EE679: Speech Processing

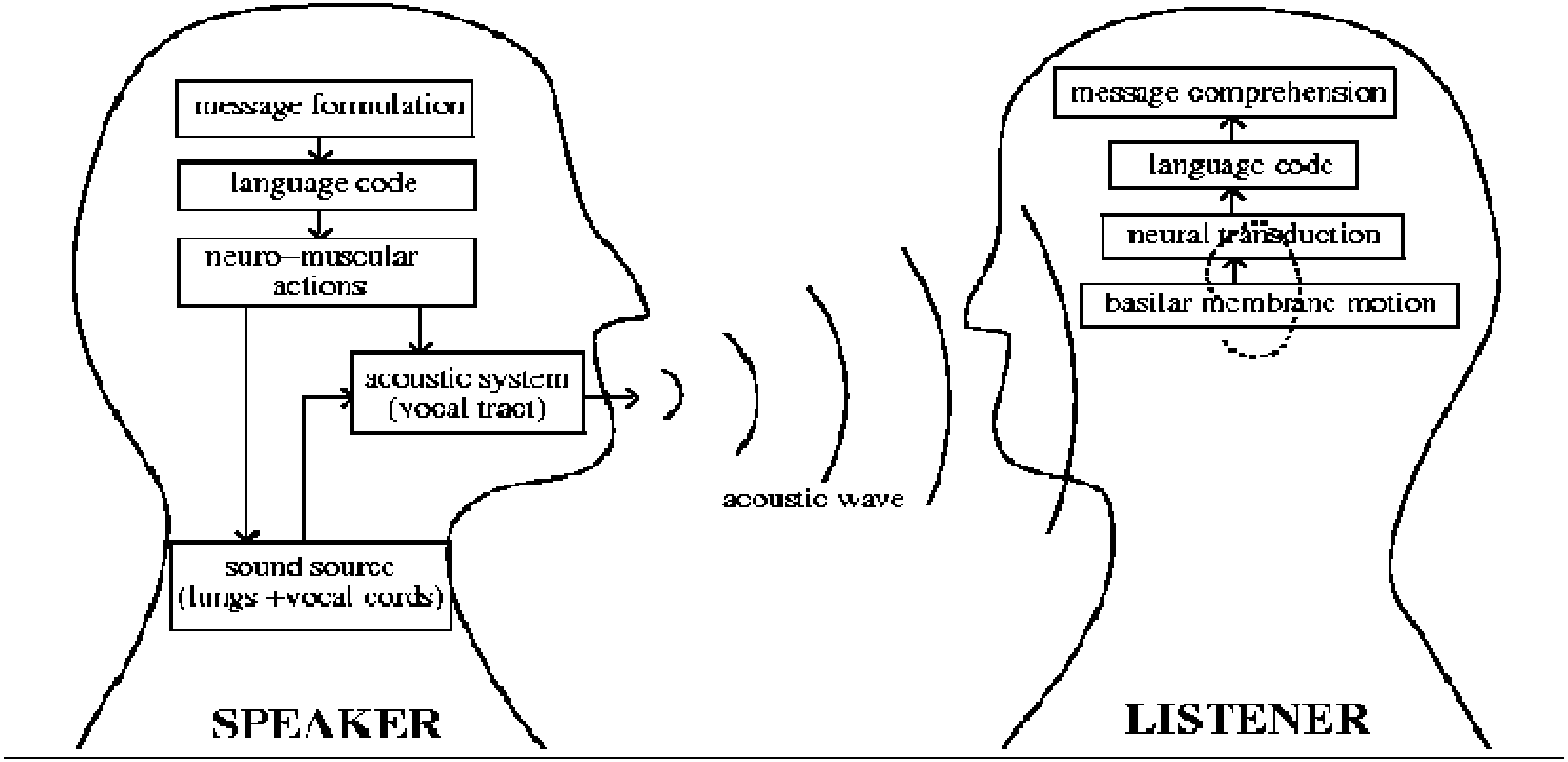
A preview

Dept of Electrical Engineering
I.I.T. Bombay

Outline

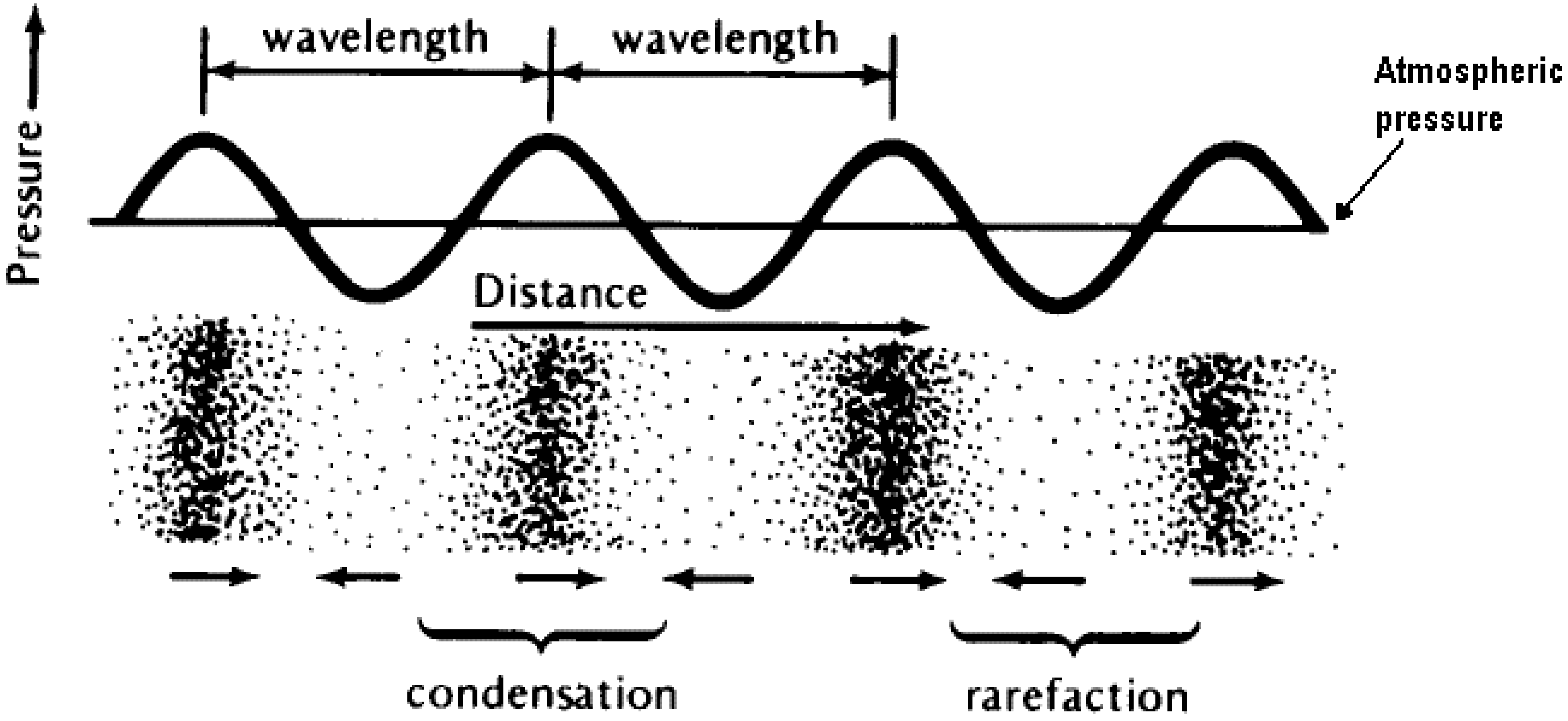
- Speech production (physiology)
- Classification of sounds: articulatory, acoustic
- Speech analysis (signal processing methods for information extraction)
- Hearing, and speech perception
- Speech technology (speech compression, ASR,TTS)
- Audio/music technology

Speech communication



Acoustic waves

Speed = wavelength x frequency



Information in speech

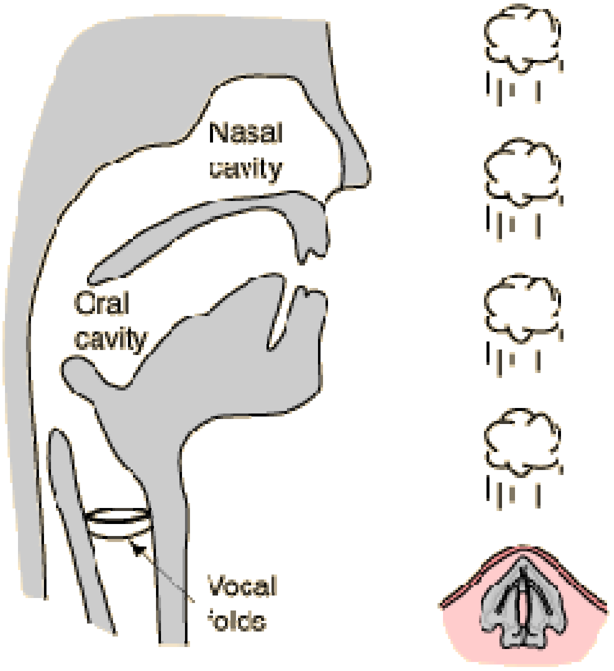
- Linguistic (phone->word->sentence->message)
- Paralinguistic:

  --speaker-based (pronunciation, age, sex,etc.),

  --expressive (emotions, mood)

The speech signal is characterised by an enormous range of perceptually contrasting sounds!

Generating speech*

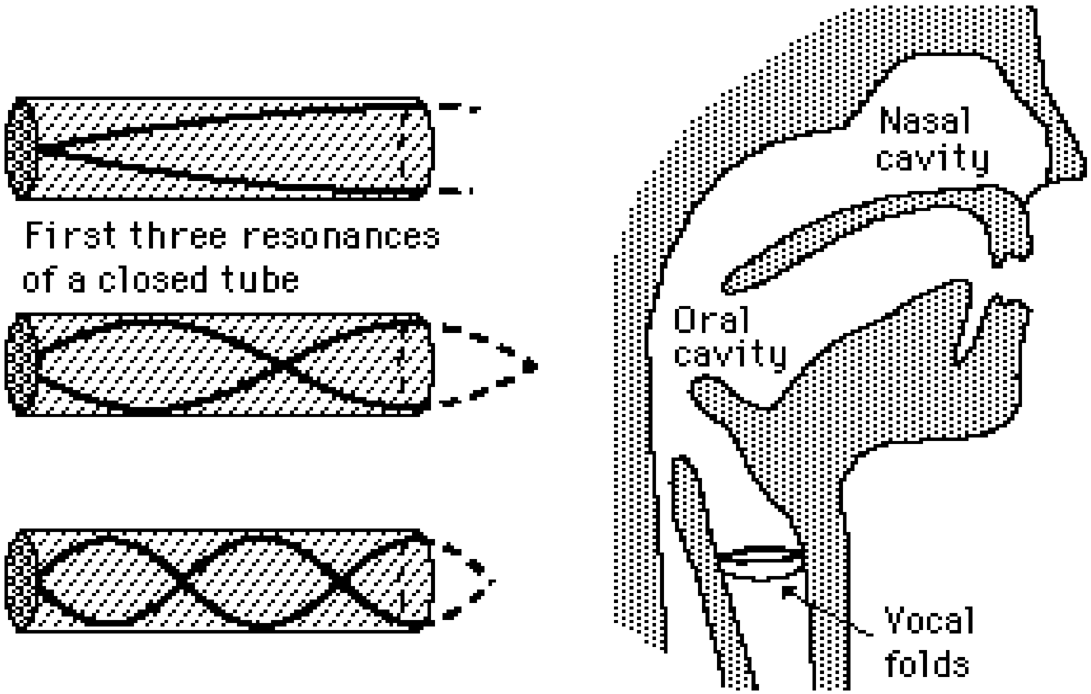


Respiration->**phonation** ->articulation

Vibrating vocal cords create puffs of air giving rise to *air pressure variations* which reach our ears.

