Return to Main

Objectives

Definitions:
Phonetics and Phonology
English
Transcription Standards
Comparison

Phonetics:
The Vowel Space
Formant Frequencies
Bandwidth

Summary:
Acoustic Theory
Consonants

On-Line Resources:
Ladefoged's Home Page
Peterson-Barney Data
HLT Central

LECTURE 06: PHONETICS AND PHONOLOGY

- Objectives:
  - Linguistics 101
  - Understand the relationship between acoustic models of speech production physiology and linguistic models of language
  - Introduce potential acoustic units for our speech recognition system
  - Understand how linguistic structure influences our approaches to speech recognition

Note that this lecture is primarily based on material from the course textbook:

> X. Huang, A. Acero, and H.W. Hon, *Spoken Language Processing - A Guide to Theory, Algorithm, and System Development*, Prentice Hall, Upper Saddle River, New Jersey, USA, ISBN: 0-13-022616-5, 2001.

In addition, information from:

> J. Deller, et. al., *Discrete-Time Processing of Speech Signals*, MacMillan Publishing Co., ISBN: 0-7803-5386-2, 2000.

has been used.

ECE 8463: FUNDAMENTALS OF SPEECH RECOGNITION

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Modern speech understanding systems merge interdisciplinary technologies from Signal Processing, Pattern Recognition, Natural Language, and Linguistics into a unified statistical framework. These systems, which have applications in a wide range of signal processing problems, represent a revolution in Digital Signal Processing (DSP). Once a field dominated by vector-oriented processors and linear algebra-based mathematics, the current generation of DSP-based systems rely on sophisticated statistical models implemented using a complex software paradigm. Such systems are now capable of understanding continuous speech input for vocabularies of hundreds of thousands of words in operational environments.

In this course, we will explore the core components of modern statistically-based speech recognition systems. We will view speech recognition problem in terms of three tasks: signal modeling, network searching, and language understanding. We will conclude our discussion with an overview of state-of-the-art systems, and a review of available resources to support further research and technology development.

Tar files containing a compilation of all the notes are available. However, these files are large and will require a substantial amount of time to download. A tar file of the html version of the notes is available here. These were generated using wget:

