



Information in Spoken Language

A quantitative approach

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ACLC
University of Amsterdam

LOT winterschool 2006



AMSTERDAM CENTER
FOR LANGUAGE AND
COMMUNICATION

ACLC



1 Acoustic information in speech

- Introduction
- Acoustics of speech
- Hearing
- Speaking
- Spectrograms
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- Bibliography



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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The speech chain consist 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



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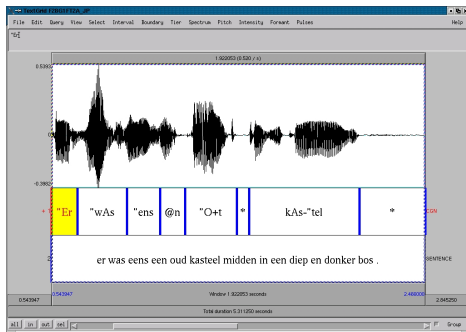
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”Er was eens een oud kasteel”

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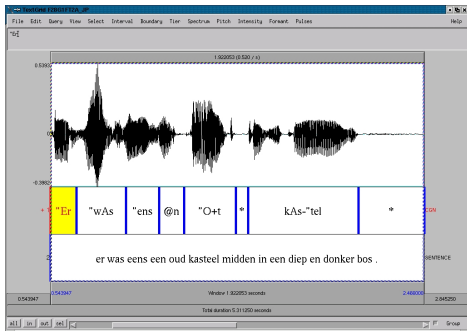
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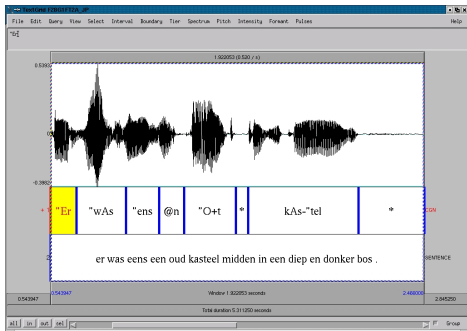
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Acoustics of speech: Digital sound and band-width



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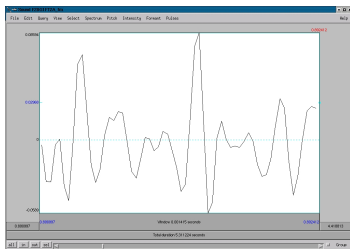
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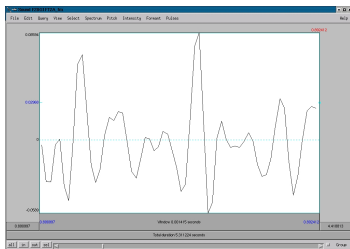
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1.5 ms of an /s/ sound from "was"

- Samples taken at 44.1 kHz (CD audio)
- Quantize at 16 bit (≈ 65000 amplitude levels)
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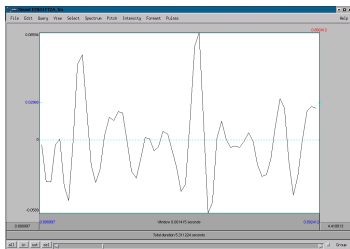
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Acoustics of speech: Amplitude and sound level



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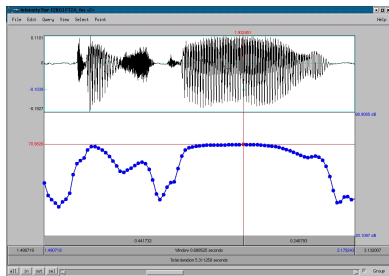
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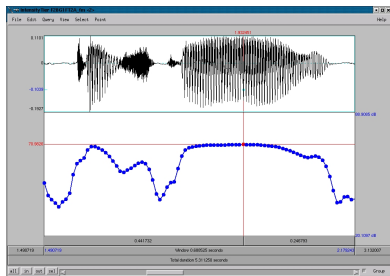
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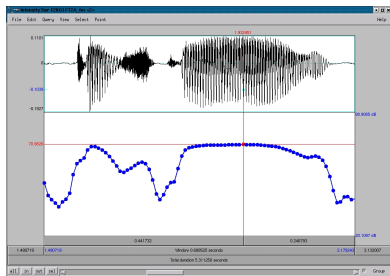
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Acoustics of speech: Durations