**HyperPhysics, Sound and Hearing, Georgia State University*

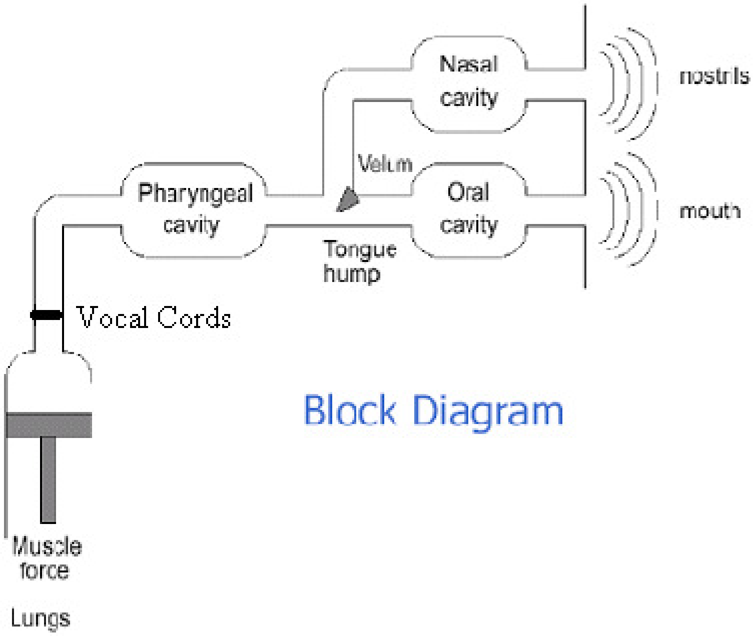
Vocal tract: Acoustic resonances*

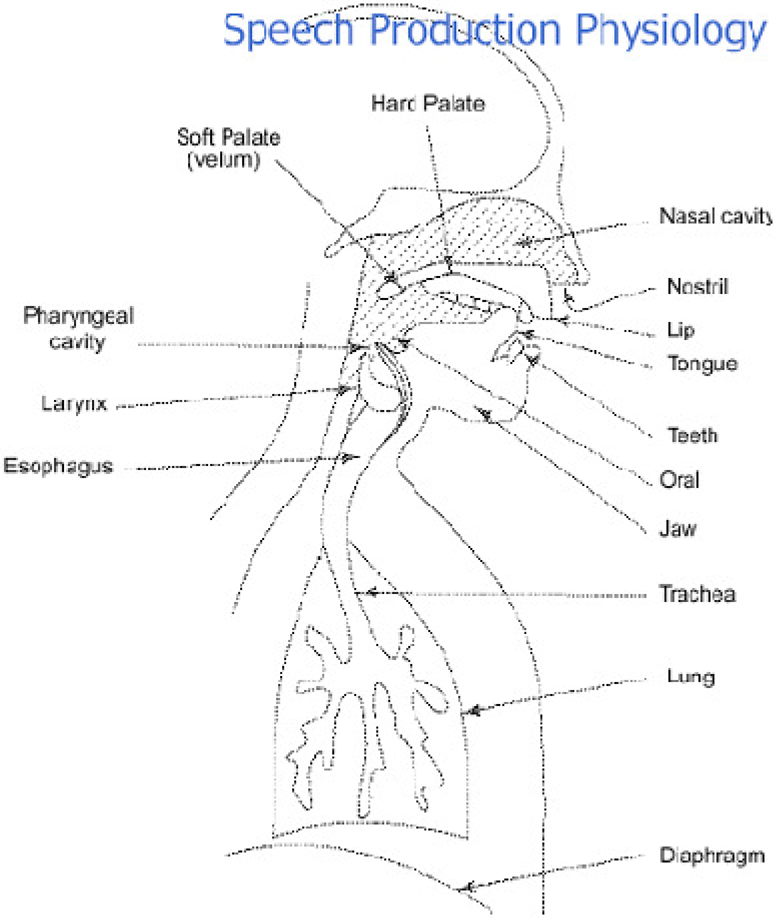


$$f_1 = \frac{c}{4L} \quad ; \quad f_2 = \frac{3c}{4L}; \quad f_3 = \frac{5c}{4L} \; ; \; \ldots\ldots$$

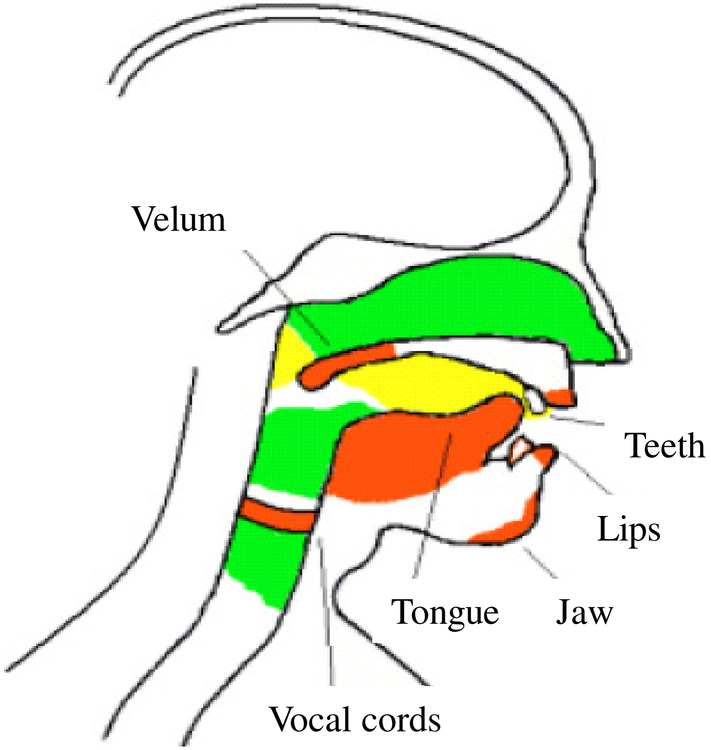
*<u>*HyperPhysics, Sound and Hearing, Georgia State University*</u>* *(http://hyperphysics.phy-astr.gsu.edu/hbase/sound/)*

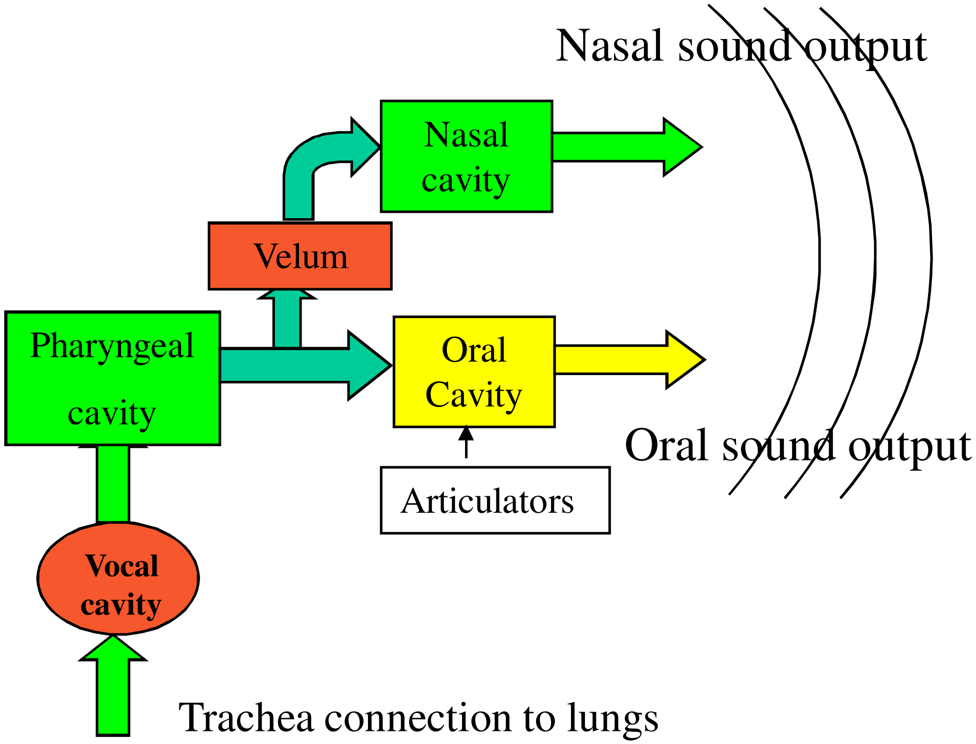
Speech production (Childers, Speech Overview, 1993)