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wget -np -k -m http://www.isip.msstate.edu/publications/courses/ece_8463/lectures/current
```

A pdf file containing the entire set of lecture notes is available here. These were generated using Adobe Acrobat.

Questions or comments about the material presented here can be directed to help@isip.msstate.edu.

LECTURE 06: PHONETICS AND PHONOLOGY

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PHONEMICS (PHONOLOGY) AND PHONETICS

Some basic definitions:

- **Phoneme**:
  - an ideal sound unit with a complete set of articulatory gestures.
  - the basic theoretical unit for describing how speech conveys linguistic meaning.
  - In English, there are about 42 phonemes.
  - Types of phonemes: vowels, semivowels, dipthongs, and consonants.
- **Phonemics**: the study of abstract units and their relationships in a language
- **Phone**: the actual sounds that are produced in speaking (for example, "d" in letter pronounced "l e d er").
- **Phonetics**: the study of the actual sounds of the language
- **Allophones**: the collection of all minor variants of a given sound ("t" in eight versus "t" in "top")
- **Monophones, Biphones, Triphones**: sequences of one, two, and three phones. Most often used to describe acoustic models.

Three branches of phonetics:

- **Articulatory phonetics**: manner in which the speech sounds are produced by the articulators of the vocal system.
- **Acoustic phonetics**: sounds of speech through the analysis of the speech waveform and spectrum
- **Auditory phonetics**: studies the perceptual response to speech sounds as reflected in listener trials.

Issues:

- Broad phonemic transcriptions vs. narrow phonetic transcriptions

ENGLISH PHONEMES

Vowels and Diphthongs		
Phonemes	**Word Examples**	**Description**
iy	f**ee**l, **e**ve, m**e**	front close unrounded
ih	f**i**ll, h**i**t, l**i**d	front close unrounded (lax)
ae	**a**t, c**a**rry, g**a**s	front open unrounded (tense)
aa	f**a**ther, **a**h, c**a**r	back open rounded
ah	c**u**t, b**u**d, **u**p	open mid-back rounded
ao	d**o**g, l**aw**n, c**au**ght	open-mid back round
ay	t**ie**, **i**ce, b**i**te	diphthong with quality: aa + ih
ax	ag**o**, c**o**mply	central close mid (schwa)
ey	**a**te, d**ay**, t**a**pe	front close-mid unrounded (tense)
eh	p**e**t, b**e**rry, t**e**n	front open-mid unrounded
er	t**ur**n, f**ur**, met**er**	central open-mid unrounded
ow	g**o**, **o**wn, t**ow**n	back close-mid rounded
aw	f**ou**l, h**ow**, **ou**r	diphthong with quality: aa + uh