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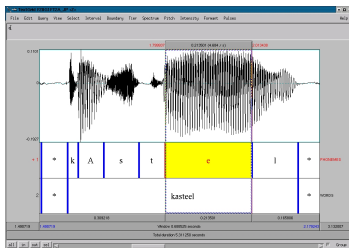
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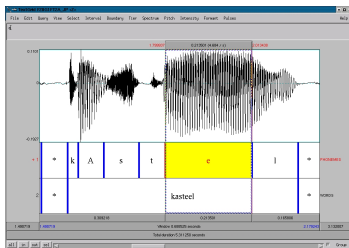
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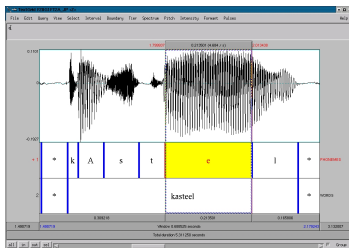
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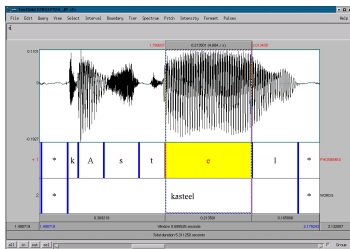
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Acoustics of speech: The perception of tones: F_0



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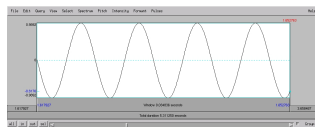
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Pitch or F_0 is the *perception* of a harmonic sequence.
Generally, perceived *pitch* is the:

- 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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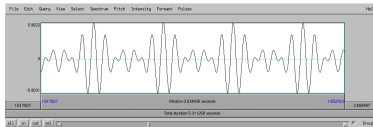
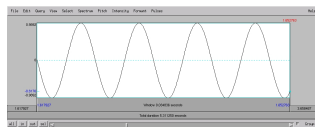
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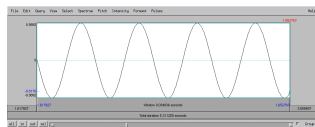
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Acoustics of speech: Measuring F_0



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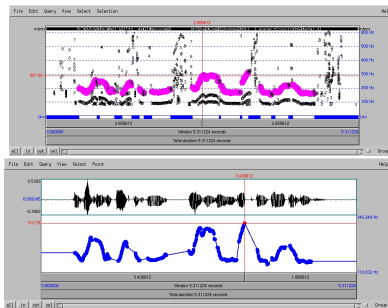
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The best F_0 candidates are determined

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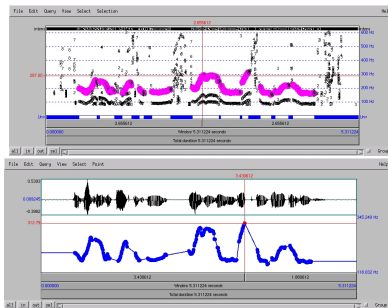
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Acoustics of speech: Pitch contours



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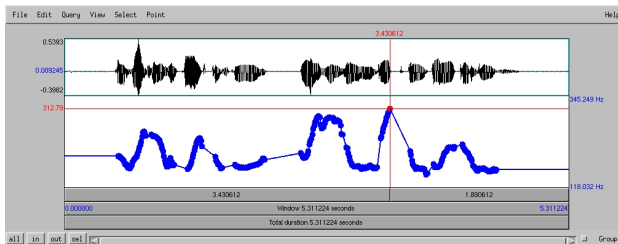
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Hummed sound

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

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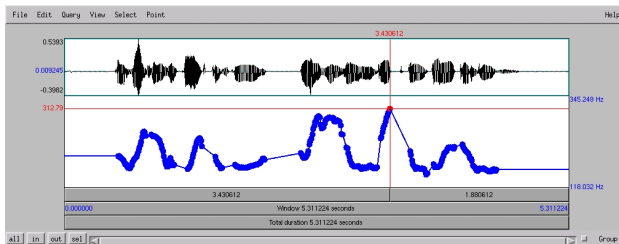
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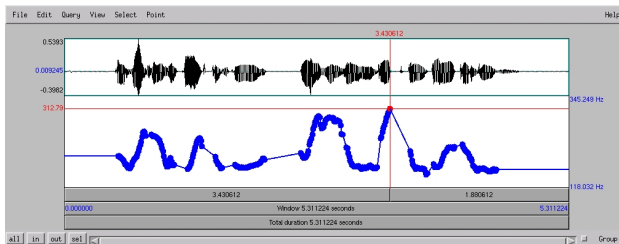
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Hearing: The human ear