Block Diagram


Speech Production Physiology

Articulation: producing the *various sounds* of speech*





🟥 Moving muscles which alter the resonant cavities

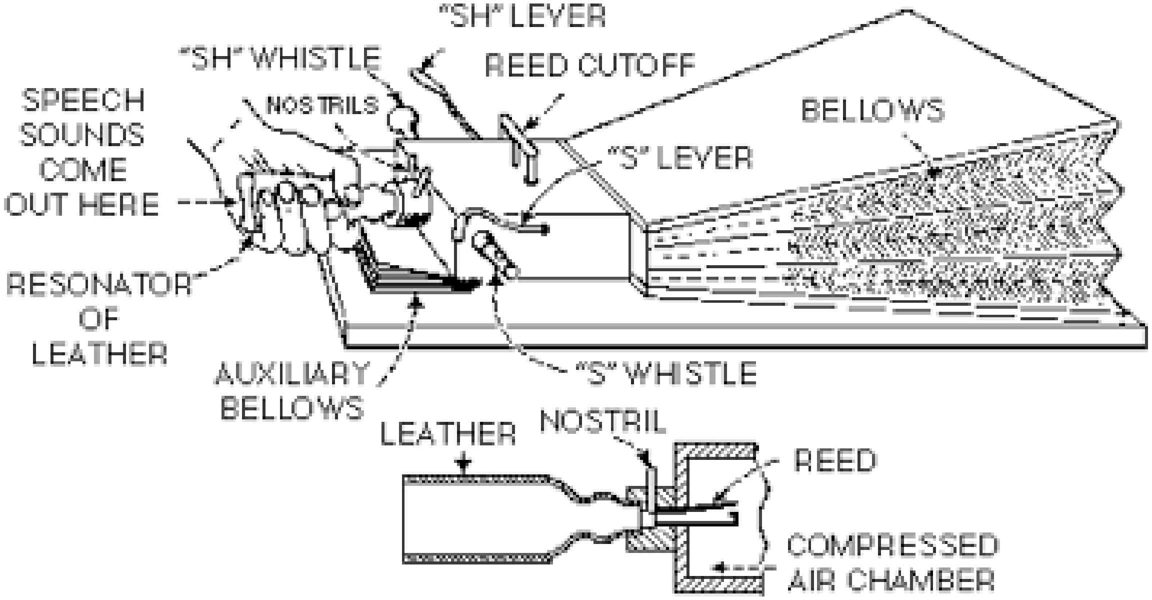
🟨 Dynamic cavity

🟩 Static cavity

***Securivox tutorial**

Von Kempelen's talking machine

1791



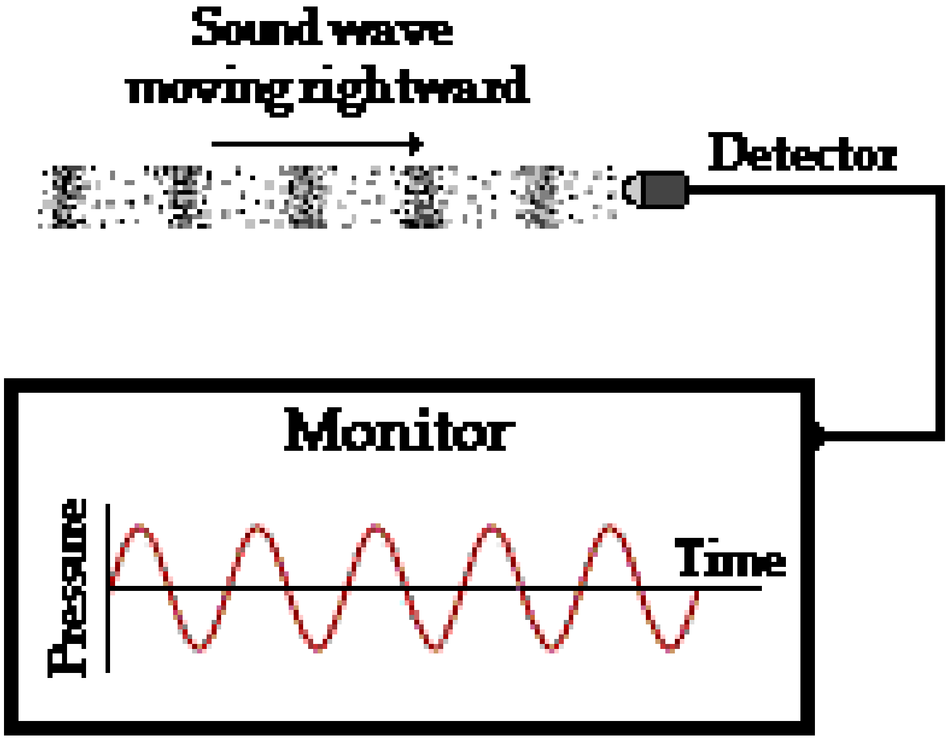
1875

- Alexander Bell invents the method of, and apparatus for, “transmitting vocal or other sounds telegraphically ... by causing electrical undulations, similar in form to the vibrations of the air accompanying the said vocal or other sound”.

=> Major impetus to modern speech processing.

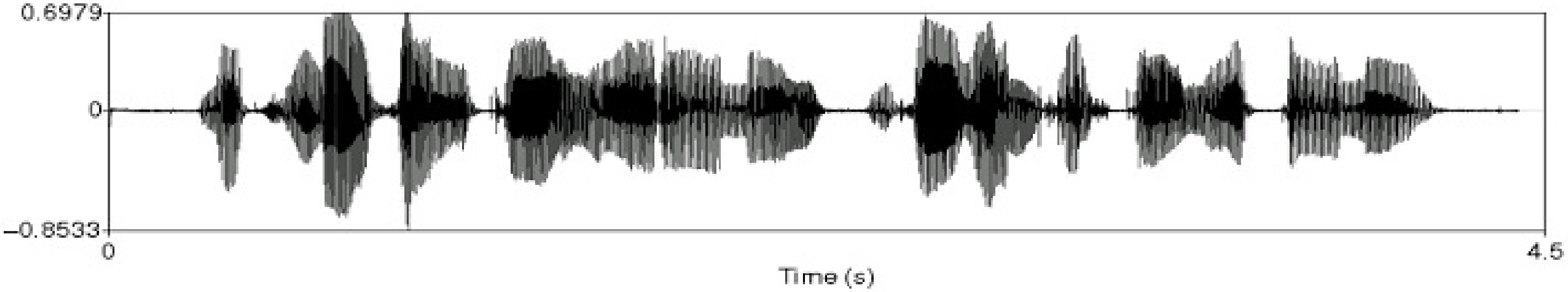
- 1930s: Electrical synthesis of speech by Dudley’s vocoder

Sound -> electrical form*



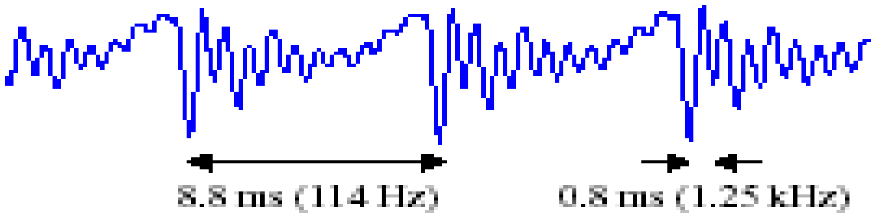
*The Physics Classroom:http://www.glenbrook.k12.il.us/gbssci/phys/Class/sound/u11l2a.html

Speech “waveform”

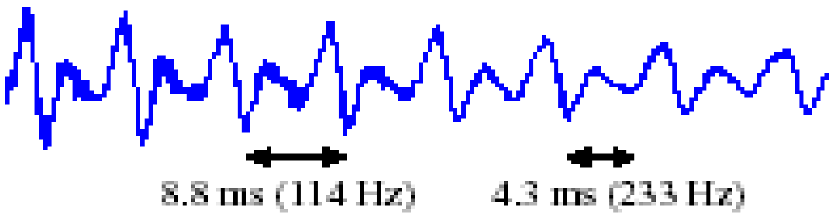


Speech Waveforms from “my speech”

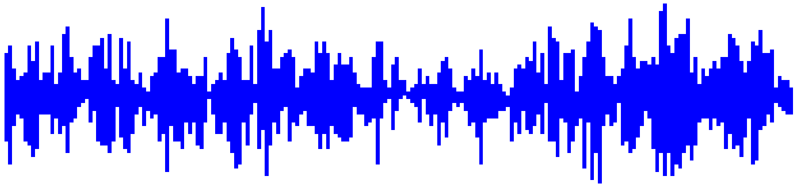
(a) start of “y” vowel



(b) “ee” vowel



(c) “s” consonant



Components of sound

A sound is usually comprised of *several* frequency components.

Depending on the relationships of the frequency components, the sound can elicit a sensation of pitch.

Speech production

- **Vocal cords** (larynx) modulate the airflow from the lungs by rapid opening-closing; the *rate of vibration* is determined by their mass and tension.

  Pitch frequency ranges:

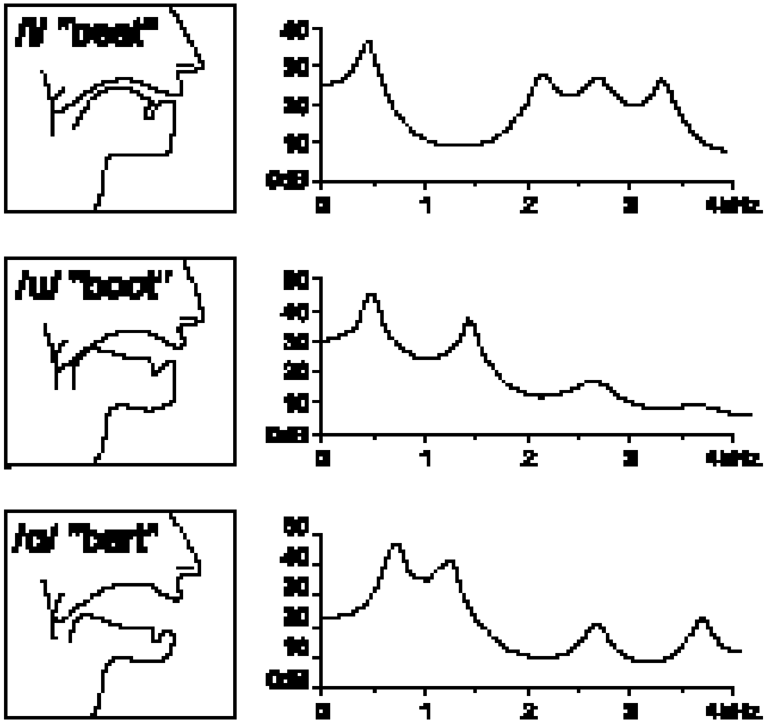
  male: 80-160 Hz; female:160-320 Hz;

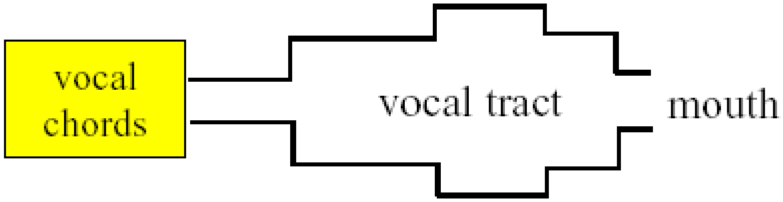
  singers: over 2 octaves.

- **Vocal tract** shapes the vocal cord vibrations into the intricate sounds of speech via *changes in shape* to produce various *acoustic resonances*.

Vocal tract “filter”*

- The sound spectrum is modified by the shape of the vocal tract.
- The resonant frequencies of the vocal tract cause peaks in the spectrum called *formants*.





*Childers, Speech Overview

Most important aspects of speech…

- The intelligence in speech is encoded in the *power spectrum* of the acoustic pressure wave.

- Different articulatory configurations result in signals with different spectra, esp. different resonance frequencies called formants, which are perceived as different sounds.

- The different spectra make up the finite alphabet of symbols (linguistic code) governed by a hierarchy of linguistic rules.

Basic sounds of speech: Phones

- The speech signal can be divided into sound segments with *fixed articulation and acoustics over short intervals.*

  i.e. articulatory configuration <=> acoustic properties

Smallest meaningful sound unit: "***phone***"

(i.e. set of distinctive sounds of a language)

In Indian written scripts, one symbol represents one phone.