oy	t**oy**, c**oi**n, **oi**l	diphthong with quality: ao + ih
uh	b**oo**k, p**u**ll, g**oo**d	back close-mid unrounded (lax)
uw	t**oo**l, cr**ew**, m**oo**	back close round

Consonants and Liquids		
Phonemes	**Word Examples**	**Description**
b	**b**ig, a**b**le, ta**b**	voiced bilabial plosive
p	**p**ut, o**p**en, ta**p**	voiceless bilabial plosive
d	**d**ig, i**d**ea, wa**d**	voiced alveolar plosive
t	**t**alk, s**a**t	voiceless alveolar plosive
g	**g**ut, an**g**le, ta**g**	voiced velar plosive
t	me**t**er	alveolar flap
g	**g**ut, an**g**le, ta**g**	voiced velar plosive
k	**c**ut, **k**en, ta**k**e	voiceless velar plosive
f	**f**ork, a**f**ter, i**f**	voiceless labiodental fricative
v	**v**at, o**v**er, ha**v**e	voiced labiodental fricative
s	**s**it, ca**s**t, to**ss**	voiceless alveolar fricative
z	**z**ap, la**z**y, ha**z**e	voiced alveolar fricative
th	**th**in, no**th**ing, tru**th**	voiceless dental fricative
dh	**th**en, fa**th**er, scy**the**	voiced bilabial plosive
sh	**sh**e, cu**sh**ion, wa**sh**	voiceless postalveolar fricative
zh	**g**enre, a**z**ure	voice postalveolar fricative
l	**l**id	alveolar lateral approximant
l	e**l**bow, sai**l**	velar lateral approximant
r	**r**ed, pa**r**t, fa**r**	retroflex approximant
y	**y**acht, **y**ard	palatal sonorant glide
w	**w**ith, a**w**ay	labiovelar sonorant glide
hh	**h**elp, a**h**ead, **h**otel	voiceless glottal fricative

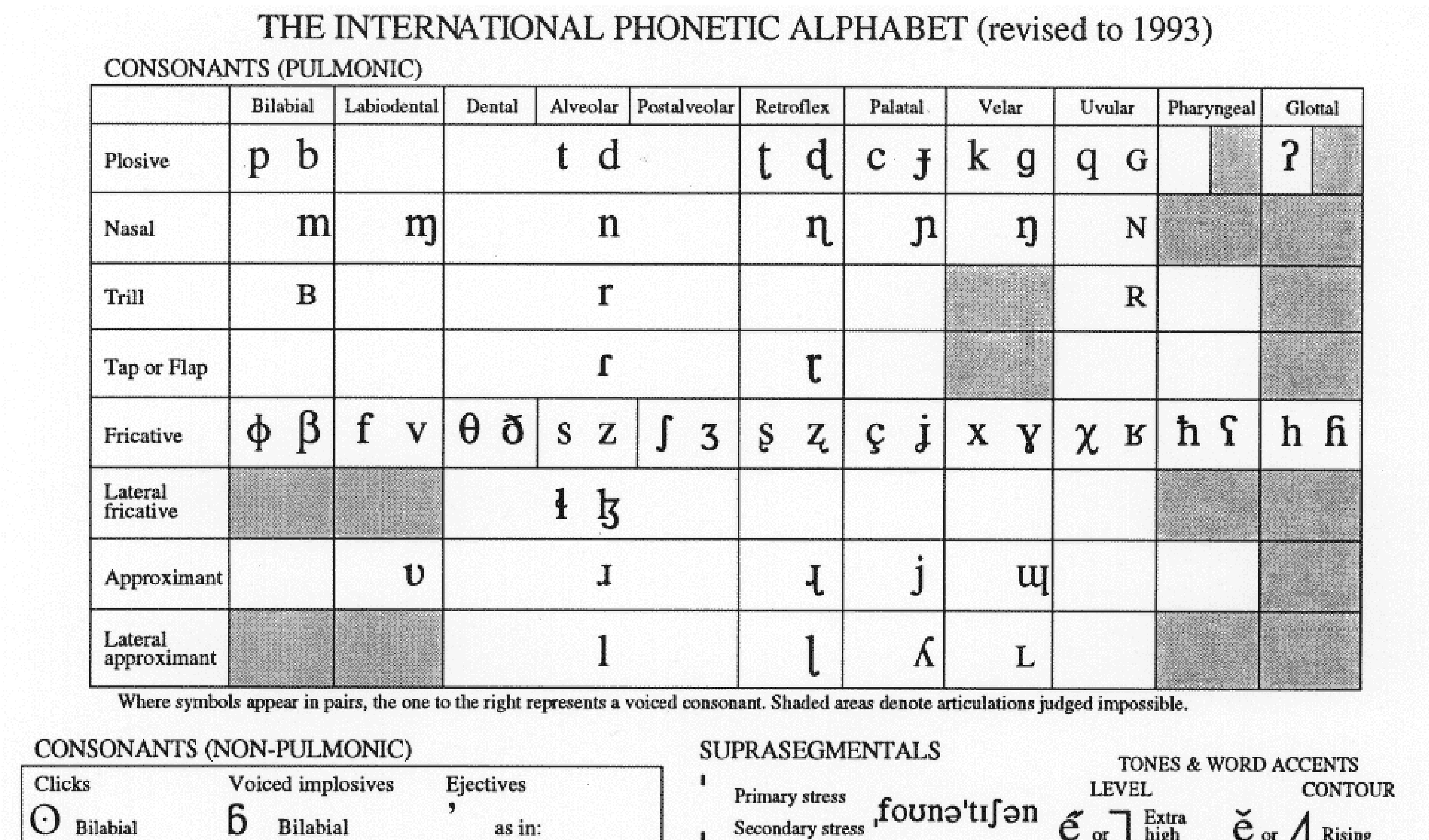
m	**m**at, a**m**id, ai**m**	biliabial nasal
n	**n**o, e**n**d, pa**n**	alveolar nasal
ng	si**ng**, a**ng**er	velar nasal
ch	**ch**in, ar**ch**er, mar**ch**	voiceless alveolar affricate: t + sh
jh	**j**oy, a**g**ile, ed**g**e	voiced alveolar affricate: d + zh

TRANSCRIPTION STANDARDS

Major governing bodies for phonetic alphabets:

- **International Phonetic Alphabet (IPA)**: over 100 years of history
- **ARPAbet**: developed in the late 1970's to support ARPA research
- **TIMIT**: TI/MIT variant of ARPAbet used for the TIMIT corpus
- **Worldbet**: developed by Hieronymous (AT&T) to deal with multiple languages within a single ASCII system
- **Unicode**: character encoding system that includes IPA phonetic symbols.

Here is a chart classifying sounds using the IPA:



THE INTERNATIONAL PHONETIC ALPHABET (revised to 1993)

CONSONANTS (PULMONIC)

	Bilabial	Labiodental	Dental	Alveolar	Postalveolar	Retroflex	Palatal	Velar	Uvular	Pharyngeal	Glottal
Plosive	p b			t d		ʈ ɖ	c ɟ	k g	q ɢ		ʔ
Nasal	m	ɱ		n		ɳ	ɲ	ŋ	ɴ		
Trill	ʙ			r					ʀ		