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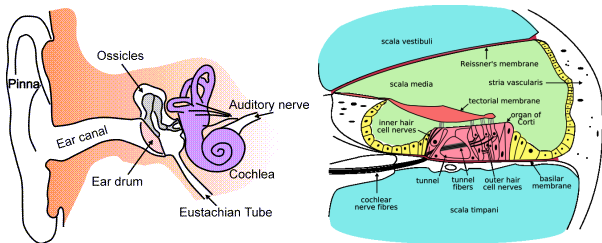
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The anatomy of the human ear (l) and cochlea (r)

- 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 excitations

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

Hearing: The human ear



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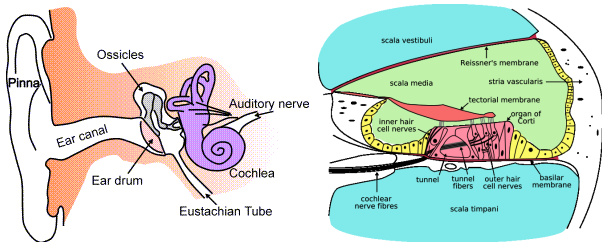
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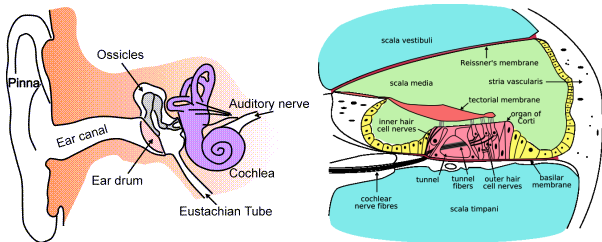
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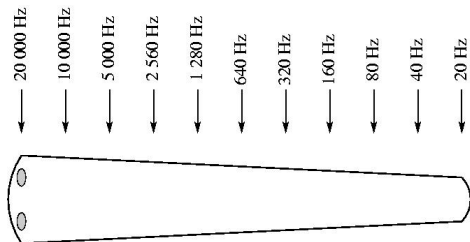


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Hearing: The basilar membrane

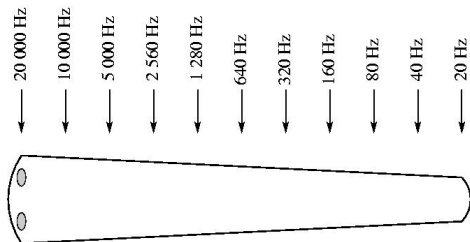


Frequency map of the basilar membrane from [Moore(2003)]

- The ear analyses 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



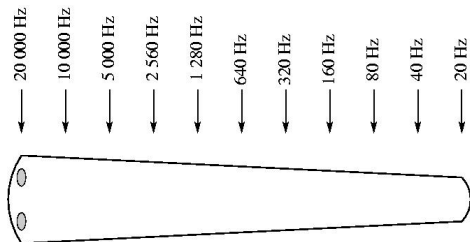
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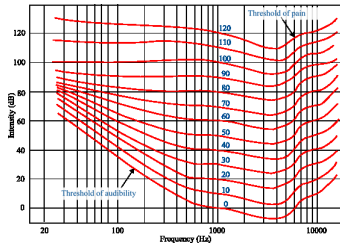


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Hearing: Loudness



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)

Hearing: Loudness



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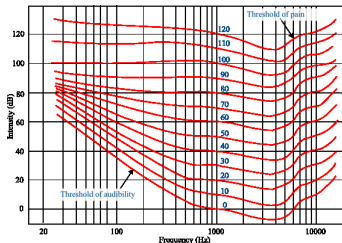
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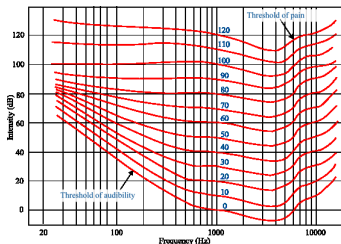
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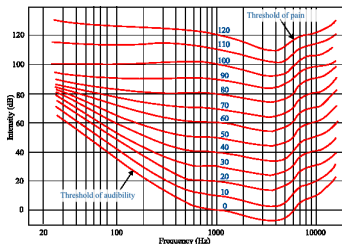
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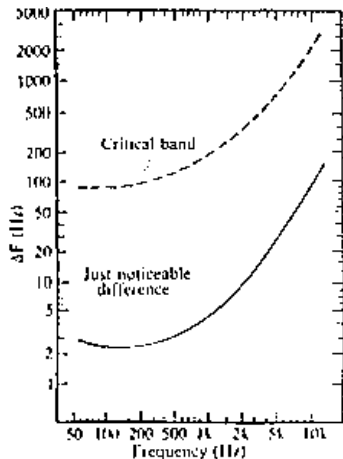


