24.964
Topics in Phonology:
Phonetic Realization

- Readings for next week:

  Zhang (2004), Zhang (2001) ch.4.

Phonological representations

- Example – phonological representations in Chomsky and Halle (1968):
  – strings of segments, essentially as in IPA-style transcription.
  – each segment is specified as a matrix of binary feature specifications.
  – Features are defined phonetically, but in rather broad terms.

Phonetic and phonological representations

E.g. Halle and Clements:

Feature	Definition of the + value
[Syllabic]	'Constitute syllable peaks'
[Consonantal]	'Sustained vocal tract constriction at least equal to that required in the production of fricatives'
[Sonorant]	'Air pressure inside and outside the mouth is approximately equal
[Coronal]	'Raising the tongue blade towards the teeth or the hard palate'
[Anterior]	'Primary constriction at or in front of the alveolar ridge'
[Labial]	'With a constriction at the lips'
[Distributed]	'With a constriction that extends for a considerable distance along the midsaggital axis of the oral tract'
[High]	'Raising the body of the tongue toward the palate'
[Back]	'With the tongue body relatively retracted'
[Low]	'Drawing the body of the tongue down away from the roof of the mouth'
[Round]	'With protrusion of the lips'
[Continuant]	'Allowing the air stream to flow through the midsaggital region of the oral tract'

Image by MIT OpenCourseWare. Adapted from Halle, M., and N. Clements. *Problem Book in Phonology: A Workbook for Courses in Introductory Linguistics and Modern Phonology*. Cambridge, MA: MIT Press, 1983.

Phonetic and phonological representations

[Lateral]	'With the tongue placed in such a way as to prevent the air stream from flowing outward through the center of the mouth, while allowing it to pass over one or both sides of the tongue'
[Nasal]	'Lowering the velum and allowing air to pass outward through the nose'
[Advanced tongue root]	'Drawing the root of the tongue forward'
[Tense]	'With a tongue body or root configuration involving a greater degree of constriction than that found in their lax counterparts'
[Strident]	'With a complex constriction forcing the air stream to strike two surfaces (sic), producing high-intensity fricative noise'
[Spread glottis]	'With the vocal folds drawn apart, producing a non-periodic (noise) component in the acoustic signal'
[Constricted glottis]	'With the vocal cords drawn together, preventing normal vocal cord vibration'
[Voiced]	'With a laryngeal configuration permitting periodic vibration of the vocal cords'

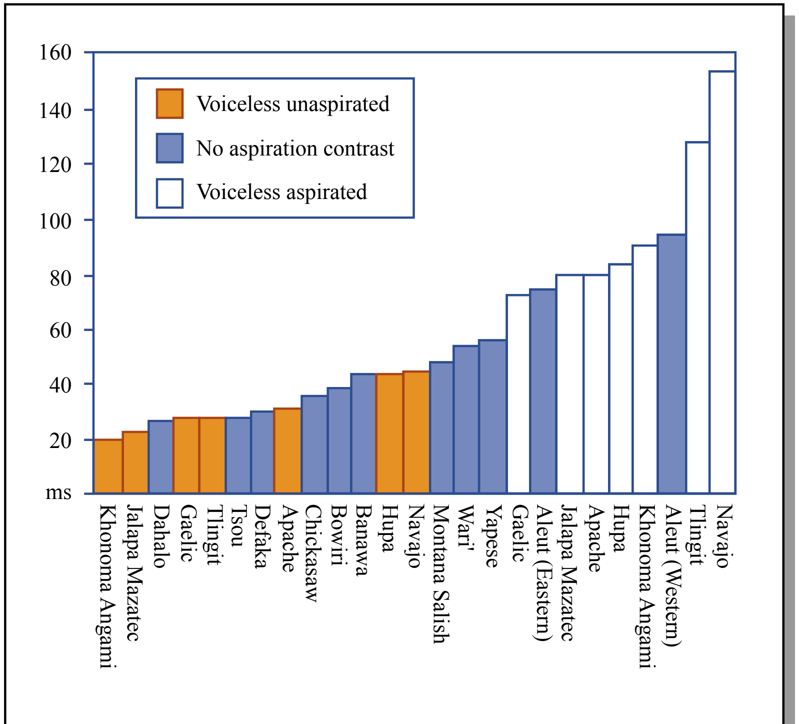
Image by MIT OpenCourseWare. Adapted from Halle, M., and N. Clements. *Problem Book in Phonology: A Workbook for Courses in Introductory Linguistics and Modern Phonology*. Cambridge, MA: MIT Press, 1983.

Phonetic and phonological representations

- So standard phonological representations can characterize speech to about the same level of detail as a broad phonetic transcription. The remaining detail is generally held to be the subject matter of phonetics.
  - Autosegmental and metrical phonology do not substantially change this picture.
- Chomsky and Halle proposed an intervening step: phonetic detail rules convert binary feature specifications into scalar values (hardly ever used).
- The remaining detail is supposed to be a matter of universal phonetics, and therefore not really part of grammar
- Keating (1985) etc: Universal phonetics cannot get us from SPE-style representations to phonetic realization because there is language-specific variation in phonetic details.