Tap or Flap				ɾ		ɽ					
Fricative	ɸ β	f v	θ ð	s z	ʃ ʒ	ʂ ʐ	ç ʝ	x ɣ	χ ʁ	ħ ʕ	h ɦ
Lateral fricative				ɬ ɮ							
Approximant		ʋ		ɹ		ɻ	j	ɰ			
Lateral approximant				l		ɭ	ʎ	ʟ			

Where symbols appear in pairs, the one to the right represents a voiced consonant. Shaded areas denote articulations judged impossible.

CONSONANTS (NON-PULMONIC)

Clicks		Voiced implosives		Ejectives	
ʘ	Bilabial	ɓ	Bilabial	ʼ	as in:

SUPRASEGMENTALS

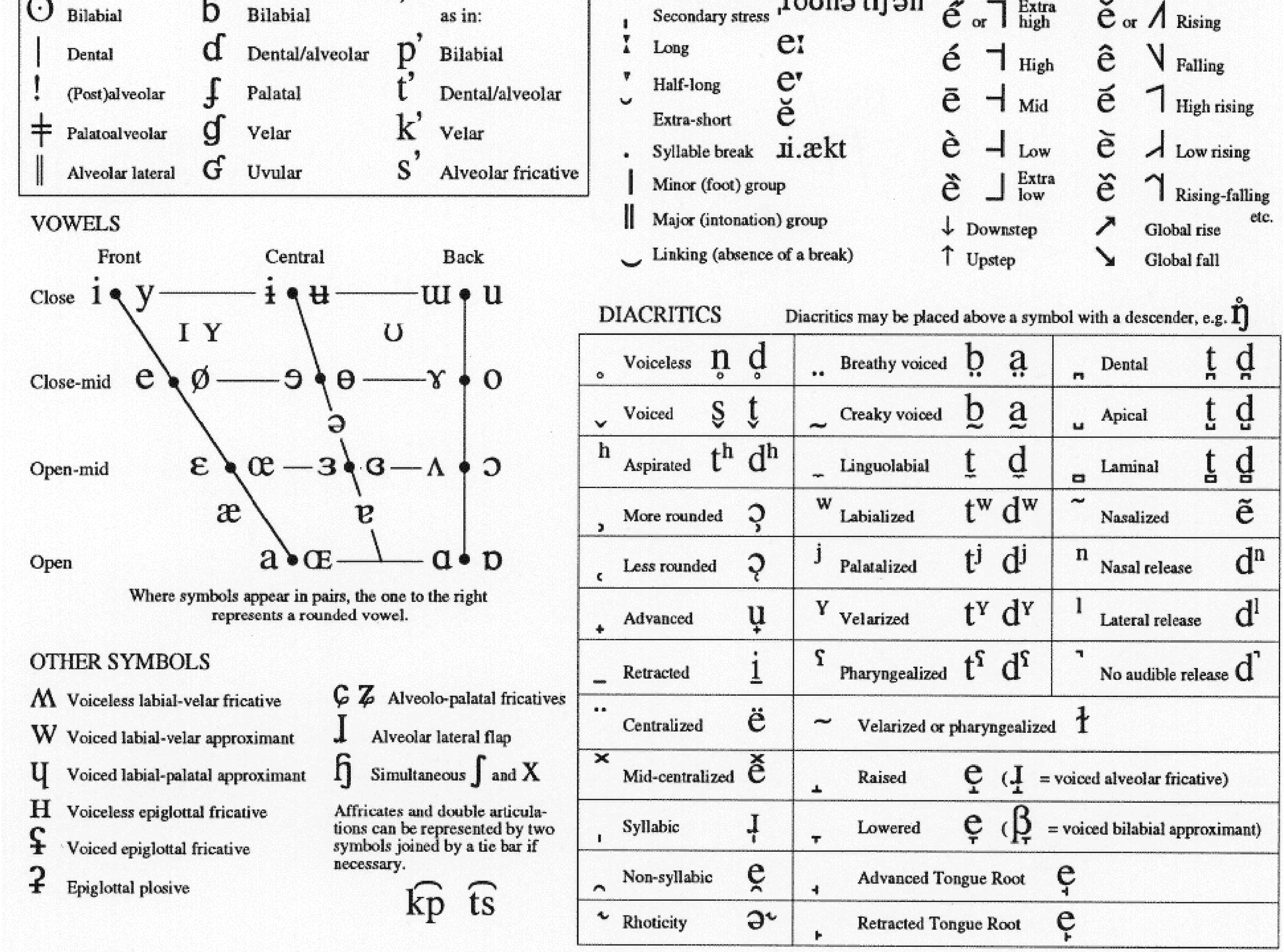
ˈ Primary stress ˌfoʊnəˈtɪʃən

ˌ Secondary stress

TONES & WORD ACCENTS

LEVEL: e̋ or ˥ Extra high

CONTOUR: ě or ˩˥ Rising



For a more detailed discusion of phone mappings across languages, see language independent acoustic modeling.

PHONEMES

- **Phoneme Mappings**

Most languages, including English, can be described in terms of a set of distinctive sounds, or phonemes. In particular, for American English, there are about 42 phonemes including vowels, diphthongs, semi-vowels and consonants. The internationally standard method to represent phonemes is International Phonetic Alphabet (IPA). To enable computer representation of the phonemes, it is convenient to code them as ASCII characters. Several schemes have been proposed, e.g., ARPABET, TIMIT, CMU, WSJ and SWB. The following table shows the mapping between these representations and IPA.

Table 1: PHONEME MAPPINGS

ARPABET	TIMIT	CMU	WSJ	SWB	ICSI	IPA
aa	lOck	lOck	lOck	lOck	stOck	ɑ
ae	bAt	bAt	bAt	bAt	bAt	æ
ah	bUt	bUt	bUt	bUt	bUt	ʌ[1]
ao	bOUght	bOUght	/	bOUght	bOUght	ɔ
aw	dOWn	cOW	cOW	cOW	tOWn	ɑu
awh	/	/	cOW	/	/	ɑu
ax	About	/	/	About	About	ə
axr	buttER	/	/	/	/	ɚ
ax-h	sUspect	/	/	/	/	/
ay	bUY	bUY	bUY	bUY	bIte	aI
b	Bet	Bet	Bet	Bet	Bet	b
bcl	b-closure	/	/	/	/	/
ch	CHurch	CHurch	CHurch	CHurch	CHurch	č
d	Debt	Debt	Debt	Debt	Difficult	d
dcl	d-closure	/	/	/	/	/
dh	THat	THat	THat	THat	They	ð
dx	baTTer	/	/	/	allophone of |d| or |t|	/
ee	/	/	bEAt	/	/	i
eh	bEt	bEt	bEt	bEt	bEt	e
el	battLE	/	/	battLE	battLE	l̩
em	bottOM	/	/	/	thEM	m̩
en	buttON	/	/	buttON	buttON	n̩
eng	syllabic NG	/	/	/	workING	/
epi	epenthetic sil	/	/	/	/	/

en	buttON	/	/	buttON	buttON	n̩
eng	syllabic NG	/	/	/	workING	/
epi	epenthetic sil	/	/	/	/	/
er	bIRd	bIRd	/	bIRd	bIRd	ɚ
ey	bAIt	bAIt	bAIt	bAIt	bAIt	eI
f	Fat	Fat	Fat	Fat	Fat	f
g	Get	Get	Get	Get	Get	g
gcl	g-closure	/	/	/	/	/
h	/	/	Hat	/	/	h
hh	Hat	Hat	/	hello	Hay	h
hw	/	/	/	/	WHat	/
hv	voiced /HH/	/	/	/	/	/
h#	utt boundary	/	/	/	/	/
ih	bIts	bIts	bIts	bIts	bIts	I[1]
ix	rosEs	/	/	/	rosEs	I
iy	bEAt	bEAt	/	bEAt	bEAt	i
j	/	/	Judge	/	/	ǰ
jh	Judge	Judge	/	Judge	Judge	ǰ