Classification of speech sounds

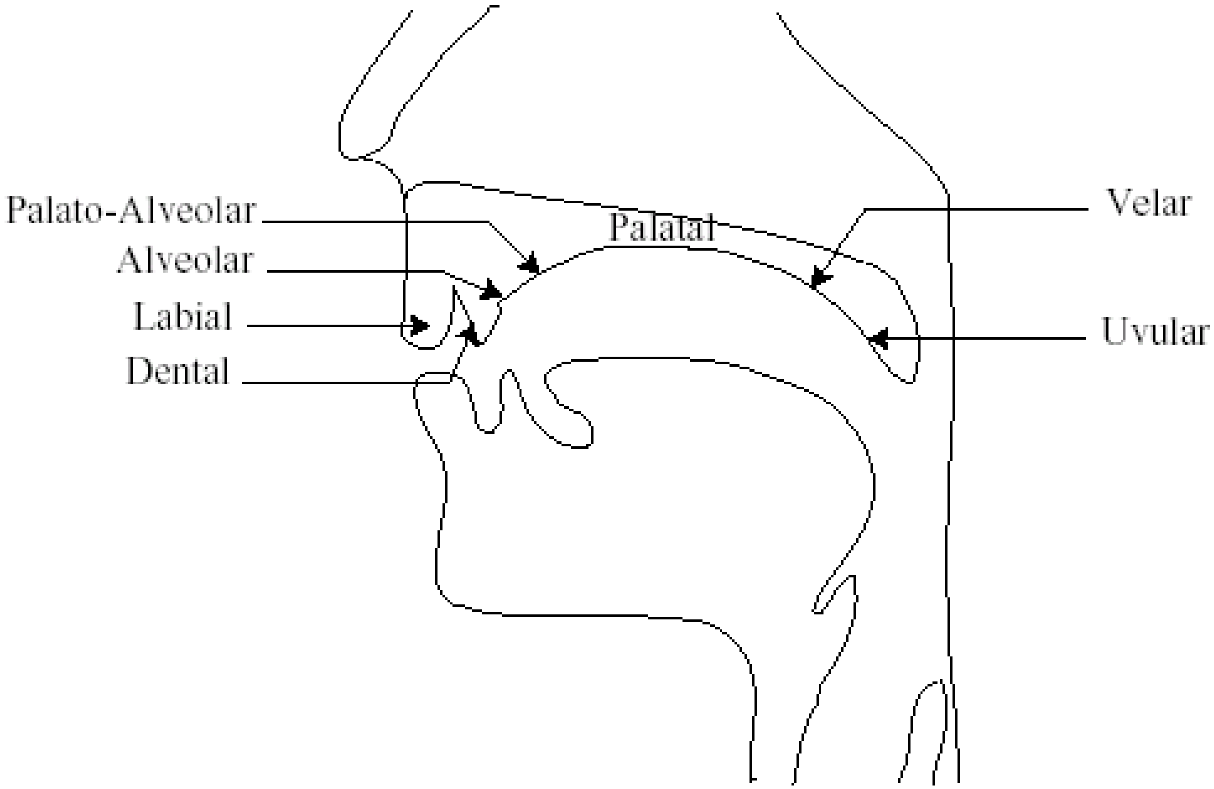
Vowels and Consonants

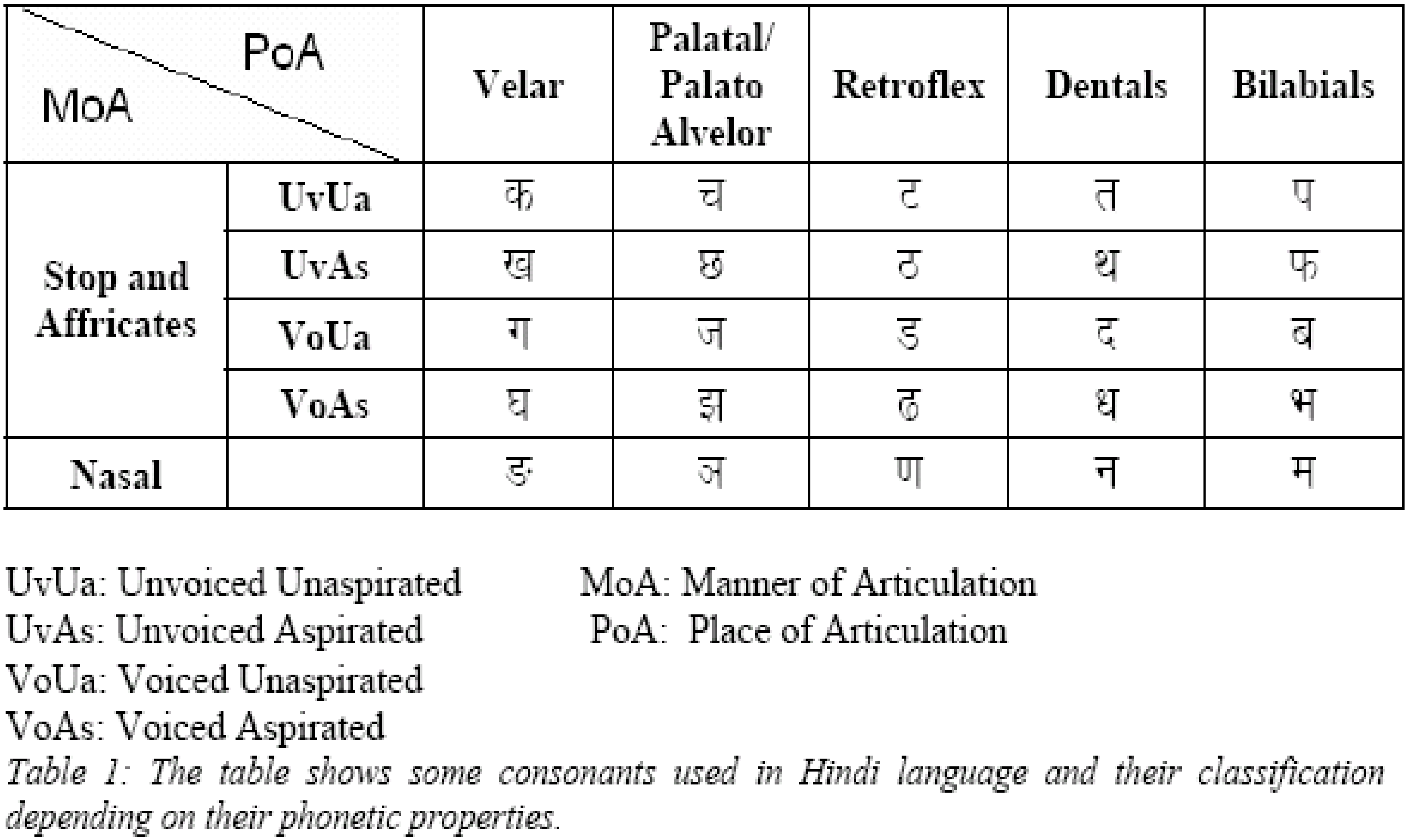
- Vowels: steady sounds specified by position of the articulators (typically, tongue)

- Consonants: are (dynamic) sounds classified by **place** and **manner** of articulation

Place of articulation

(*constriction of vocal tract*)





PoA MoA		Velar	Palatal/ Palato Alvelor	Retroflex	Dentals	Bilabials
Stop and Affricates	UvUa	क	च	ट	त	प
	UvAs	ख	छ	ठ	थ	फ
	VoUa	ग	ज	ड	द	ब
	VoAs	घ	झ	ढ	ध	भ
Nasal		ङ	ञ	ण	न	म

UvUa: Unvoiced Unaspirated	MoA: Manner of Articulation
UvAs: Unvoiced Aspirated	PoA: Place of Articulation
VoUa: Voiced Unaspirated	
VoAs: Voiced Aspirated	

Table 1: The table shows some consonants used in Hindi language and their classification depending on their phonetic properties.

“Decoding” the speech signal: visible speech

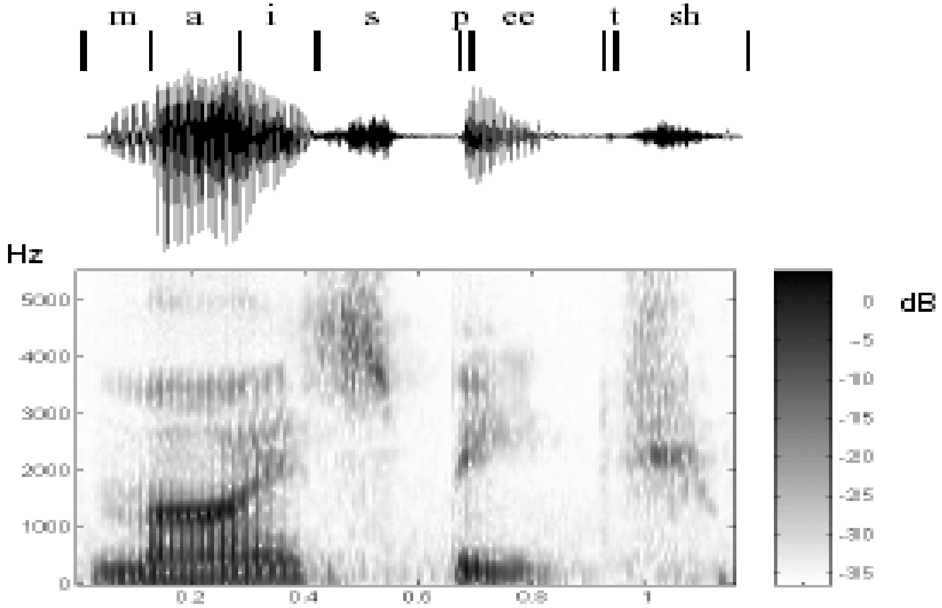
Dark areas of *spectrogram* show high intensity

– Voiced segments are much louder than unvoiced

– Horizontal dark bands are the formant peaks

– “s” has high frequency content
– Vertical bands are individual larynx closures
– The “y” of “my” is a diphthong: two successive vowels

“my speech”