Evidence for language-specific phonetic detail - Cross-linguistic variation in the realization of phonological categories

- Voiceless aspirated and unaspirated stops (Cho and Ladefoged 1999, Ladefoged and Cho 2001).

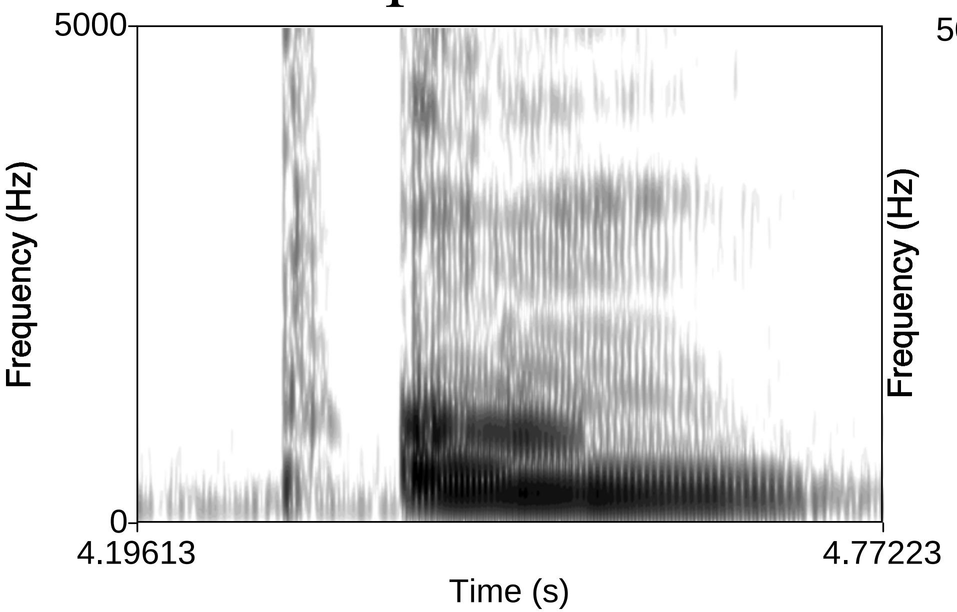


Mean VOTs (ms) for voiceless velar stops in 18 languages. (Values for voiced velar stops are not shown.)

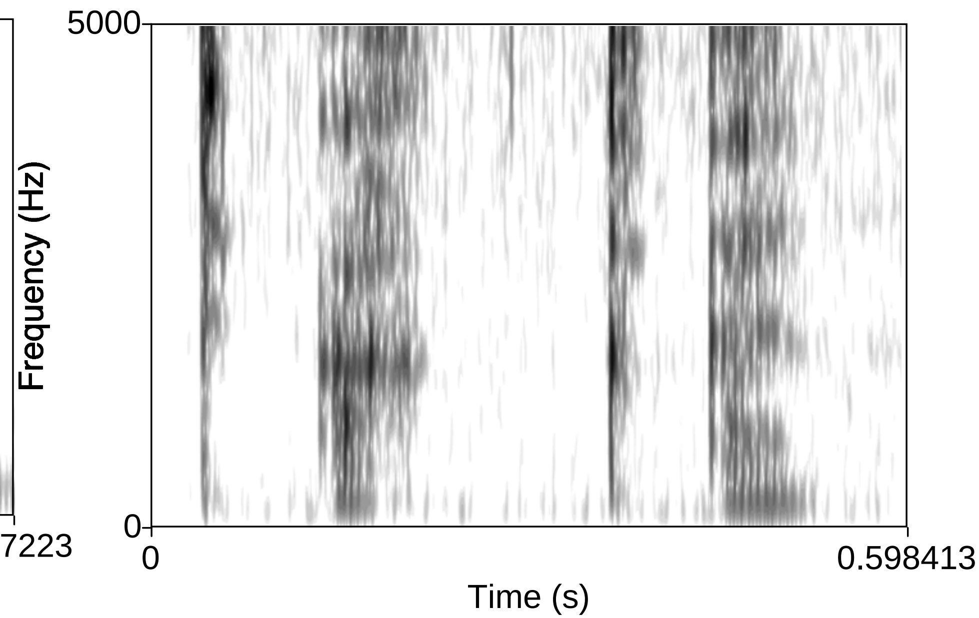
Image by MIT OpenCourseWare. Figure adapted from Ladefoged, Peter, and Taehong Cho. "Linking Linguistic Contrasts to Reality: The Case of VOT." *UCLA Working Papers in Phonetics* 98 (2001): 1-9. Reference: Cho, Taehong, and Peter Ladefoged. "Variations and Universals in VOT: Evidence from 18 Languages." *Journal of Phonetics* 27 (1999): 207-229.