k	Kit	Kit	Kit	Kit	Called	k
kcl	k-closure	/	/	/	/	/
l	Let	Let	Let	Let	Let	l
lg	/	/	/	/	oLd	/
m	Met	Met	Met	Met	Met	m
n	Net	Net	Net	Net	Net	n
ng	siNG	siNG	siNG	siNG	siNG	ŋ
nx	wiNTer	/	/	/	allophone |n|	n
oh	/	/	bOAt	/	/	o
oo	/	/	bOOt	/	/	u
ooh	/	/	bOOk	/	/	ʊ
ow	bOAt	bOAt	bOAt	bOAt	bOAt	o
oy	bOY	bOY	bOY	bOY	bOY	ɔi

p	Pet	Pet	Pet	Pet	Pot	p
pau	pause	/	/	/	/	/
pcl	p-closure	/	/	/	/	/
pv	/		/	/	filled pause - "uh"	/
q	glottal stop	/	/	/	glottal stop	/
r	Rent	Rent	Rent	Rent	Red	ɹ
s	Sat	Sat	Sat	Sat	niCE	s
sh	SHut	SHut	SHut	SHut	SHut	ʃ
sil	/	/	/	/	silence	/
t	Ten	Ten	Ten	Ten	sTock	t
tcl	t-closure	/	/	/	/	/
th	THing	THing	THing	THree	THief	θ
uh	bOOk	bOOk	bOOk	bOOk	bOOk	ʊ
ul	/	/	dULl	/	/	/
um	/	/	bUM	/	/	/
un	/	/	bUN	/	/	/
ur	/	/	bIRd	/	/	ɝ
uw	bOOt	tOO	/	tOO	bOOt	u
ux	tOO	/	/	/	sUIt	u
v	Vat	Vat	Vat	Vat	Vat	v
w	Wit	Wit	Wit	Wit	Wet	w
y	You	You	You	You	Yet	j
z	Zoo	Zoo	Zoo	Zoo	Zoo	z
zh	pleaSure	pleaSure	pleaSure	pleaSure	pleaSure	ʒ
?	/	/	/	/	unknown speech	/

- **Features of Phonemes**

  Phonemes can be classified in terms of distinct features, such as vowels, consonants, etc.

Table 2: FEATURES OF PHONEMES

FEATURES			PHONEMES
Vowels	Front		iy (i), ih (I^1), eh (e), ae (æ)
	Mid		aa (α), ah ($Λ^1$), ax (ə), er (ɚ)
	Back		uw (u), uh (ʊ), ao(ɔ)
Diphthongs			ay (aI), oy (ɔi), aw (αu), ey (eI), ow (o)
Semi-vowels	Liquid		w (w), l (l), el (l)
	Glides		r (ɹ), y (j)
Consonants	Stops	voiced	b (b), d (d), g (g)
		unvoiced	p (p), t (t), k (k)
	Nasals		m (m), n (n), ng (η)
	Whisper		h (h)
	Fricatives	voiced	v (v), dh(ð), z (z), zh (ʒ)
		unvoiced	f (f), th (θ), s (s), sh (ʃ)
	Affricates		jh(ǰ), ch (č)

Note: In the above table, the phonemes are represented by SWB and IPA.

- **References**

1. International Phonetic Alphabet, http://www.arts.gla.ac.uk/IPA/ipa.html

2. LDC TIMIT lexicon, http://www.ldc.upenn.edu/doc/timit/phoncode.doc

3. LDC PRONLEX Transcription, http://www.ldc.upenn.edu/readme_files/comlex_pron.readme.html.

4. The CMU Pronouncing Dictionary, http://www.speech.cs.cmu.edu/cgi-bin/cmudic.

5. Phoneme Classification, http://www-dsp.rice.edu/courses/elec532/PROJECTS96/synthesis/phoneme_descriptions.html, Rice University

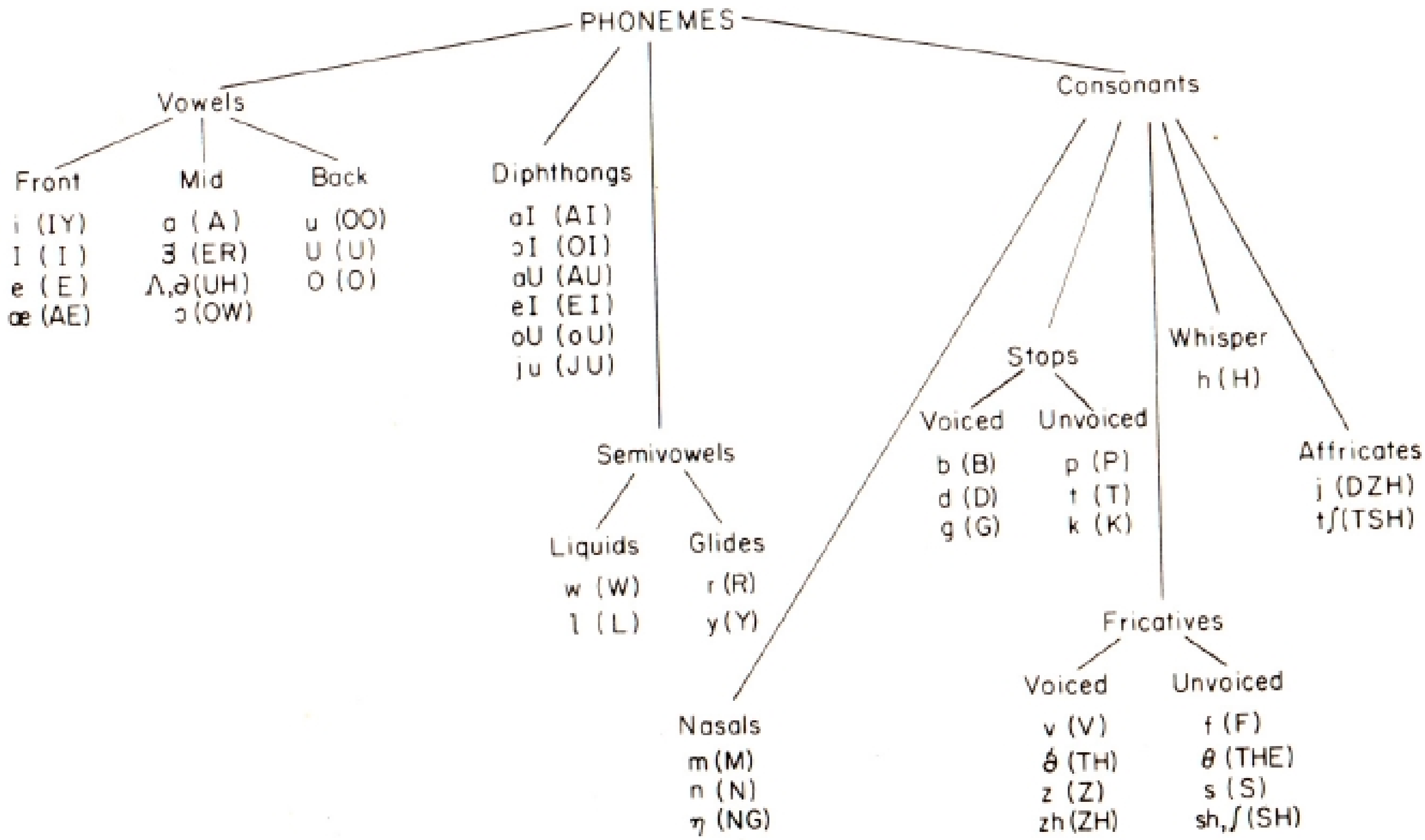
6. ARPABET-IPA MAPPINGS, http://www.cs.cmu.edu/~laura/pages/arpabet.ps

7. WordNet - a Lexical Database for English, http://www.cogsci.princeton.edu/~wn/

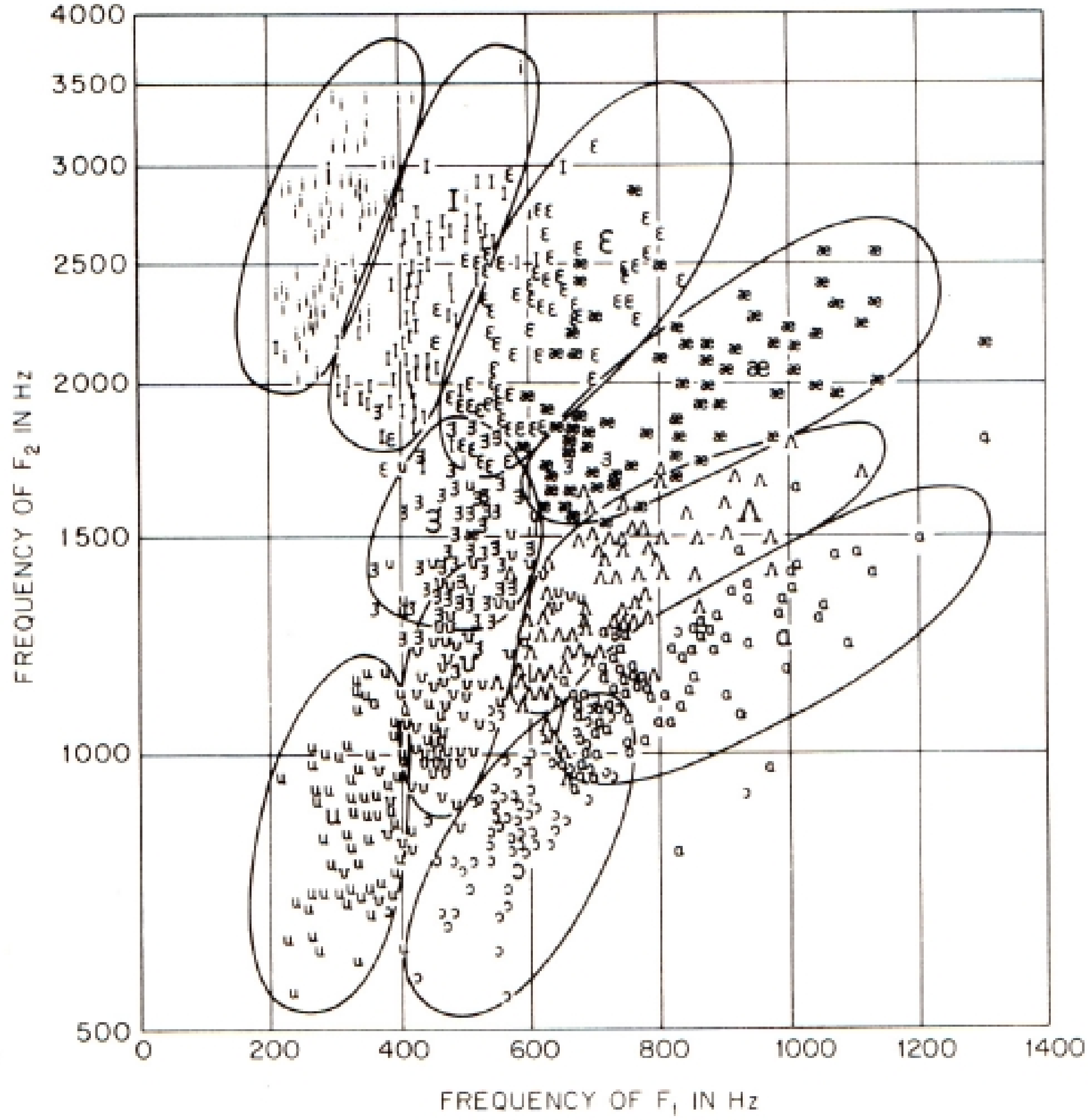
8. Calvert, Donald R. *Descriptive Phonetics* , Thieme Medical Publishers, 1992.

THE VOWEL SPACE