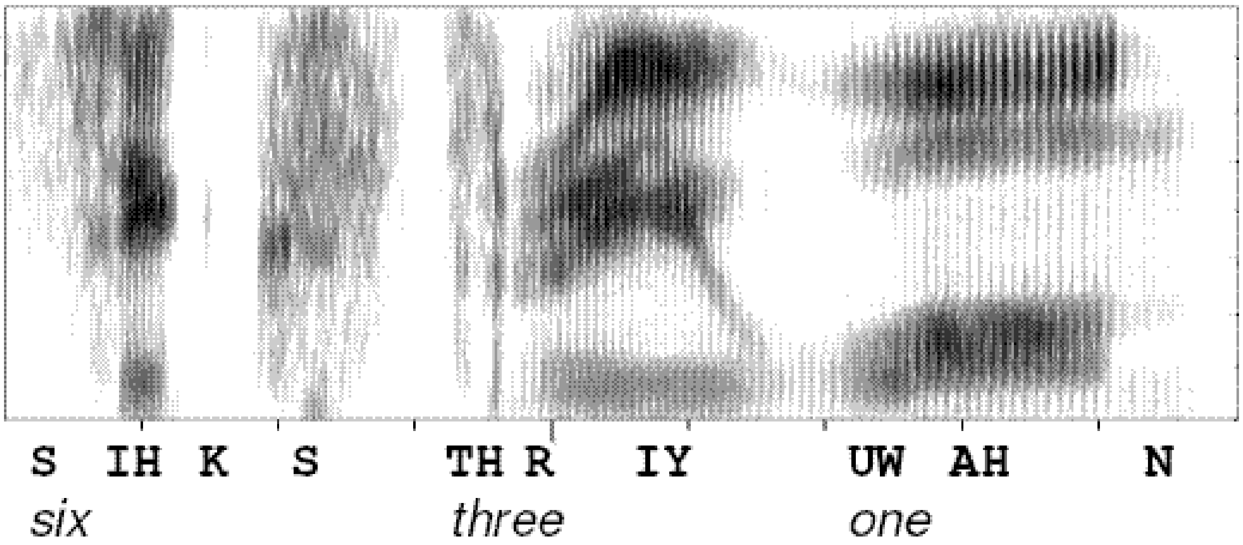
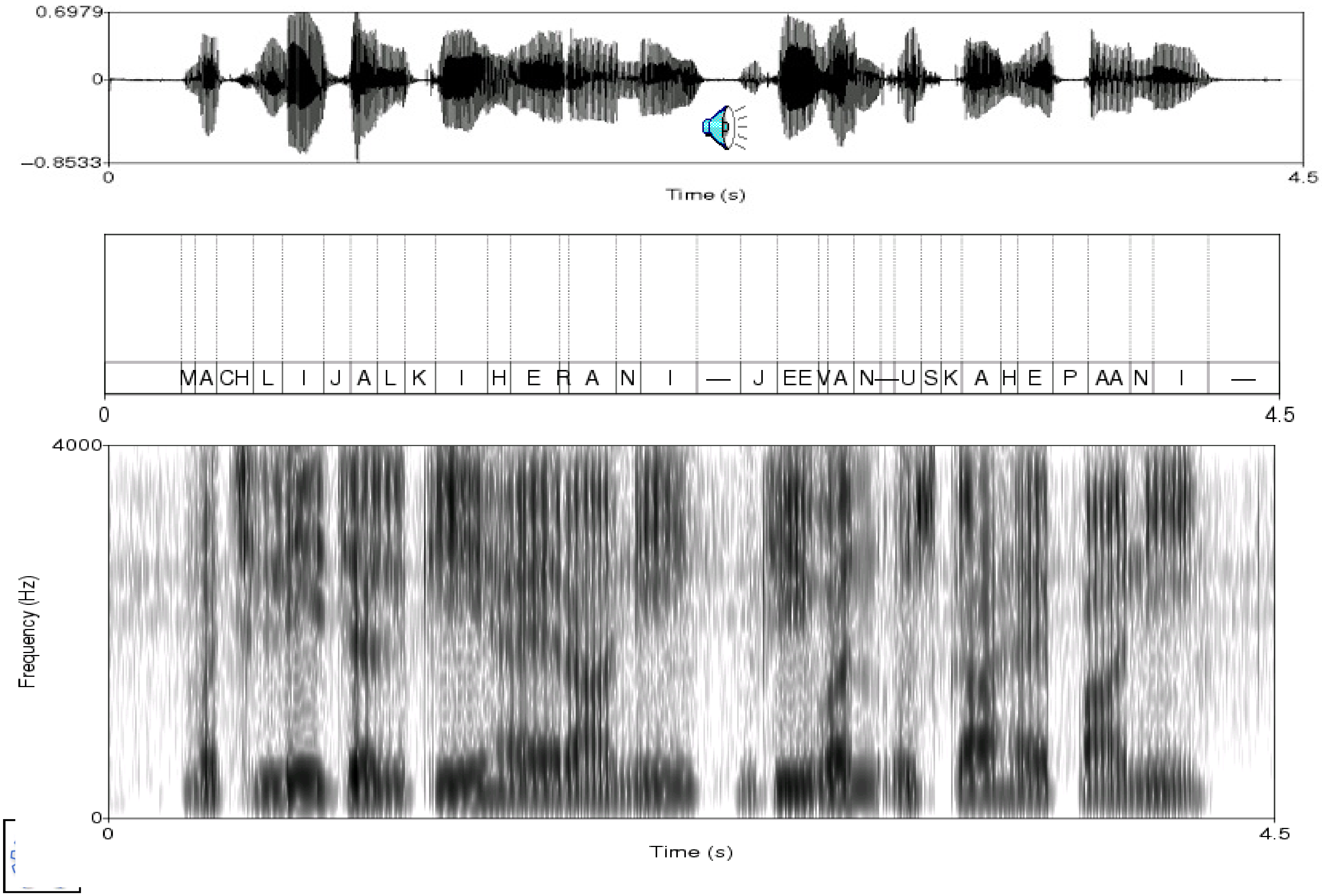
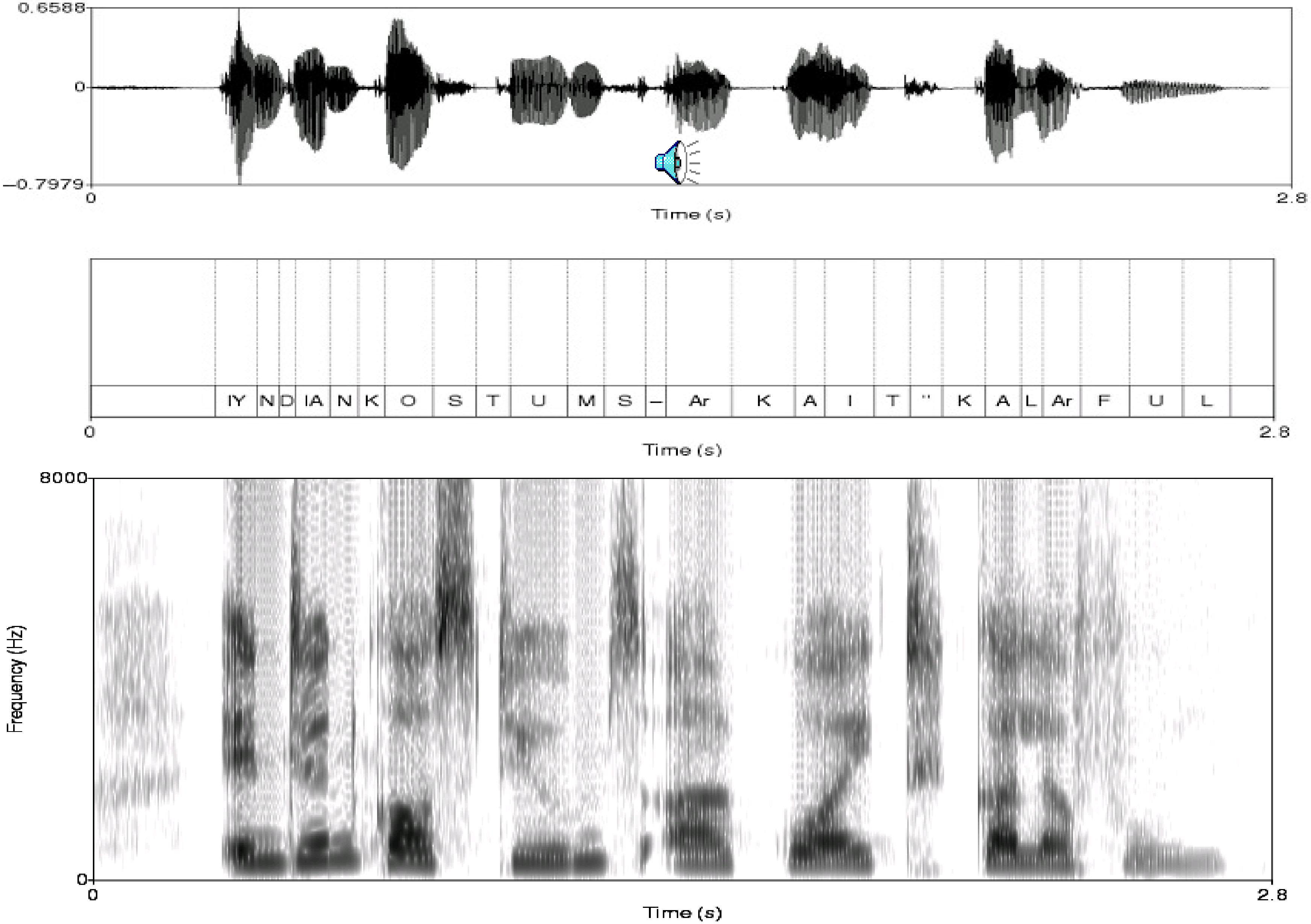


Figure 1: Speech spectral characteristics

Machli jal ki hai raani   jeevan uska he paani



Indian costumes are quite colourful

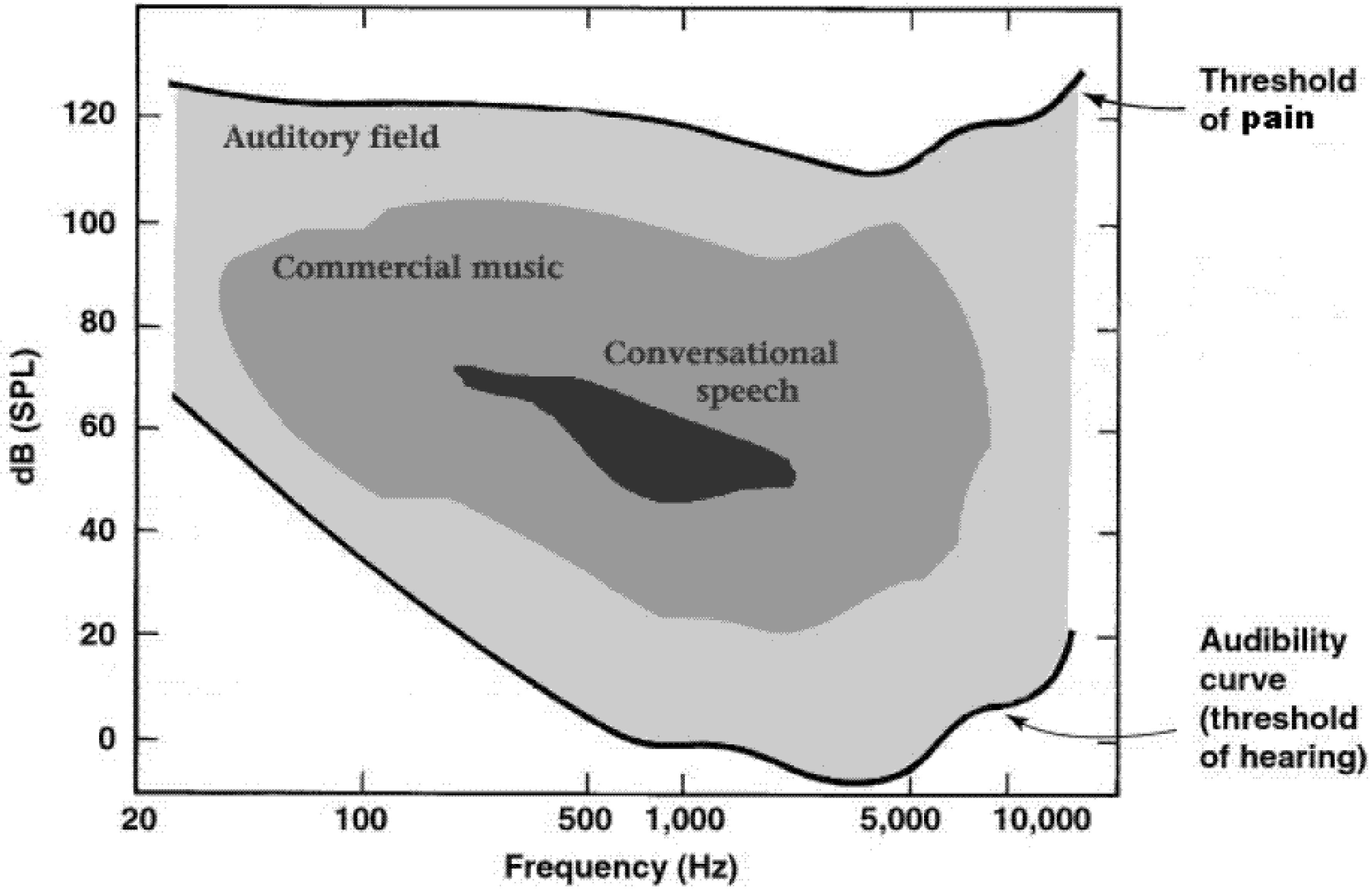


Speech perception

Distinct stages of physiological processing
in the auditory system:

Peripheral auditory system	(Ears)	← analysis
Auditory nervous system	(Brain)	←synthesis

Audible sound



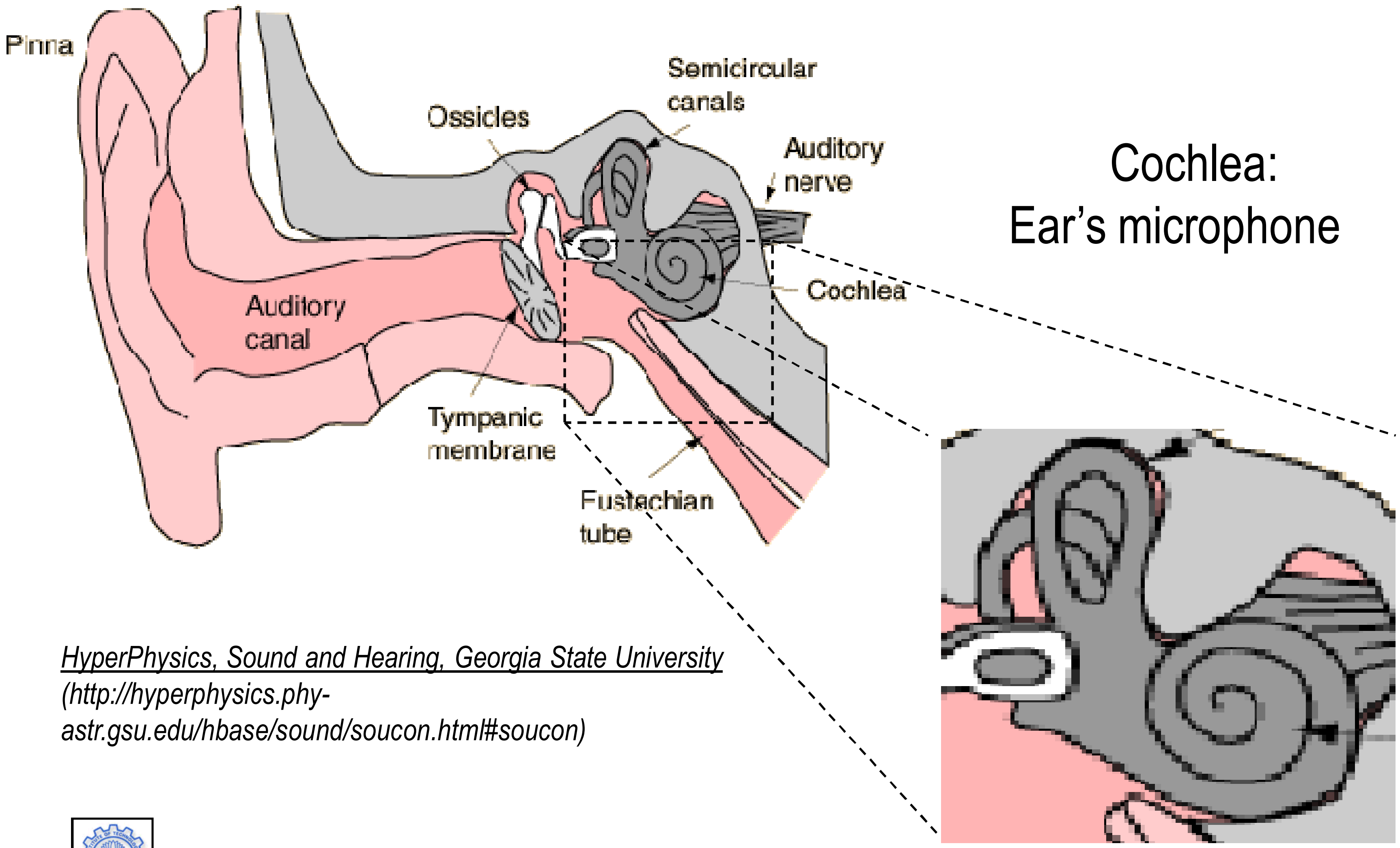
Sound and Sensation

A sound of given frequency components and sound pressure levels leads to perceived sensations that can be distinguished in terms of:

- ***loudness*** *<-- intensity*
- ***pitch*** *<-- fundamental frequency*
- ***timbre ("quality" or "colour")***

  <--ther spectro-temporal properties

Our auditory apparatus



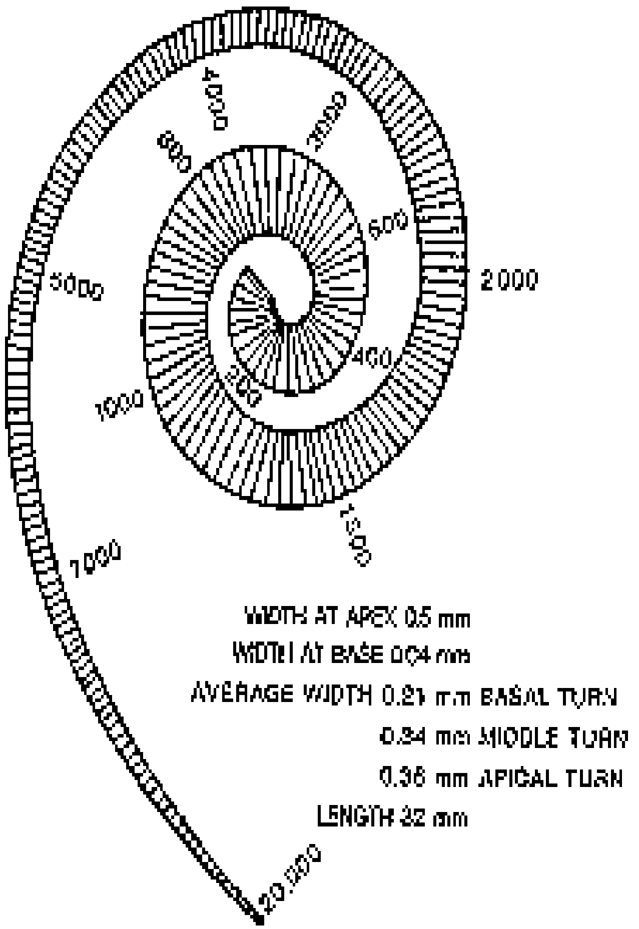
Cochlea:
Ear’s microphone

HyperPhysics, Sound and Hearing, Georgia State University
(http://hyperphysics.phy-astr.gsu.edu/hbase/sound/soucon.html#soucon)

Basilar Membrane
Location-dependent frequency “resonance”

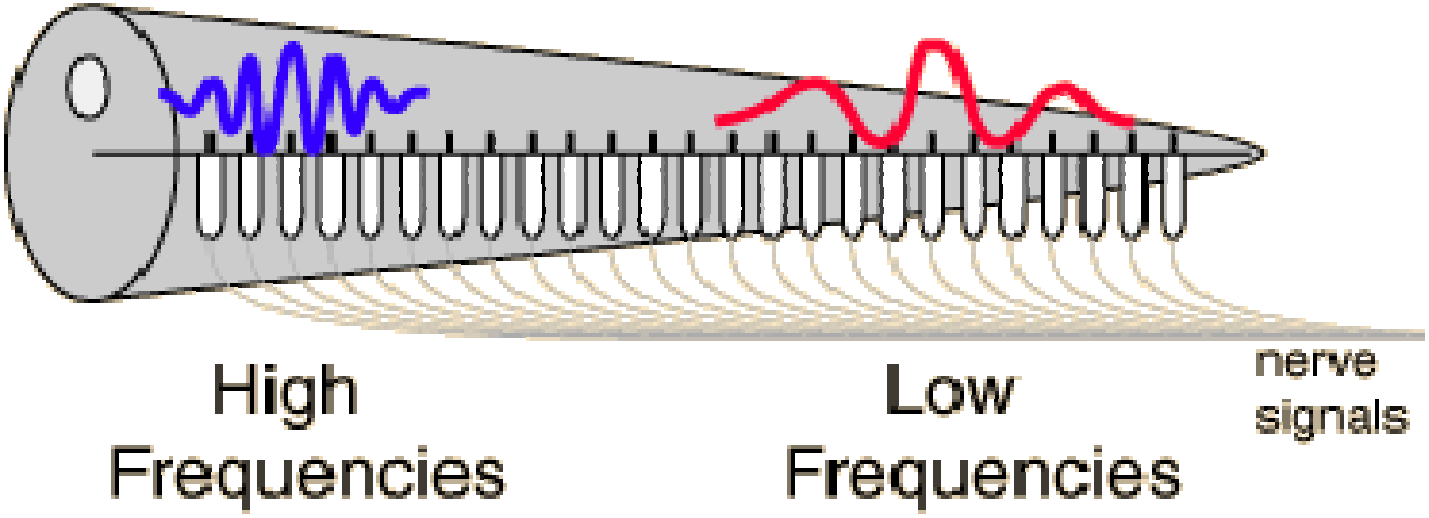
- Thickness and tension vary along its length

- Traveling wave has maximum vibration amplitude at a location depending on its frequency



Basilar Membrane

Frequency-to-place transformation (Fourier analysis)



HyperPhysics, Sound and Hearing, Georgia State University (http://hyperphysics.phy-astr.gsu.edu/hbase/sound/soucon.html#soucon)

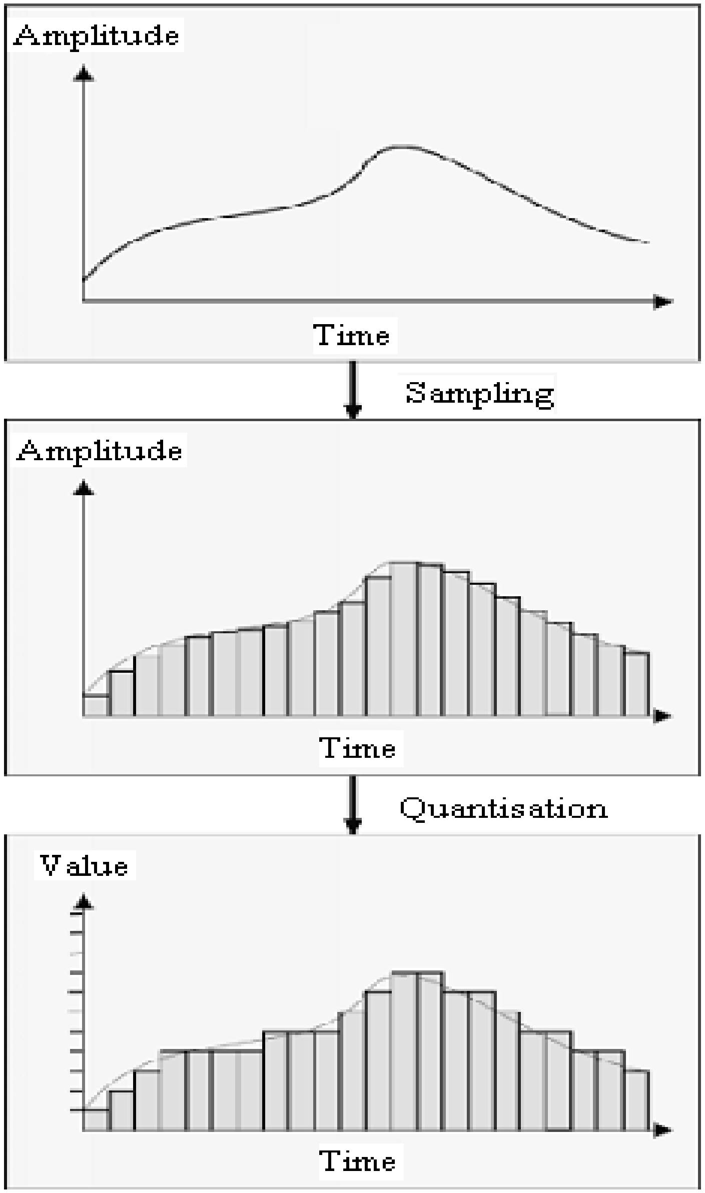
Applications

- Automatic speech recognition/ understanding
- Text-to-speech synthesis
- Speaker verification (biometric)
- Digital storage/transmission of speech
- Aids to the handicapped
- Enhancement of quality

