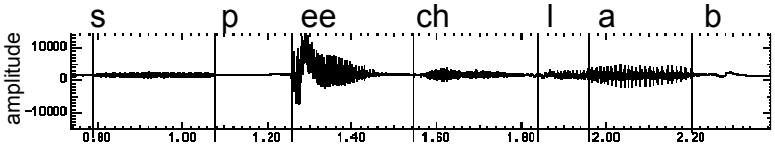
Statistical NLP
Spring 2010

Lecture 8: Speech Signal

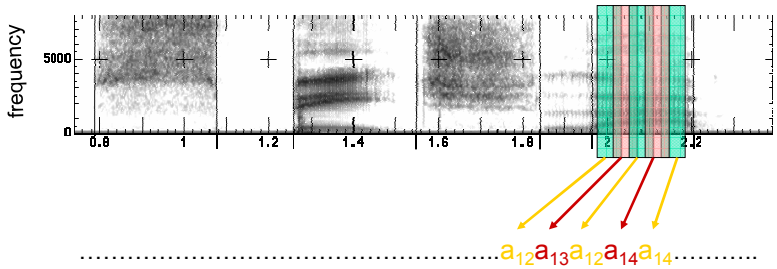
Dan Klein – UC Berkeley

Speech in a Slide

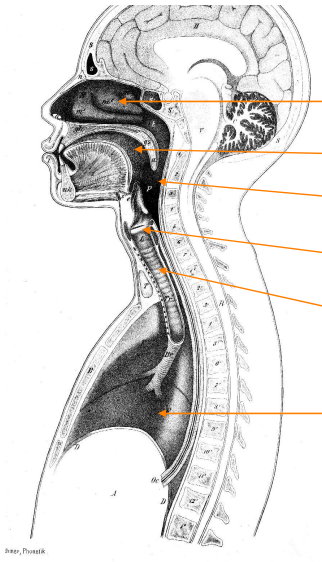
- Frequency gives pitch; amplitude gives volume



- Frequencies at each time slice processed into observation vectors



Articulatory System



Nasal cavity

Oral cavity

Pharynx

Vocal folds (in the larynx)

Trachea

Lungs

Sagittal section of the vocal tract (Techmer 1880)

Text from Ohala, Sept 2001, from Sharon Rose slide

Places of Articulation

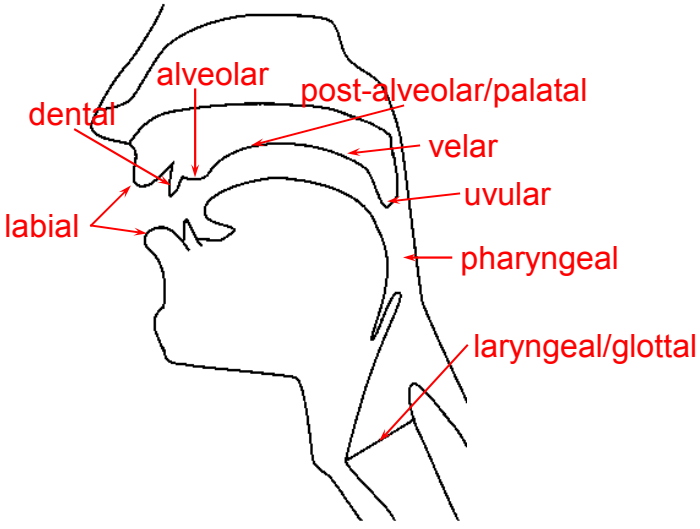
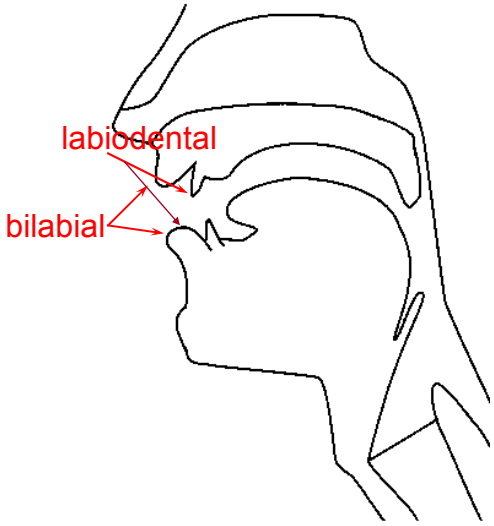