- Each fundamental speech sound can be categorized according to the position of the articulators. This is often known as the study of Acoustic Phonetics.

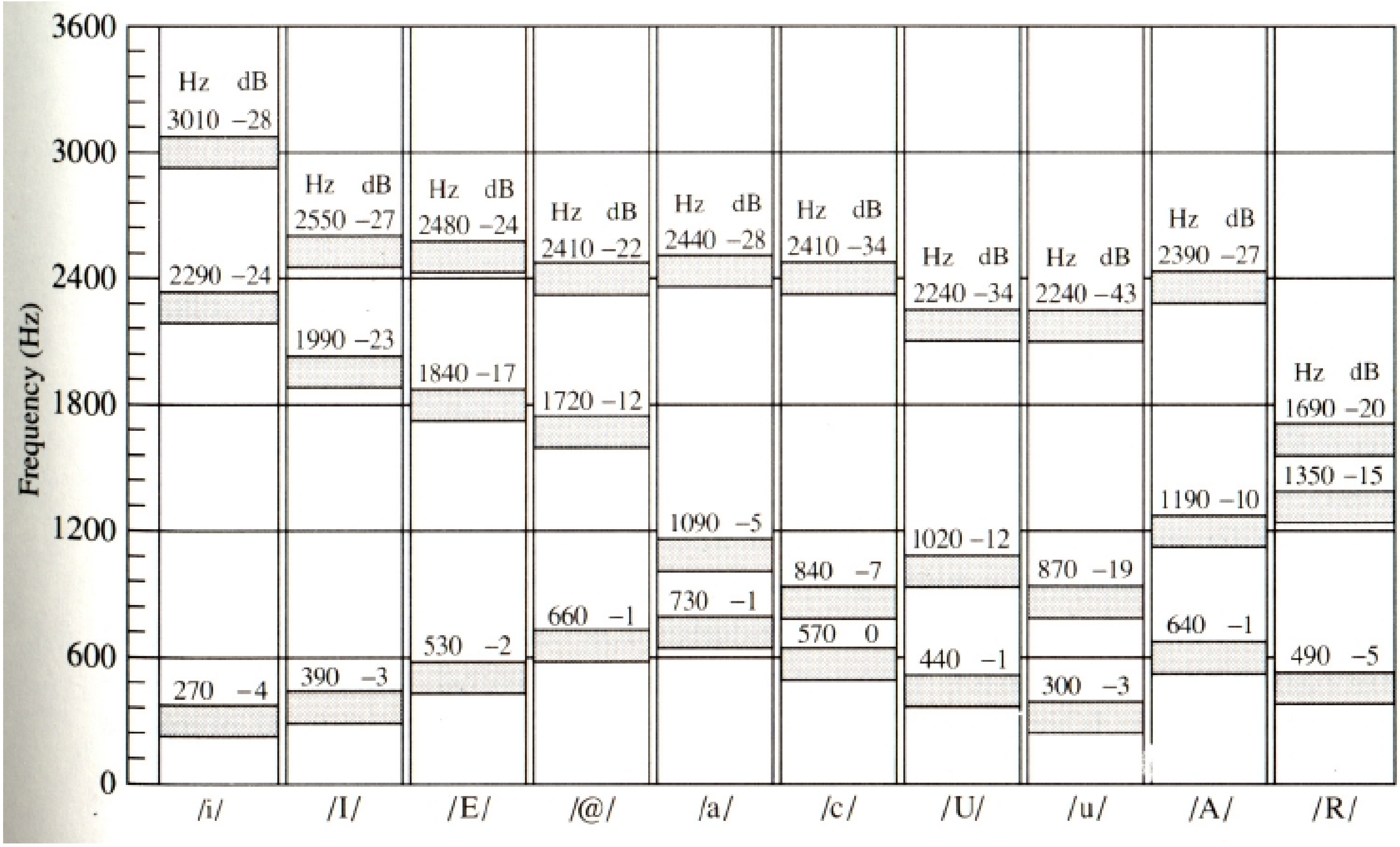


- We can characterize a vowel sound by the locations of the first and second spectral resonances, known as formant frequencies:

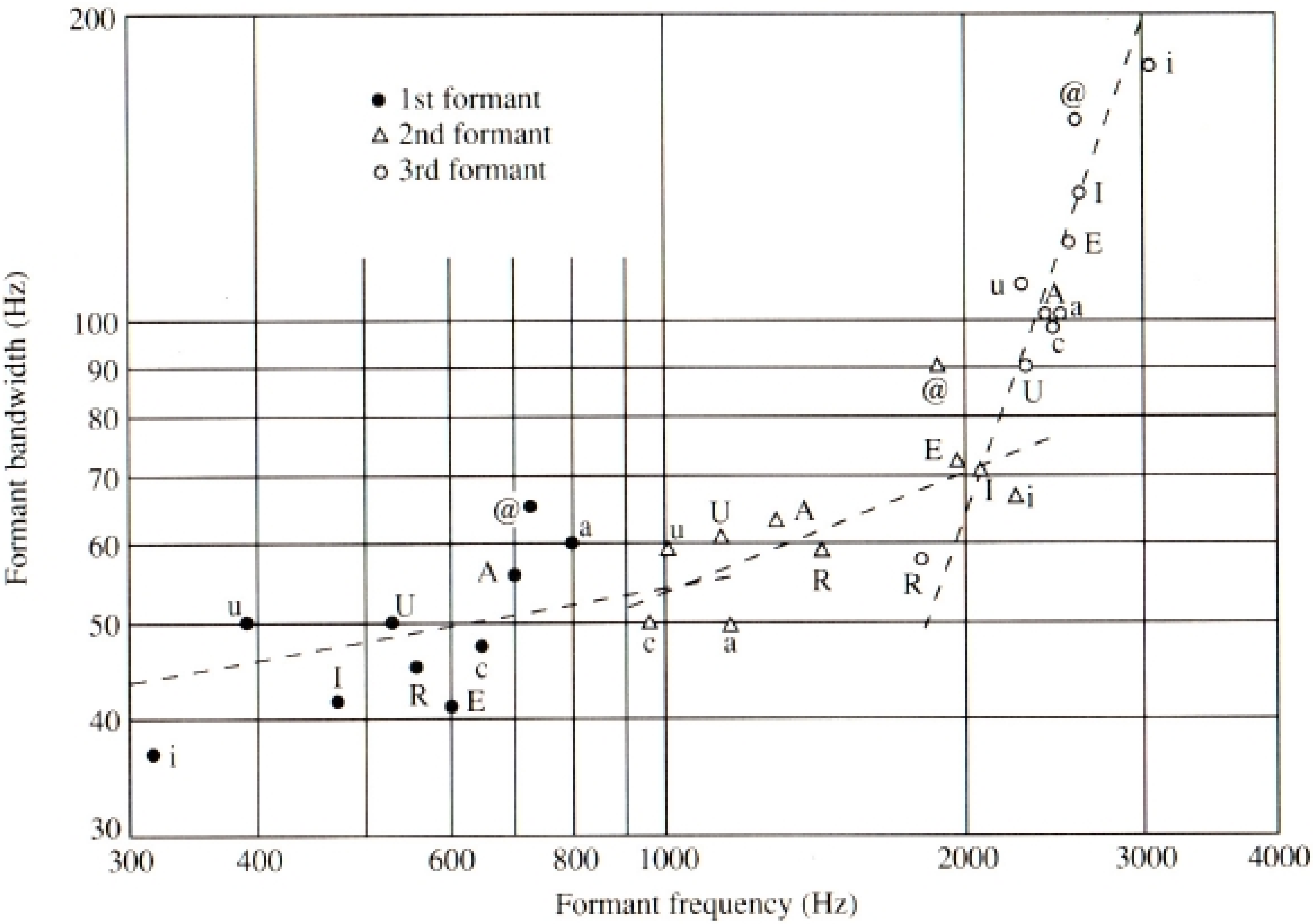


- Some voiced sounds, such as diphthongs, are transitional sounds that move from one vowel location to another.

THE RANGE OF FORMANT FREQUENCIES



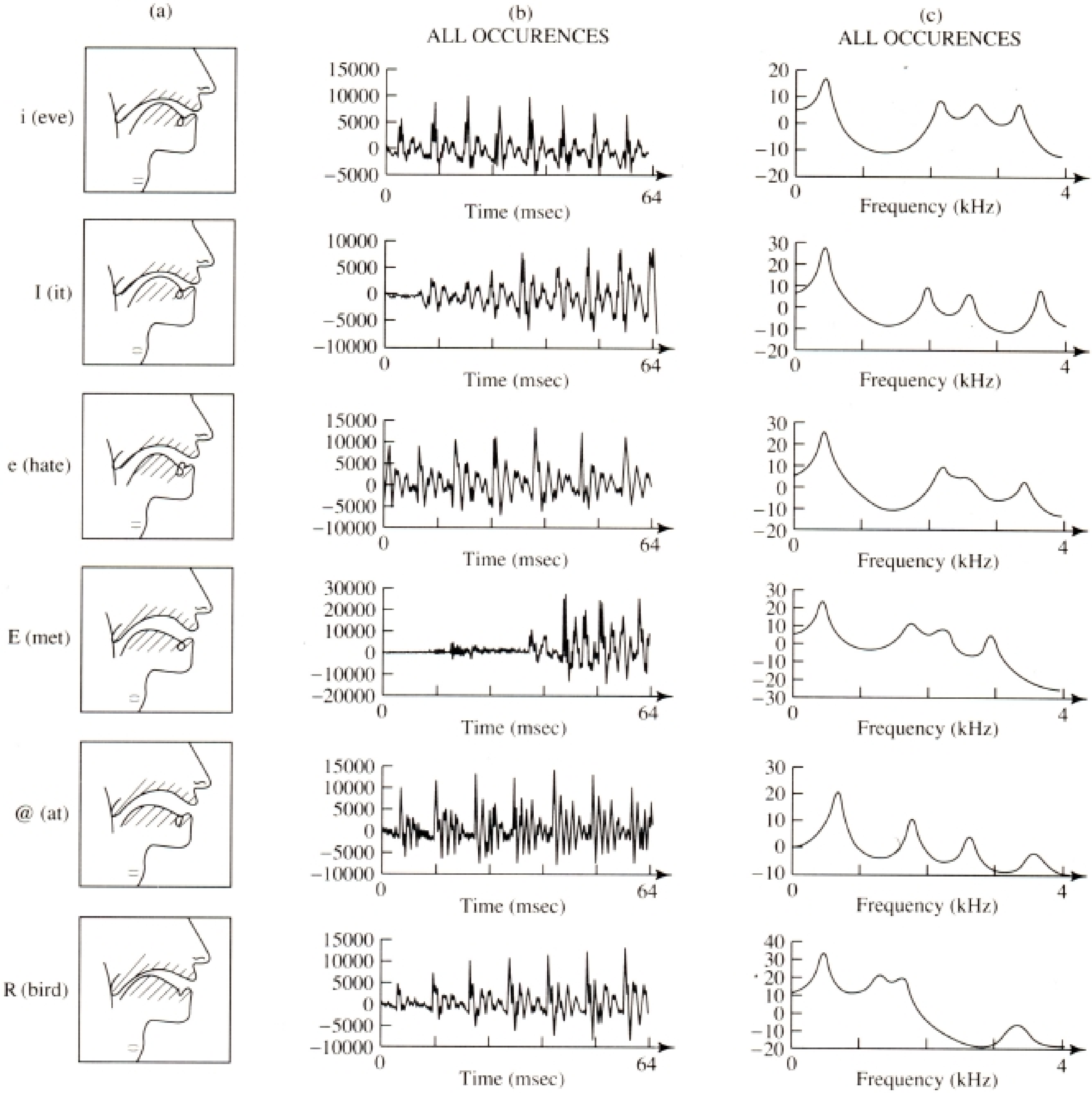
THE RELATIONSHIP BETWEEN
FORMAT FREQUENCIES AND BANDWIDTHS



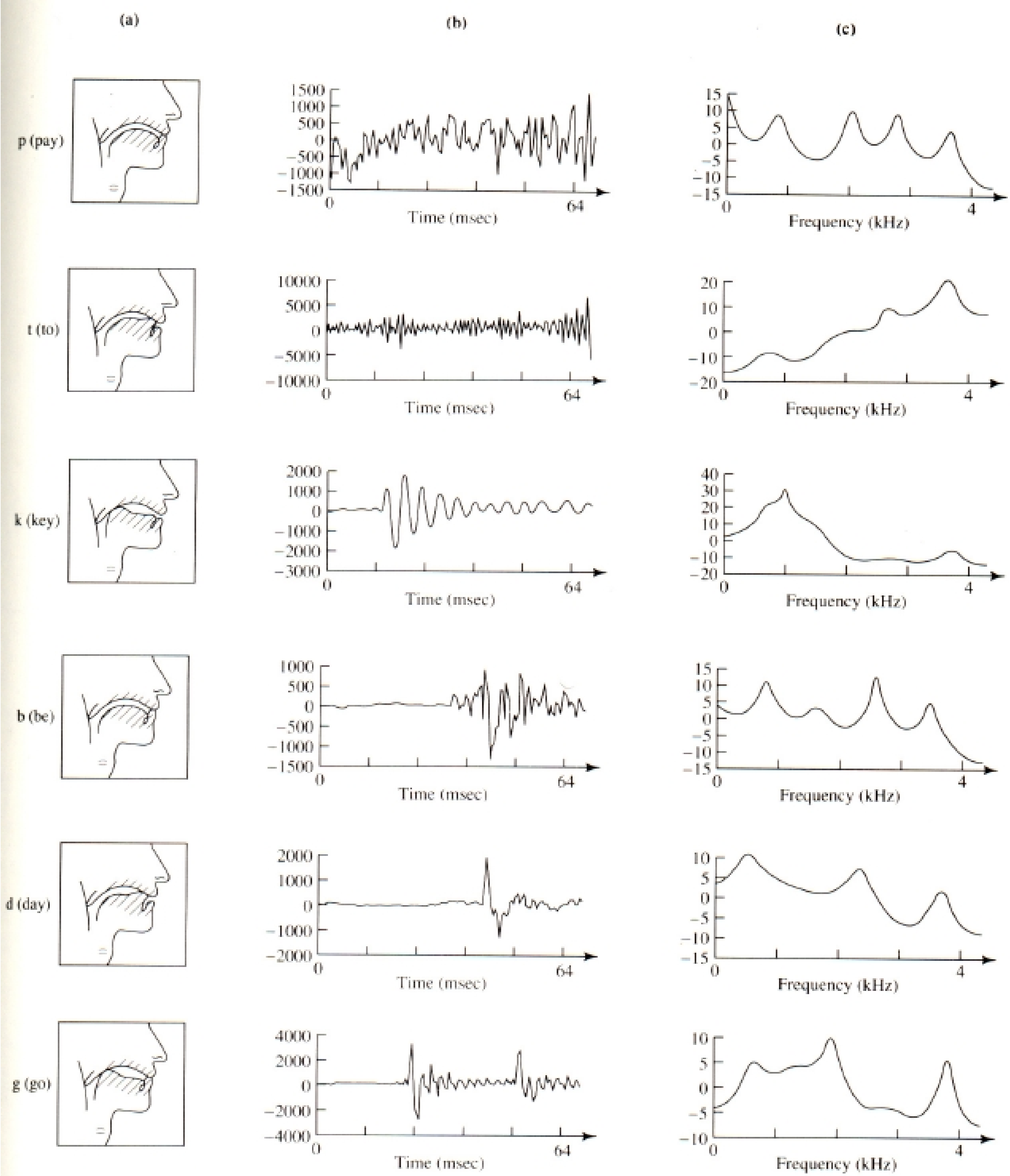
Vowels	F1 Avg.	F1 Extremes		F2 Avg.	F2 Extremes		F3 Avg.	F3 Extremes	
i	38	30	80	66	30	120	171	60	300
I	42	30	100	71	40	120	142	60	300
E	42	30	120	72	30	140	126	50	300
@	65	30	140	90	40	200	156	50	300
a	60	30	160	50	30	80	102	40	300
c	47	30	120	50	30	200	98	40	240
u	50	30	120	58	30	200	107	50	200
U	51	30	100	61	30	140	90	40	200
A	56	30	140	63	30	140	102	50	300
R	46	30	80	59	30	120	58	40	120
Avg.	49.7			64.0			115.2		

U	51	30	100	61	30	140	90	40	200
A	56	30	140	63	30	140	102	50	300
R	46	30	80	59	30	120	58	40	120
Avg.	49.7			64.0			115.2		

AN ACOUSTIC THEORY FOR VOWEL PRODUCTION



THIS THEORY IS ALSO APPLICABLE TO CONSONANTS



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Research Interests

- **Current activity**
  Writing a book *Phonetic Data Analysis: An introduction to phonetic fieldwork and instrumental techniques.* A draft of the first part of this book is available.
- **Recent work**
  Publication of a book *Vowels and Consonants* designed as a very elementary introduction to phonetics. The book is accompanied by a CD illustrating the sounds being discused. A web version of the CD.
- **The use of the respiratory system in speech.**
  Preliminary studies are in progress investigating subglottal pressure and muscular activity (a return to work begun 40 years ago). A draft of a preliminary paper.
- **Editor of the *Journal of the International Phonetic Association***
- **Phonetic studies of endangered languages.**
  Thousands of languages all over the world will not be spoken in a generation or two. Thanks to an NSF grant, Ian Maddieson and I have worked with fieldworkers and students over the last few years on languages spoken in Africa, India, Australia, Brazil, the U.S. and elsewhere.
- **Sounds of the World's Languages**
