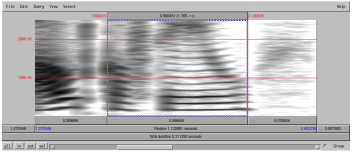


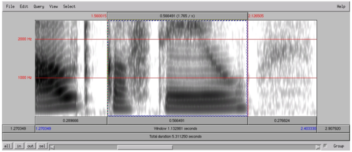


Two views on spectrograms

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

Spectrograms: Narrow versus Wide band





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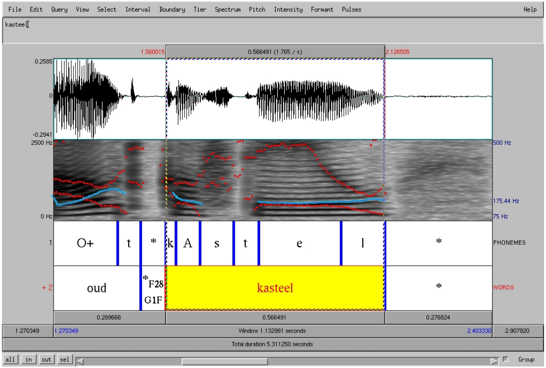
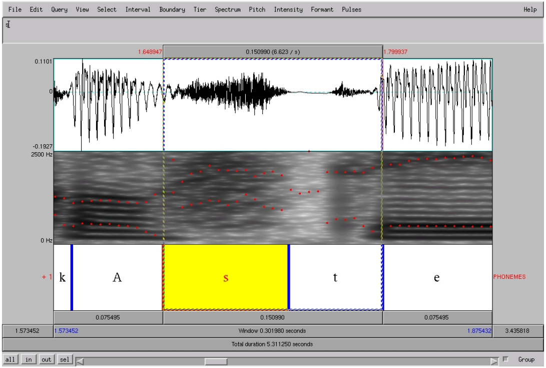
Spectrograms: Formant and Pitch tracking



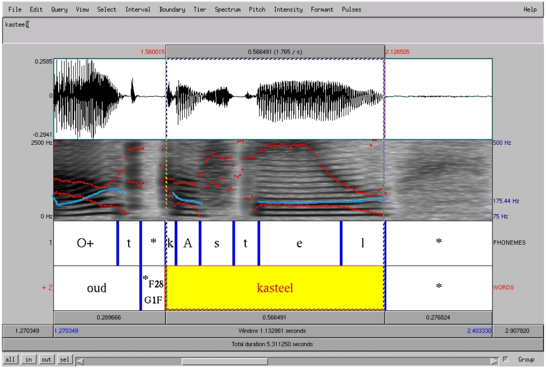
Formants (red dots) and Pitch (blue line) can be automatically determined and plotted into a spectrogram.

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)].

Corpora: 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)
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Human annotator transcriptions: Difficult and expensive

- Accents, stress, and boundaries (always ambiguous)
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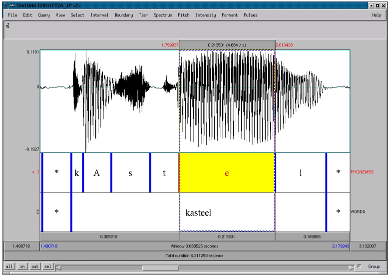
Identifying and annotating phonemes



Phonemes are not pearls on a string

- Phonemes always overlap and are extremely variable
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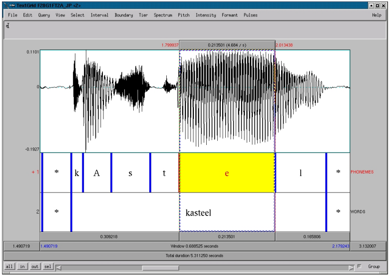

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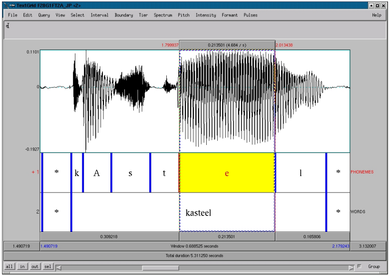

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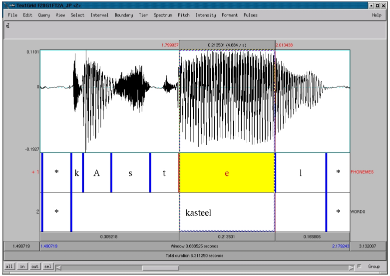

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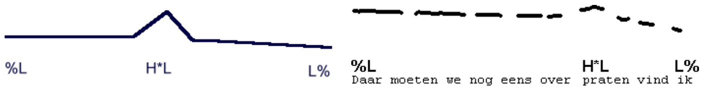
ToBI like systems for intonation transcription



ToDI symbols (IP: Intonational Phrase)

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

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*

Corpora

There is no data like more data

- Speech and Language are extremely complex
- Large amounts of data are necessary to model them
- "The best application/research is the one with the largest corpus"
- 10-1000 hours of speech recordings needed
- 10^8 - 10^9 word text corpus needed

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A language corpus is a documented collection of coherent text, speech, video, and transcriptions and annotations of these

Requirements

- Meta data (fixed): Information on the items
- Normalization (fixed): All items must adhere to certain guidelines
- Data (fixed): Immutable text or speech records
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Contents ($\frac{2}{3}$ Dutch, $\frac{1}{3}$ Flemish)

- 500 hours (5,650,000 words) recorded in The Netherlands
- 300 hours (3,250,000 words) in Flanders
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Contents ($\frac{2}{3}$ Dutch, $\frac{1}{3}$ Flemish)

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Annotations and transcriptions

- Orthographic transcription (the full 8,900,000 words)
- Manually verified POS tagging and lemmatization (all)
- Lexicon and identification of multi word units (all)
- Automatic time alignment and phonetic transcription at the word level (all)
- Manually verified broad phonetic transcription (1,000,000 words)
- Manually verified time alignment at the word level (1,000,000 words)
- Syntactic annotation (1,000,000 words)
- Two independent prosodic annotations (250,000 words)

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