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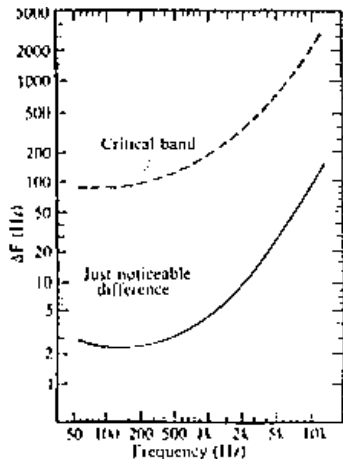
Hearing: Critical bands



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

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

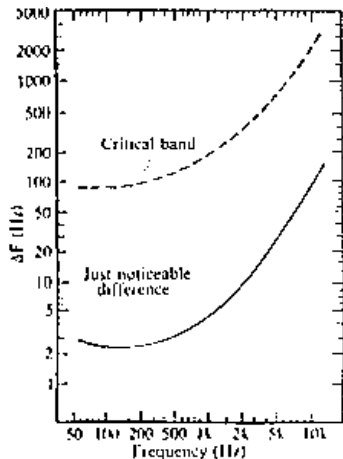
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- Time resolution $\approx 25ms$

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

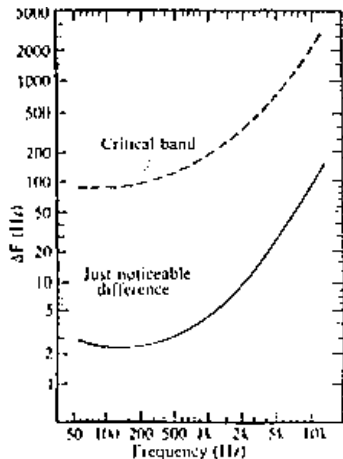
Hearing: Critical bands



- Sounds grouped in *critical bands* (CB)
- CB is around 30 times JND
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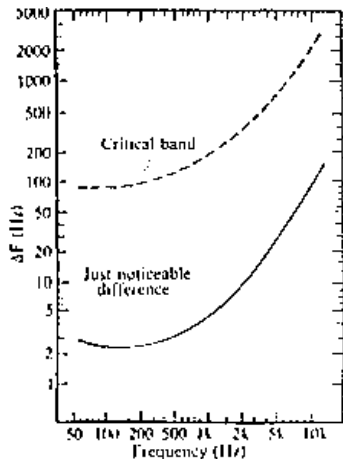
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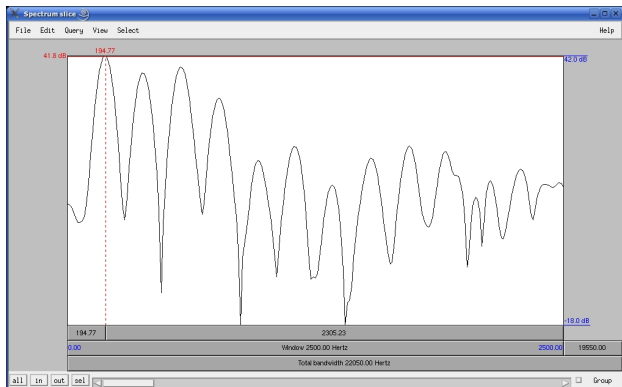
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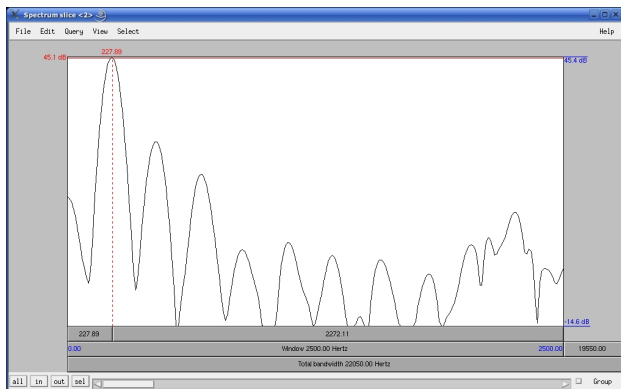
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Hearing: Example of /ε/