  A long-time ambition has been to hear and describe all the distinct sounds of the world's languages, perhaps 900 consonants and 200 vowels. This interest has led to co-authoring with Ian Maddieson *The Sounds of the World's Languages*, and supervising a set of hypercard stacks with the same name. With this go two other interests:
  1. Developing an explanatory phonetic classificatory system.
  2. Maintaining the International Phonetic Alphabet (the IPA).
- **Simplifying acoustic phonetic problems**.
  A second edition of Elements of Acoustic Phonetics (University of Chicago Press) with new material on articulatory-acoustic relations and computer speech processing (including FFT and LPC analysis) has recently been published.

Publications

Books

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Personal

Married for 48 years to [Jenny Ladefoged,](#) a notorious Episcopal Church Woman. (I am a member of Atheists for Jesus.)
Three offspring (plus grandchildren): Lise Friedman, Bookseller; Thegn Ladefoged, Archaeologist,University of Auckland; Katie Weiss, Criminal Defence Attorney.

Informal CV

In my early career I never stayed long enough in a particular field to be contradicted. I started as a poet learning about the sounds of words with David Abercrombie. Then, remembering my background in physics, I moved to studying acoustic phonetics. From there I became a pseudo-psychologist testing perceptual theories, until a meeting with a physiologist led to work on the respiratory muscles used in speech. Eventually I landed in Africa teaching English phonetics and learning about African languages. So by the time I was asked to set up a lab at UCLA I was a specialist in nothing. But I was able to use my background to describe the sounds of a wide range of languages, becoming a sort of linguist. Computers and *bright students led to other ways of analyzing sounds. Building a research group who felt that they had a stake in the development of the lab taught me their varied ideas from statistics to engineering, and the philosophy of linguistics. Now, still looking for the growing edge of the field, I think it might be in the physically observable activity of the brain; but perhaps this is because I have never been a pseudo-neurologist.*

My formal CV is also available online.

Last Updated: March 2001

Peterson Barney: Vowel formant frequency database

areas/speech/database/pb/

This directory contains the Peterson and Barney vowel formant frequency database, as used in their 1952 JASA paper. Peterson and Barney measured the frequency and amplitude of F1, F2 and F3 for 10 vowels and 76 speakers.