Figure thanks to Jennifer Venditti

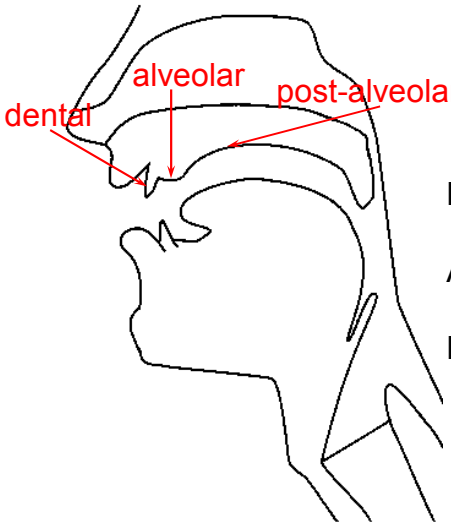
Labial place



Bilabial:
p, b, m
Labiodental:
f, v

Figure thanks to Jennifer Venditti

Coronal place



Dental:
th/dh
Alveolar:
t/d/s/z/l/n
Post:
sh/zh/y

Figure thanks to Jennifer Venditti

Dorsal Place

Velar:
k/g/ng

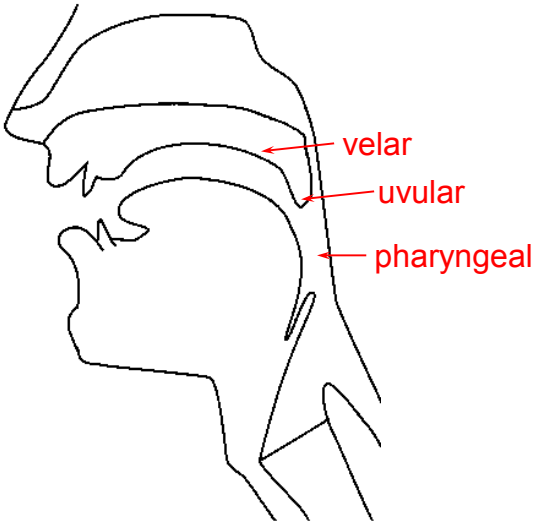


Figure thanks to Jennifer Venditti

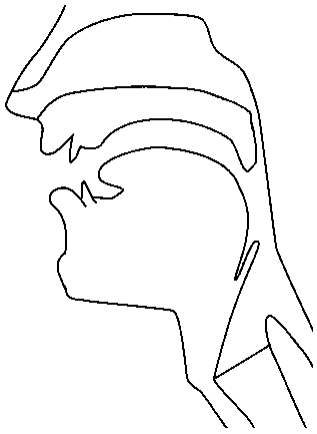
Space of Phonemes

	LABIAL		CORONAL				DORSAL			RADICAL		LARYNGEAL
	Bilabial	Labio-dental	Dental	Alveolar	Palato-alveolar	Retroflex	Palatal	Velar	Uvular	Pharyngeal	Epi-glottal	Glottal
Nasal	m	ɱ		n		ɳ	ɲ	ŋ	N			
Plosive	p b			t d		ʈ ɖ	c ɟ	k g	q ɢ		ʡ	ʔ
Fricative	ɸ β	f v	θ ð	s z	ʃ ʒ	ʂ ʐ	ç ʝ	x ɣ	χ ʁ	ħ ʕ	ʜ ʢ	h ɦ
Approximant		ʋ		ɹ		ɻ	j	ɰ				
Trill	ʙ			r					R		ʀ	
Tap, Flap		ⱱ		ɾ		ɽ						
Lateral fricative				ɬ ɮ								
Lateral approximant				l		ɭ	ʎ	ʟ				
Lateral flap				ɺ		ɭ̆						

- Standard international phonetic alphabet (IPA) chart of consonants

Manner of Articulation

- In addition to varying by place, sounds vary by manner
- Stop: complete closure of articulators, no air escapes via mouth
  - Oral stop: palate is raised (p, t, k, b, d, g)
  - Nasal stop: oral closure, but palate is lowered (m, n, ng)
- Fricatives: substantial closure, turbulent: (f, v, s, z)
- Approximants: slight closure, sonorant: (l, r, w)
- Vowels: no closure, sonorant: (i, e, a)