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/



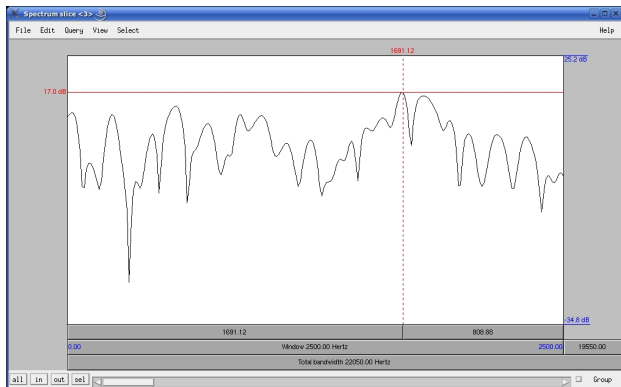
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Note the noisy structure and the broad bandwidth



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
- Just an order of magnitude estimation



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How much information is actually needed?

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



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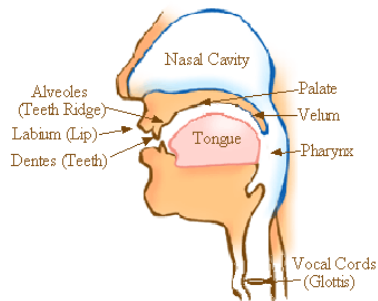
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Vocal tract and primary
articulators

- 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

Speaking: Articulators



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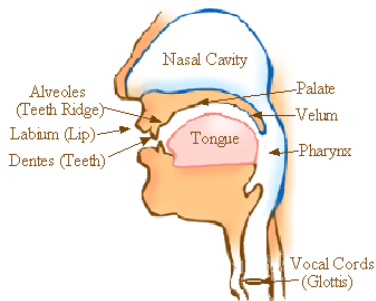
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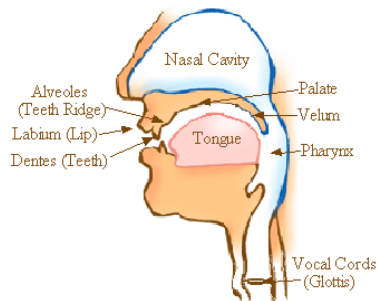


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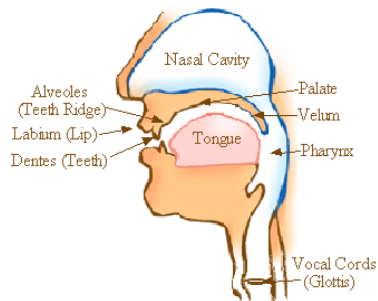


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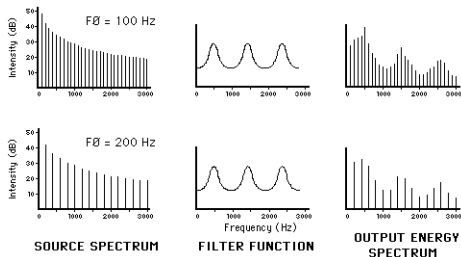
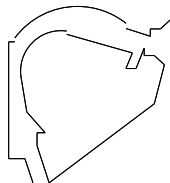


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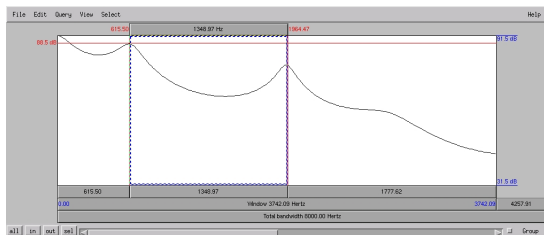
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Speaking: Source Filter model of speech



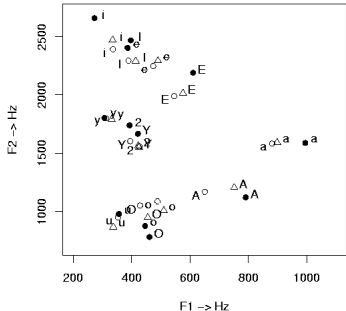
Sound enters the oral cavity (vocal tract) from below and is filtered by the resonances of the cavity

Speaking: Resonances and formants



Oral cavity filter function of / ϵ / (LPC model). Peaks are formants F_1 and F_2 .