```
Origin:

   ftp.cis.upenn.edu:/pub/ldc/pb.data.tar.Z
```

Version: 5-JAN-93 CD-ROM: Prime Time Freeware for AI, Issue 1-1 Keywords: Authors!Barney, Authors!Peterson, Speech Recognition!Databases, Speech Synthesis!Databases, Vowel Formant Frequency Database References: Peterson and Barney, "Control methods used in a study of the vowels", JASA 24, 175-184, 1952. Watrous, JASA, vol 89, May 1991

Welcome
About Language and Speech
- Elements of study
- Speech Communication
- Speech Production
- Speech Perception
- Phonology
- Acoustic Phonetics
- Phonetic Variation
- 1st Language Acquisition
- 2nd Language Acquisition
- Communication Disorders
- Singing
- Methods and Tools (IPA)
- Language Resources
- Speech Signal Processing
- Speech Coding
- Speech Synthesis
- Speech Recognition
- Spoken Dialogue Modelling
- Natural Language Processing
- Applications
Navigation Map
The Jewellers

Acoustic Phonetics

Elements of study
Suggested Reading
Products

Speech sounds, like sounds in general, are transmitted through the air as small, rapid variations in air pressure that spread in longitudinal waves from the speaker's mouth and can be heard, recorded, visualized and measured. Differences between individual speech sounds are directly reflected as differences in either one or several or all of the parameters duration, pitch, loudness and quality of the belonging speech waves.

Acoustic phonetics, which deals with the study and description of the acoustical properties of individual speech sounds, prodosy and voice quality, forms not only the immediate link between articulatory phonetics and speech perception, but is also important for applications in the fields of signal processing and speech technology.

Top
Suggested Reading
Products

Elements of study

Basic concepts of acoustic phonetics [see also Speech Signal Processing]

- **What is sound?**
  - Waveforms
  - Omnidirectionality
  - Air pressure and electrical analogies
  - Sinusoids and complex signals
  - Periodicity
  - Aperiodicity (random noise, transient noise)
- **Scales and Measurements**
  - Intensity
  - Duration
  - Frequency
  - Phase
- **Speech recording**
  - Microphones
  - Analog and digital recordings

Acoustic theory of speech production: Fant's source-filter model [see also Speech Signal Processing]

- **The source component**
  - Glottal wave shape models
  - Random and Iransient noises
  - Source spectrum
  - Variability and individuality
- **The filter component**
  - Area functions
  - Poles and zeros
  - Formants (frequencies, amplitudes and bandwidths)
  - Variability and individuality
- **The radiation component**
  - Lip radiation
  - Nose radiation
  - Interference problems and effects

Experimental methods and tools [see also Speech Signal Processing]

- **Sound oscillograph**
    - Waveforms
- **Sound spectrograph**
    - Spectrum and spectrogram
    - Wide-band and narrow-band spectrogram
    - Short-term and long-term spectra
    - Filtering, rectification and smoothing
    - Gain

Acoustic properties of speech sounds

- **Vowels**
    - Formant structure
    - intrinsic duration, fundamental frequency and intensity
    - Oral and nasal vowels; other vowel types
    - Vowel reduction
    - Diphthongs, triphthongs, glides
    - Duration: neutral, short, long, contextual, etc.
- **Consonants**
    - Stops
    - Nasals
    - Fricatives
    - Affricates
    - Laterals
    - Approximants
    - Thrills, taps and flaps
    - Ejectives and implosives
    - Coarticulation and transitions
- **Word level prosody**
    - Tone
    - Accent
    - Quantity
    - Stress
- **Sentence level prosody**
    - Intonation
    - Tempo (speech rate and articulation rate)
    - Stress
    - Rhythm
    - Final lengthening
    - Juncture
    - Pausing
- **Discourse level intonation**
    - Text and discourse intonation
    - Dialogue intonation
    - Speaking styles
- **Voice quality (phonetic settings)**
    - Laryngeal settings (phonation types)
    - Supra-laryngeal settings

Top
Elements of Study
Products

Suggested reading

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Zwicker, E. & Zollner, M. (1984). Elektroakustik. Berlin: Springer.

Journal

Journal of the Acoustical Society of America.

Top
Suggested Reading
Products

Products

Product	Operating System	Web site information
KAY CSL 4300	PC/DOS	www.kayelemetrics.com/
Signalyze	Macintosh	http://agoralang.com/signalyze.html
ESPS/Waves	UNIX	www.entropic.com/products/esps/esps.html
KAY 5500	Special Purpose	www.kayelemetrics.com/
KAY Multispeech	PC/Win	www.kayelemetrics.com/
SFS	PC/Win or UNIX	www.phon.ucl.ac.uk/resource/sfs.html
MATLAB	Various OS	www.mathworks.com/
HTK/HMM	UNIX	www-white.media.mit.edu/~nuria/HTKV2.0/htk.html
CSRE 3.0	PC/Win	www.avaaz.com/products.html
SoundScope	Macintosh	www.gwinst.com/web-pages/products.html
KAY Visipitch 6087	PC/DOS	www.kayelemetrics.com/
PRAAT 3.7	PC/Various	http://fonsg3.let.uva.nl/praat/praat.html

Mounted by Gerrit Bloothooft

Top