Space of Phonemes

	LABIAL		CORONAL				DORSAL			RADICAL		LARYNGEAL
	Bilabial	Labio-dental	Dental	Alveolar	Palato-alveolar	Retroflex	Palatal	Velar	Uvular	Pharyngeal	Epi-glottal	Glottal
Nasal	m	ɱ		n		ɳ	ɲ	ŋ	N			
Plosive	p b	pˠ bˠ		t d		ʈ ɖ	c ɟ	k g	q ɢ		ʡ	ʔ
Fricative	ɸ β	f v	θ ð	s z	ʃ ʒ	ʂ ʐ	ç ʝ	x ɣ	χ ʁ	ħ ʕ	ʜ ʢ	h ɦ
Approximant		ʋ		ɹ		ɻ	j	ɰ				
Trill	ʙ			r					ʀ		ʀ̠	
Tap, Flap		ⱱ		ɾ		ɽ						
Lateral fricative				ɬ ɮ								
Lateral approximant				l		ɭ	ʎ	ʟ				
Lateral flap				ɺ		ɭ̆						

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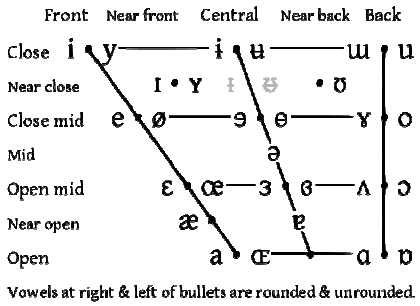
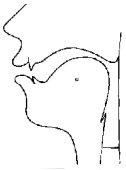
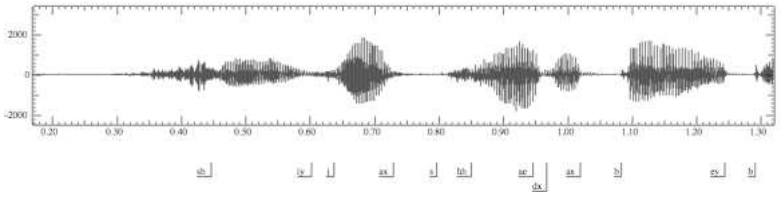
Vowel Space



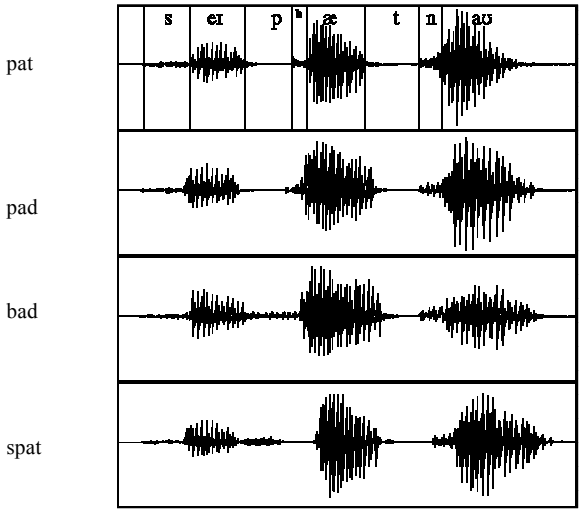


"She just had a baby"



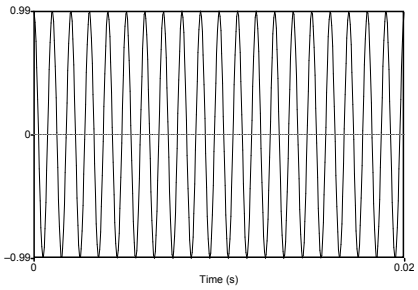
- What can we learn from a wavefile?
  - No gaps between words (!)
  - Vowels are voiced, long, loud
  - Length in time = length in space in waveform picture
  - Voicing: regular peaks in amplitude
  - When stops closed: no peaks, silence
  - Peaks = voicing: .46 to .58 (vowel [iy], from second .65 to .74 (vowel [ax]) and so on
  - Silence of stop closure (1.06 to 1.08 for first [b], or 1.26 to 1.28 for second [b])
  - Fricatives like [sh]: intense irregular pattern; see .33 to .46