Transmission/storage

Waveform coding:

distortion vs bit rate

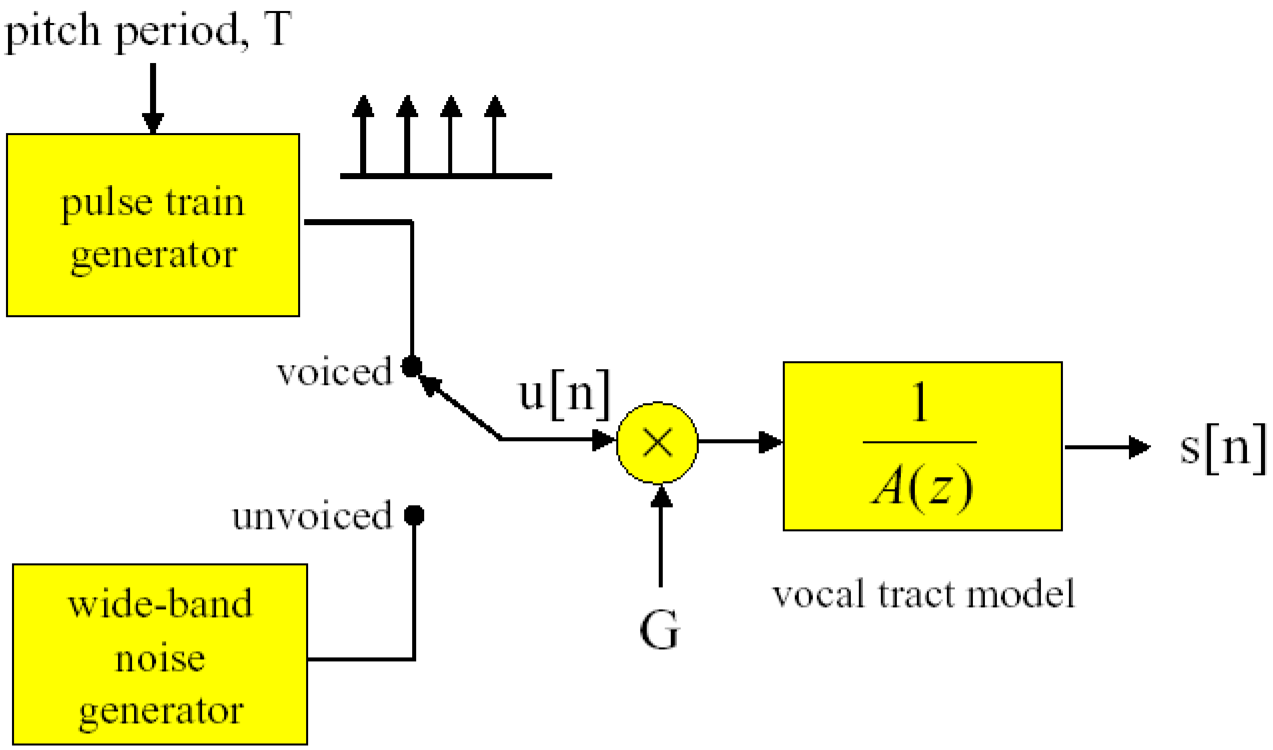


What distortion is "acceptable" depends on the application and on human perception.

Digital audio bit rates: Waveform coding

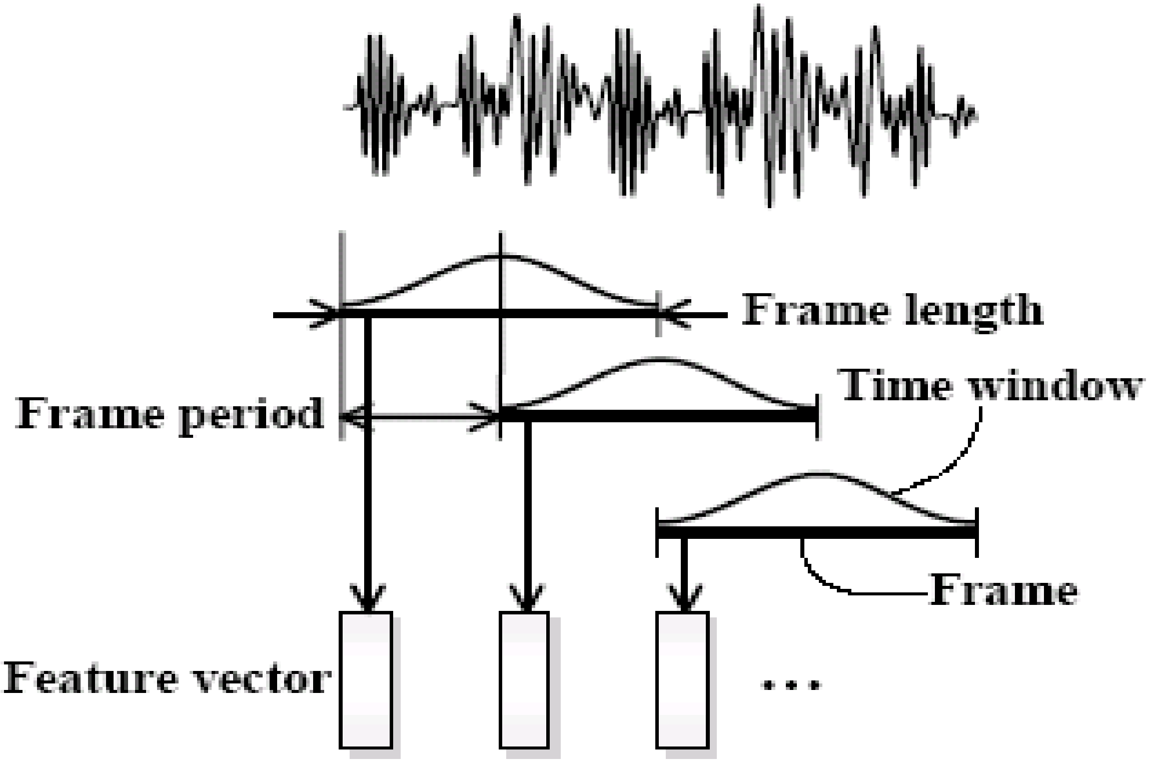
Format	Sample Rate (kHz)	Bits/sample
Telephony	**8**	**12** (=> 96 kbps)
Wideband audio	**16**	**16**
Hi-fidelity audio	**44.1**	**16**

Source-filter model parameters



Pitch and vocal tract shape vary slowly in time

Frame-based coding of speech



Feature vector (short-time spectrum) extraction from speech

Automatic speech recognition

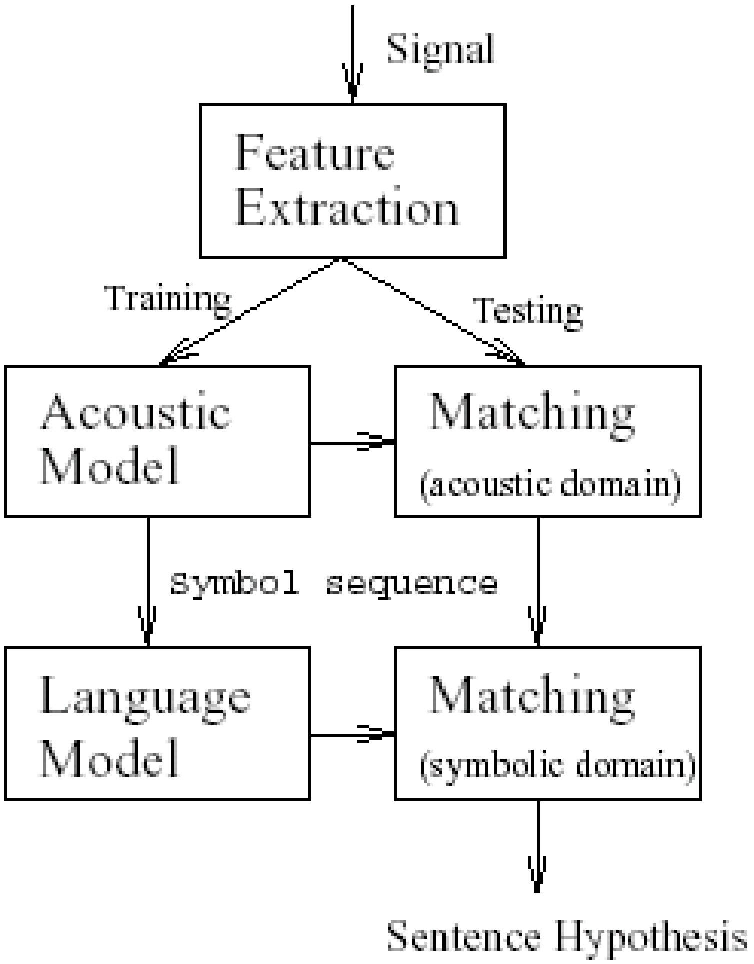
- To extract the linguistic code (a *structured sequence of discrete symbols*) from an ***analysis of the acoustic speech signal***.

- That is, continuous, noisy measurements of a non-stationary function of time only are available.

Automatic speech recognition

- Feature calculation (to a more distinctive domain)
- Pattern classification with respect to previously trained models of phones/words
- Improved transcription based on language model

ASR: block diagram*



**K.Samudravijaya, A Tutorial on Speech and Speaker Recognition*

ASR: Challenges

- Inter- and intra-speaker variations
- Effects of coarticulation in continuous speech
- Background noise and variable channels

Categories of speech recognition tasks

Human to machine:

- Database query/ information retrieval
- Dictation

Human to human:

- Broadcast news
- Lectures
- Voice mail
- Meeting
- Telephone conversation

Speaker recognition
(*voice-based biometric)*

- The voice signal is considered relatively easy to acquire/collect.
- Speech enables an (indirect) measurement of physiological features (i.e. characteristics of the speaker's *voice production system*).