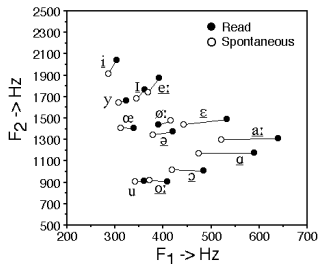
The resonances of the vocal tract are called Formants, and numbered from below, i.e., F_1 , F_2 , F_3 , \dots . Normally, the first three are sufficient to describe (voiced) speech.



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.

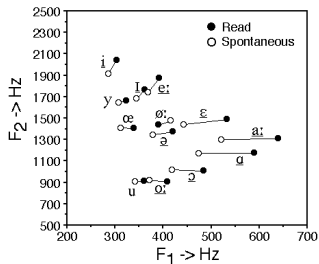
Speaking: Reduction



Articulation takes effort and humans are “lazy”

- Unimportant, unstressed, items are articulated “less well”
- Leads to less distinctive sound segments
- Visible as a smaller vowel triangle (see above)
- Also found in consonants

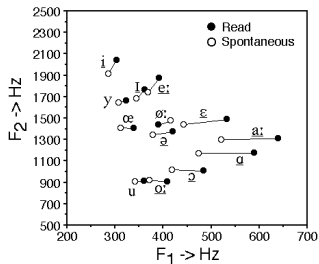
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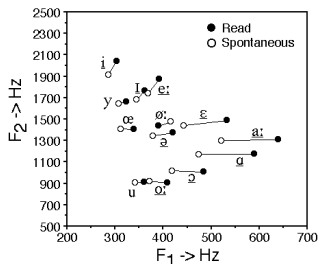
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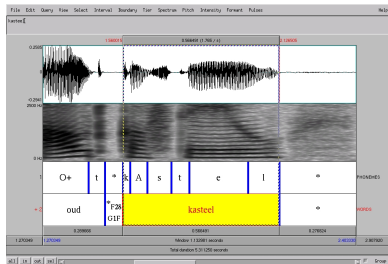
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Spectrograms



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

Spectrograms



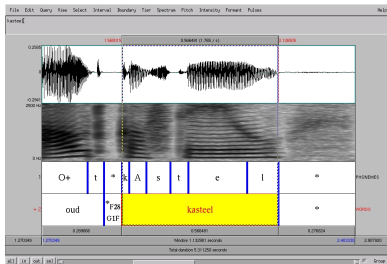
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Spectrograms: Narrow versus Wide band



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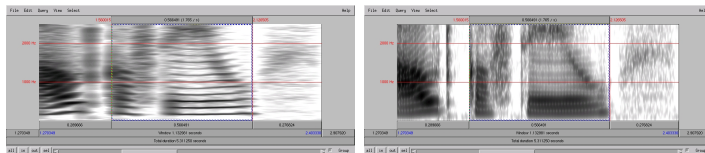
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Two views on spectrograms

- **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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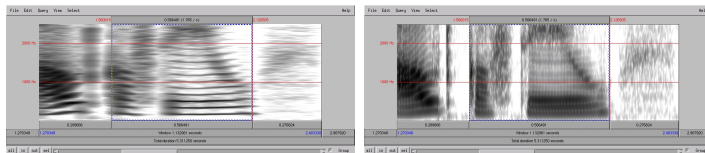
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Spectrograms: Formant and Pitch tracking



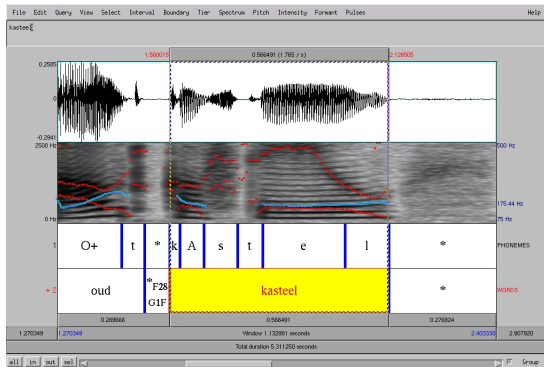
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Formants (red dots) and Pitch (blue line) can be automatically determined and plotted into a spectrogram.