Non-Local Cues



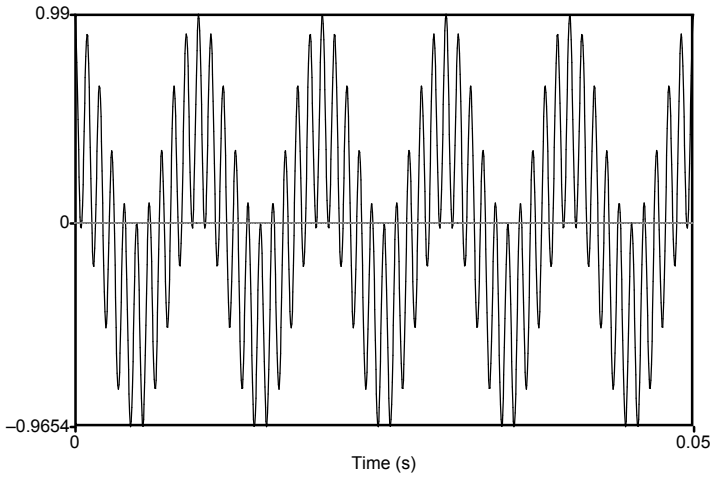
Example from Ladefoged

Simple Periodic Waves of Sound



- Y axis: Amplitude = amount of air pressure at that point in time
  - Zero is normal air pressure, negative is rarefaction
- X axis: Time.
- Frequency = number of cycles per second.
- 20 cycles in .02 seconds = 1000 cycles/second = 1000 Hz

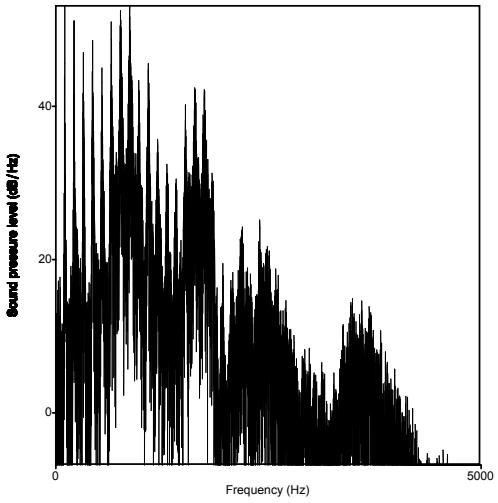
Complex Waves: 100Hz+1000Hz



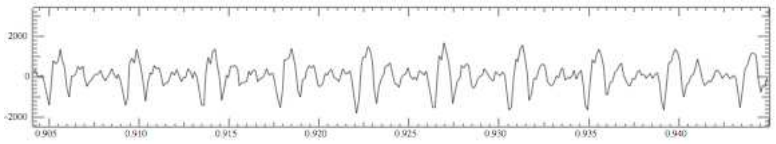
Spectrum

Frequency components (100 and 1000 Hz) on x-axis

Spectrum of an Actual Soundwave



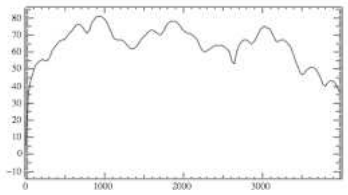
Part of [ae] waveform from “had”



- Note complex wave repeating nine times in figure
- Plus smaller waves which repeats 4 times for every large pattern
- Large wave has frequency of 250 Hz (9 times in .036 seconds)
- Small wave roughly 4 times this, or roughly 1000 Hz
- Two little tiny waves on top of peak of 1000 Hz waves

Back to Spectra

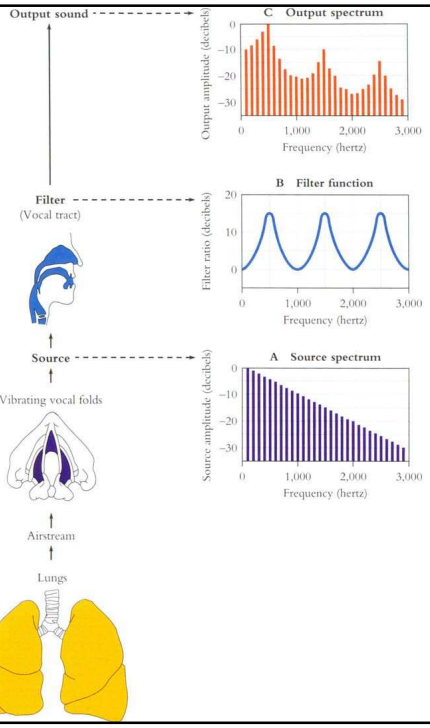
- Spectrum represents these freq components
- Computed by Fourier transform, algorithm which separates out each frequency component of wave.