- Applications:

  Commercial (access control, segmentation)

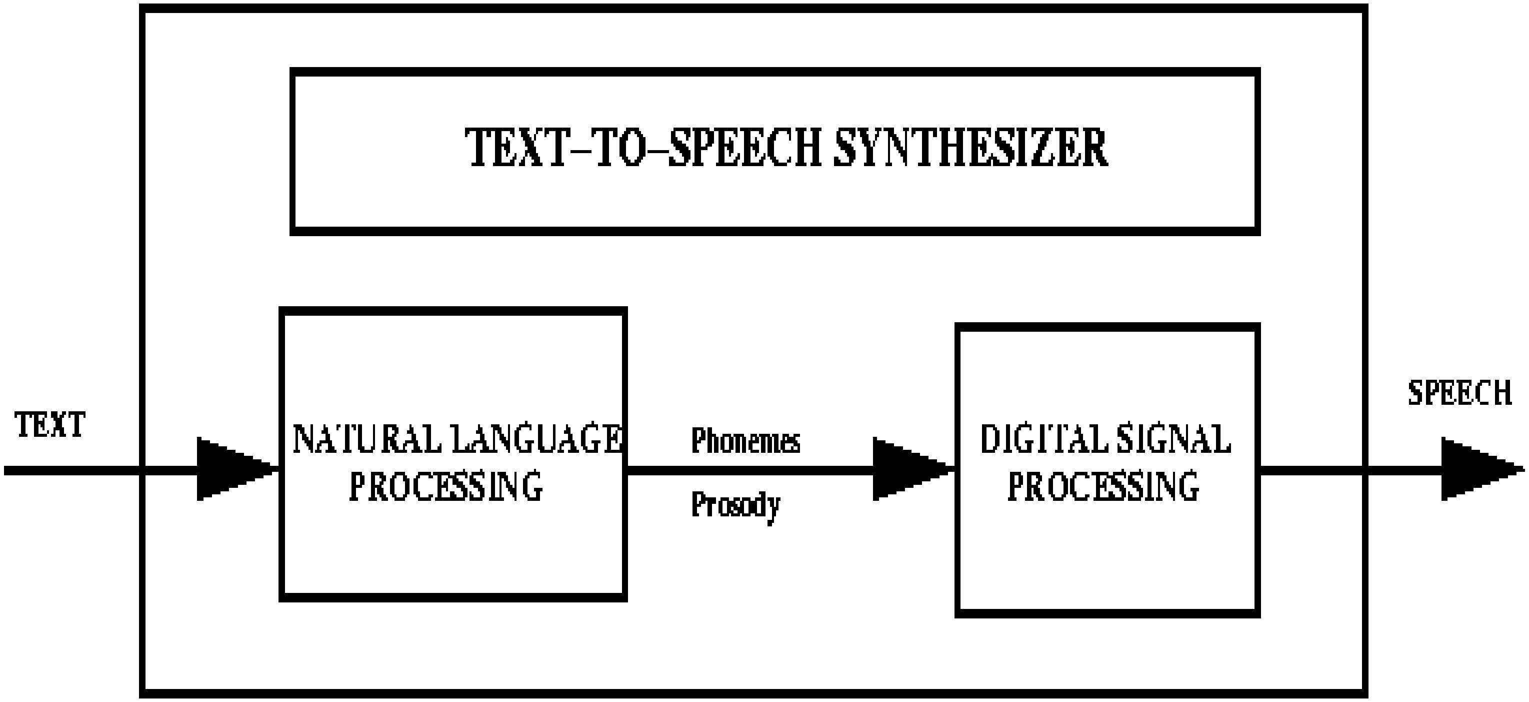
  Military, Forensic

Speech Synthesis

What: To convert a text string into a speech waveform

Why: For technology to communicate when a display would be inconvenient.

Basic TTS System


TEXT-TO-SPEECH SYNTHESIZER
TEXT
NATURAL LANGUAGE PROCESSING
Phonemes
Prosody
DIGITAL SIGNAL PROCESSING
SPEECH

Prosody => A phone is *long*/*short*, *loud*/*soft*, *high*/*low-pitched*

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- Audio/music technology

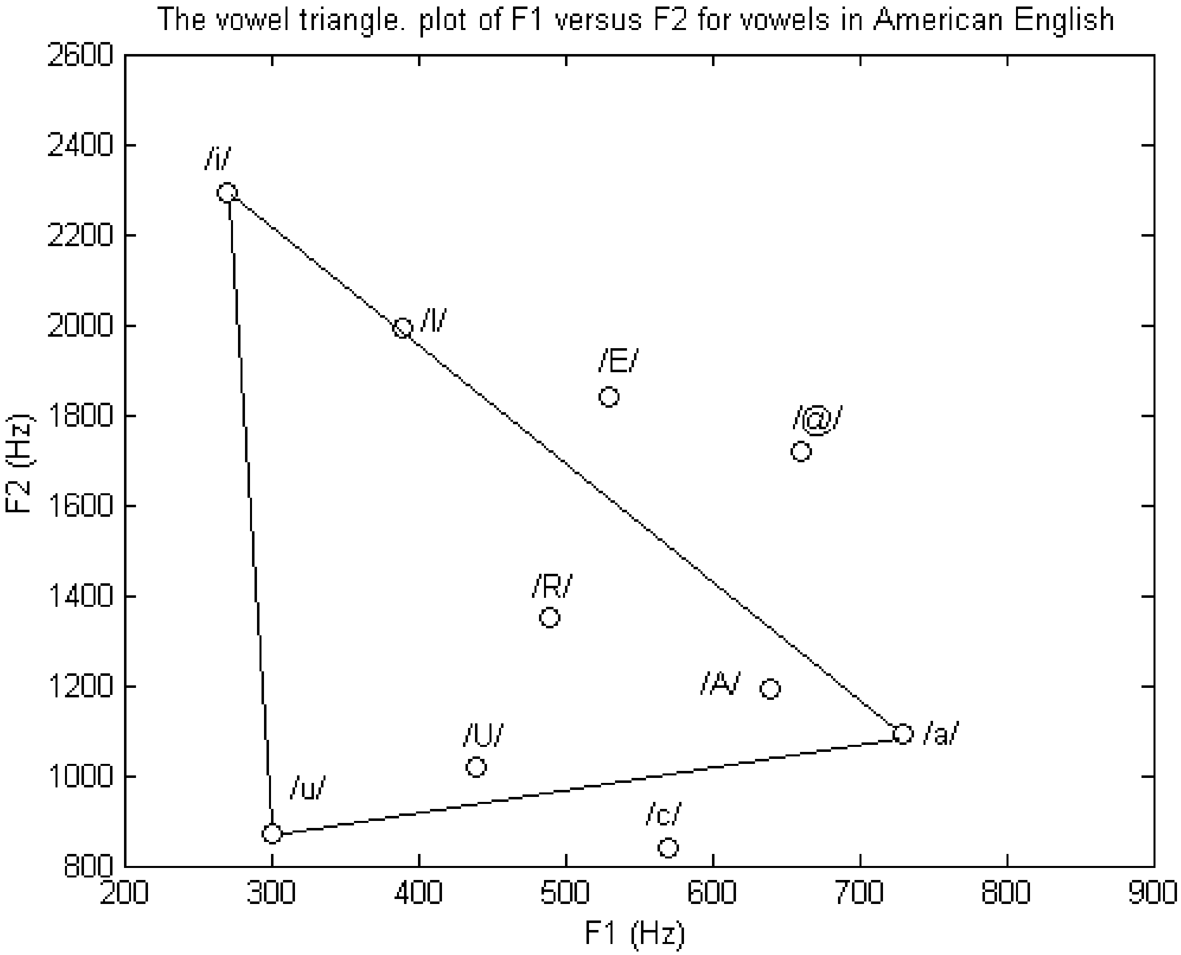
Text / References

- Douglas O'Shaughnessy, Speech Communications: Human and Machine, Universities Press (India) Ltd., 2001

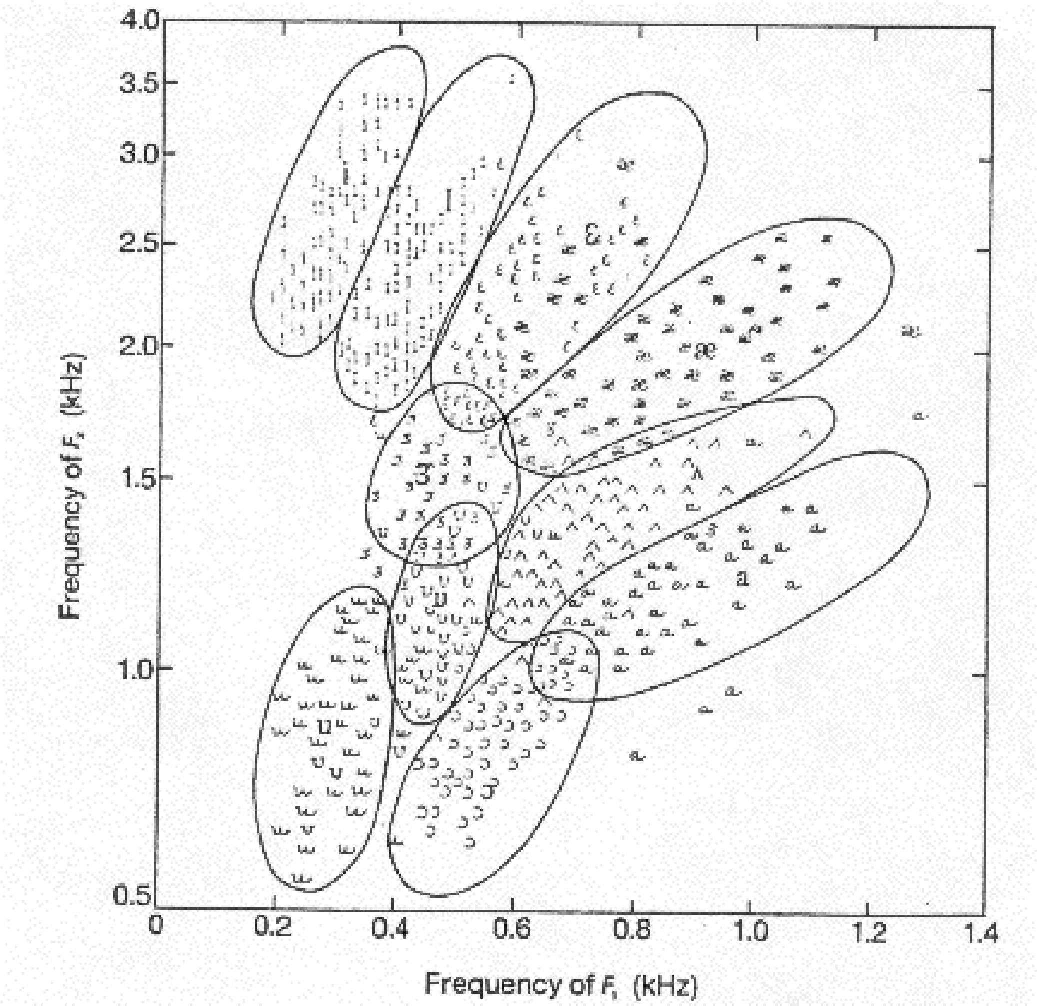
- Rabiner and Schafer, Digital Processing of Speech Signals

- IITB Moodle for all course-related hand-outs

Recognition: “Vowel triangle”



Speaker variability: due to differences in vocal physiology


Frequency of F_2 (kHz)
Frequency of F_1 (kHz)
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