Spectrograms: Noise and bursts



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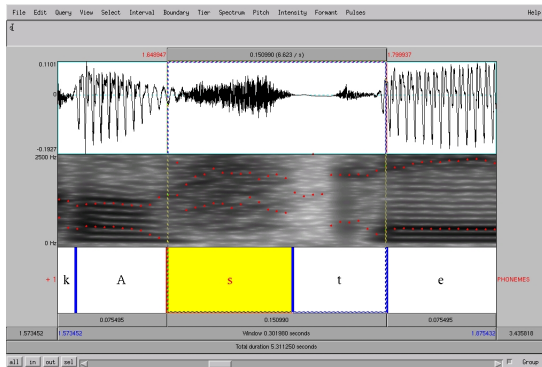
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Fricatives are visible as gray noise patches. Plosives as a silent part followed by a noisy burst.

Spectrograms: Spectrogram reading



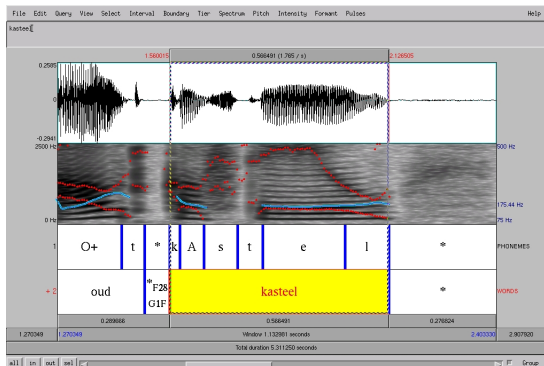
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It is actually possible, after a few weeks training, to read spectrograms. All the information needed to "understand" the speech is in the spectrogram [Lander and Carmell(1997)].

Corpora: Transliteration



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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

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Human annotator transcriptions: Difficult and expensive

- Accents, stress, and boundaries (always ambiguous)
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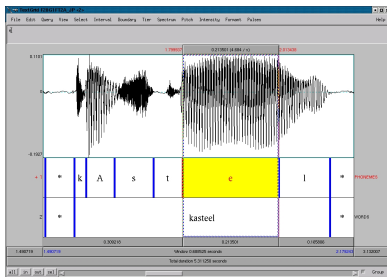
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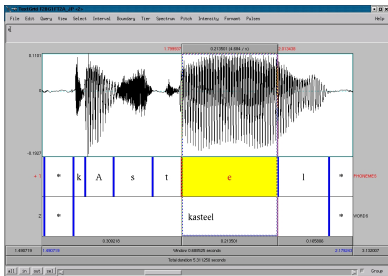
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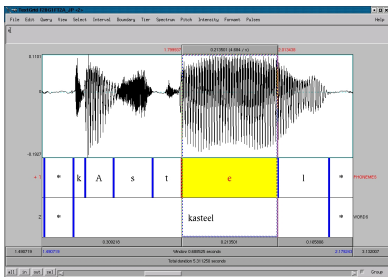
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- Phonemes always overlap and are extremely variable
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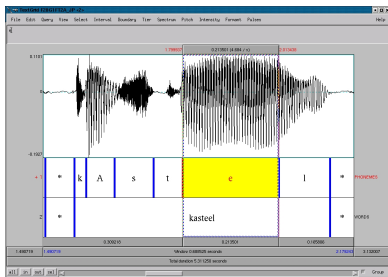
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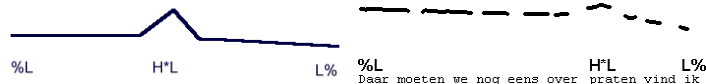
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ToDI symbols (IP: Intonational Phrase)

[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*



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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Corpora: for Speech and Language research



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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
- Transcriptions and annotations (cumulative): Added value of interpretations and analysis
- Storage, distribution, access, and software (volatile):
Practical use

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- Normalization (fixed): All items must adhere to certain guidelines
- Data (fixed): Immutable text or speech records
- Transcriptions and annotations (cumulative): Added value of interpretations and analysis
- Storage, distribution, access, and software (volatile):
Practical use

Corpora: for Speech and Language research



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

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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
- 9 million words
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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)
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