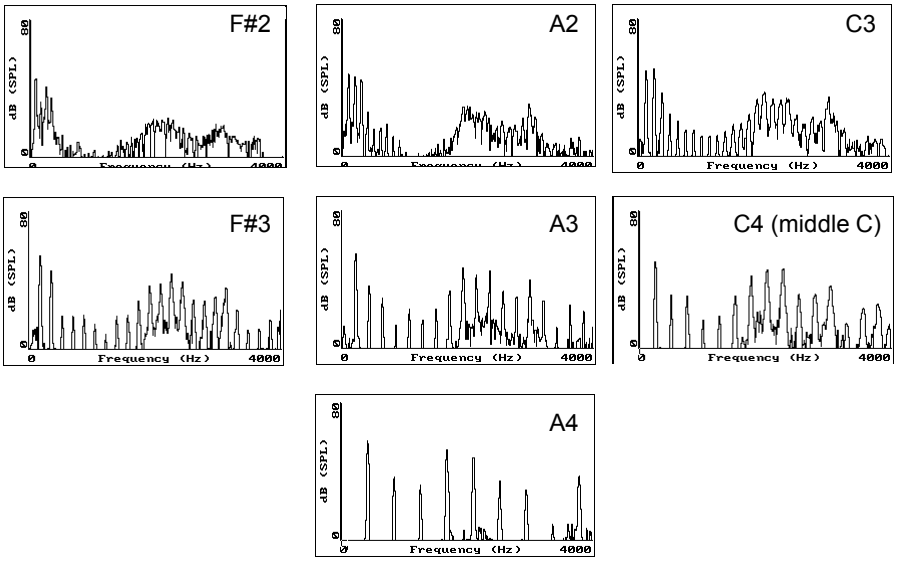
- x-axis shows frequency, y-axis shows magnitude (in decibels, a log measure of amplitude)
- Peaks at 930 Hz, 1860 Hz, and 3020 Hz.

Why these Peaks?

- Articulator process:
  - The vocal cord vibrations create harmonics
  - The mouth is an amplifier
  - Depending on shape of mouth, some harmonics are amplified more than others



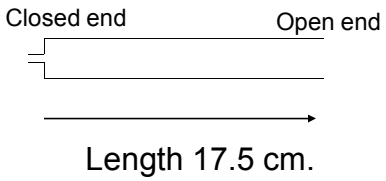
Vowel [i] sung at successively higher pitches



Figures from Ratree Wayland

Resonances of the Vocal Tract

- The human vocal tract as an open tube:



- Air in a tube of a given length will tend to vibrate at resonance frequency of tube.
- Constraint: Pressure differential should be maximal at (closed) glottal end and minimal at (open) lip end.

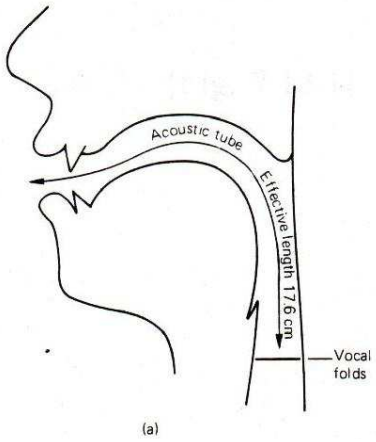
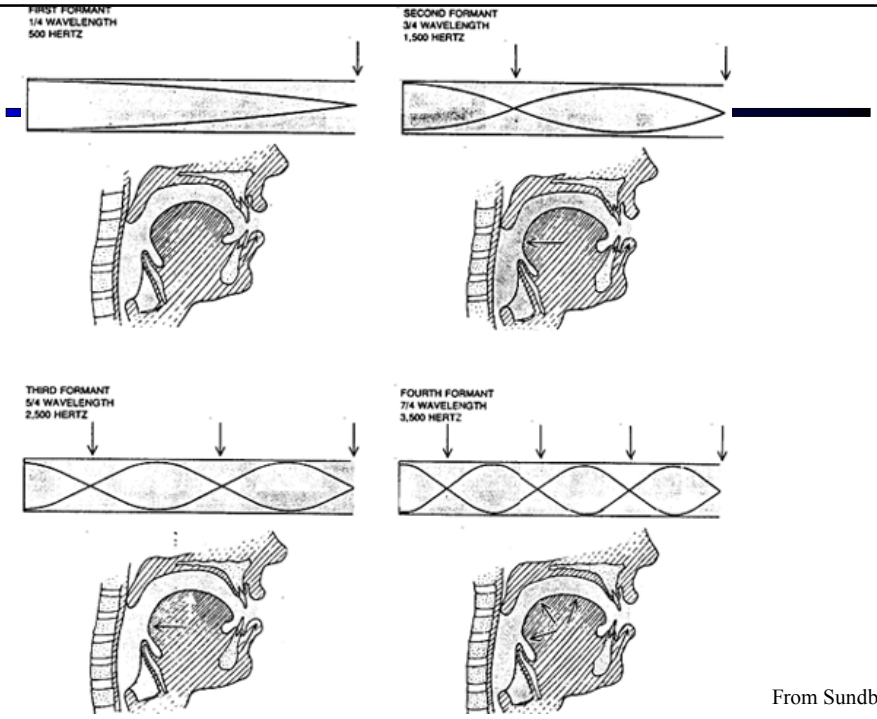


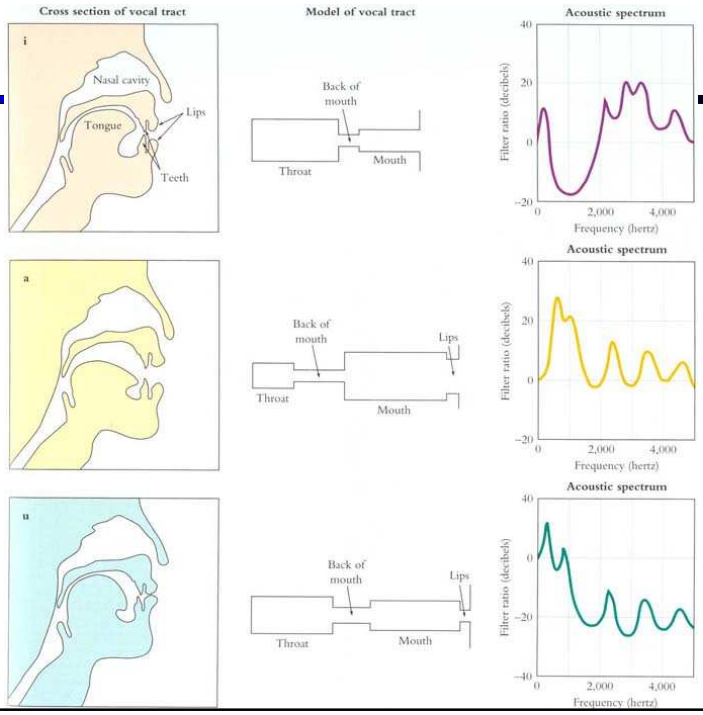
Figure from W. Barry



From Sundberg

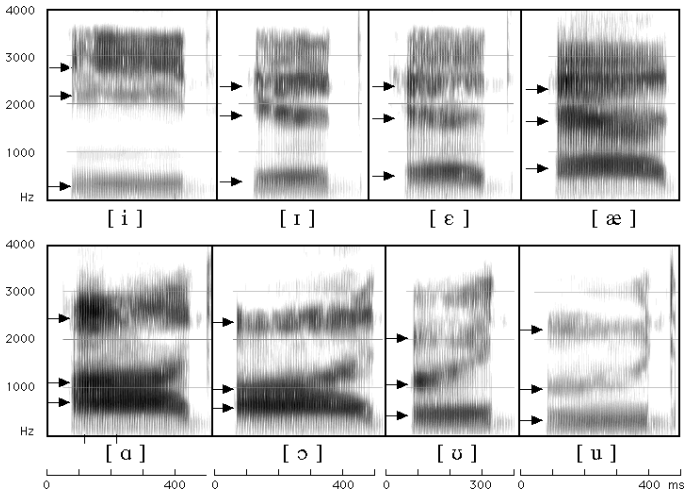
Computing the 3 Formants of Schwa

- Let the length of the tube be L
  - $F_1 = c/\lambda_1 = c/(4L) = 35{,}000/4*17.5 =$ 500Hz
  - $F_2 = c/\lambda_2 = c/(4/3L) = 3c/4L = 3*35{,}000/4*17.5 =$ 1500Hz
  - $F_3 = c/\lambda_3 = c/(4/5L) = 5c/4L = 5*35{,}000/4*17.5 =$ 2500Hz
- So we expect a neutral vowel to have 3 resonances at 500, 1500, and 2500 Hz
- These vowel resonances are called formants

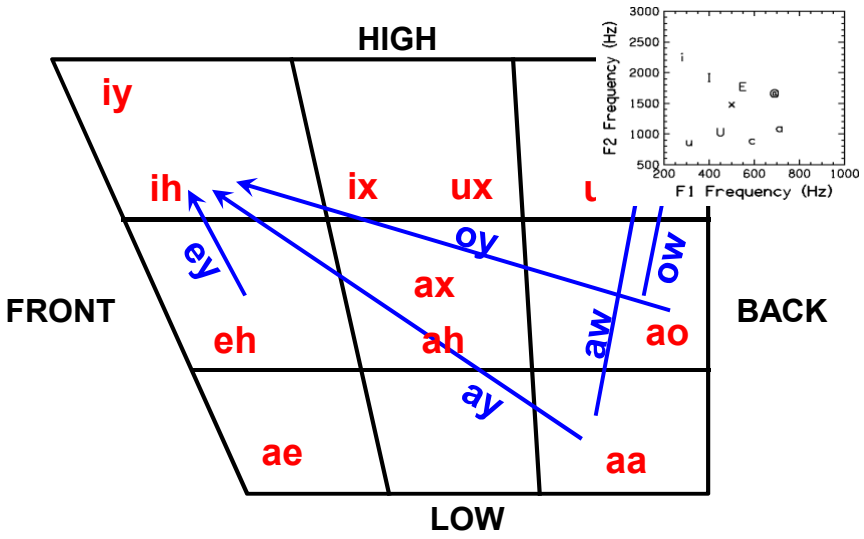


From Mark Liberman's Web site

Seeing Formants: the Spectrogram

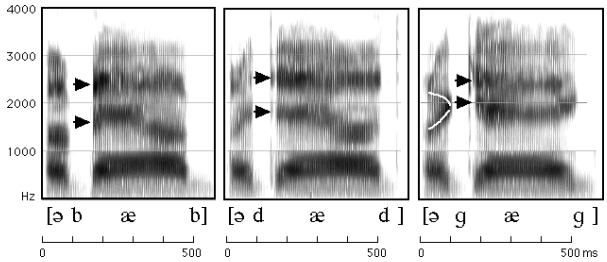


American English Vowel Space



Figures from Jennifer Venditti, H. T. Bunnell

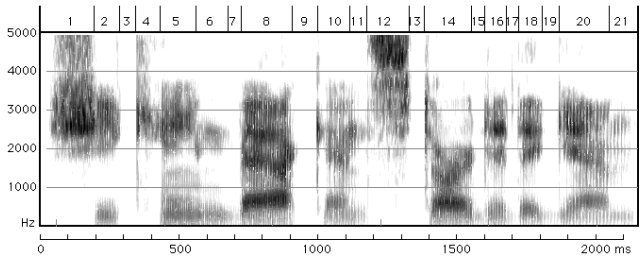
How to Read Spectrograms



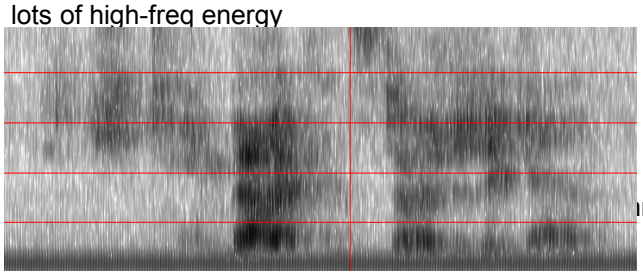
- bab: closure of lips lowers all formants: so rapid increase in all formants at beginning of "bab"
- dad: first formant increases, but F2 and F3 slight fall
- gag: F2 and F3 come together: this is a characteristic of velars. Formant transitions take longer in velars than in alveolars or labials

From Ladefoged “A Course in Phonetics”

“She came back and started again”



1. lots of high-freq energy
3.
4.
5.
6.
7.
8. ıning
9.



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