Cross-linguistic variation in the realization of phonological categories

- ‘VOT’ in ejectives
- Examples: Montana Salish



p’úm



t’áq’ən

Audio: 1_clip1.wav.

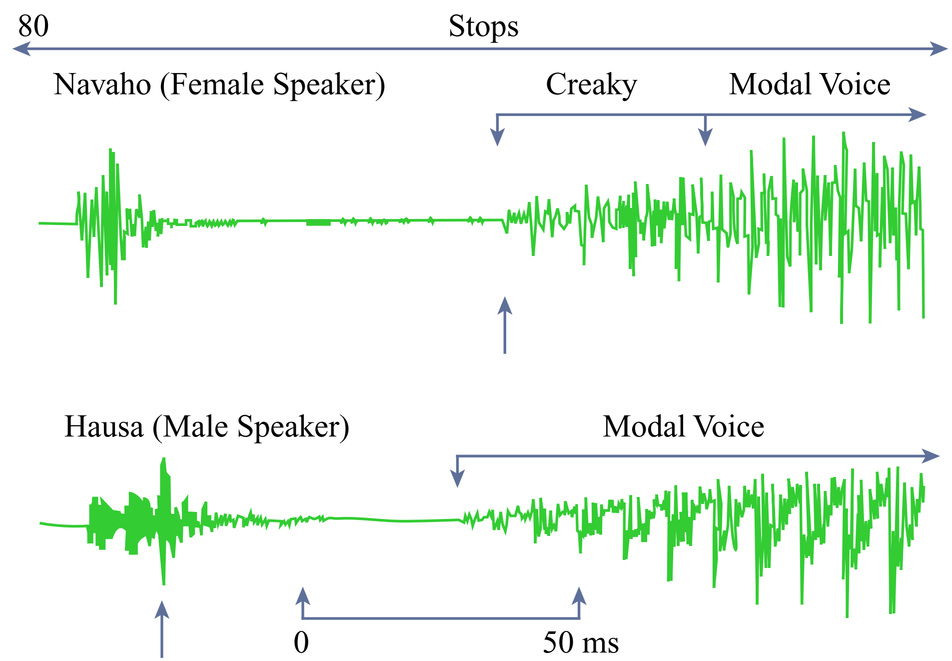
Audio: 1_clip2.wav.

VOT in ejectives

- Navaho [k’aːʔ] vs. Hausa [k’aːràː]
- Navajo 94ms vs. Hausa 33ms

For the sound files, please see Peter Ladefoged’s *A Course in Phonetics*
http://hctv.humnet.ucla.edu/departments/linguistics/VowelsandConsonants/course/contents.html

Specifically:
Chapter 11: Navajo
Chapter 6: Hausa



Waveforms illustrating differences between Navajo and Hausa ejectives. The arrows indicate the releases of the glottal closures.

VOT in ejectives

- Cho and Ladefoged (1999)

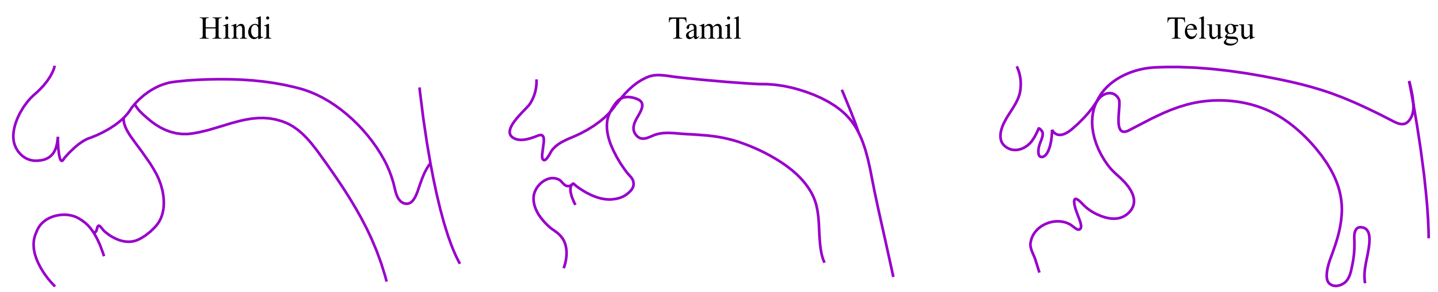
Voice Onset Time (ms) for Ejectives in Six Languages				
Language	Bilabial	Alveolar	Velar	Uvular
Apache		46	60	
Hupa		93	80	89
Montana Salish	81	65	86	81
Navajo		108	94	
Tlingit		95	84	117
Yapese	60	64	78	

Image by MIT OpenCourseWare. Adapted from Cho, Taehong, and Peter Ladefoged. "Variations and Universals in VOT: Evidence from 18 Languages." *Journal of Phonetics* 27 (1999): 207-229.

Degrees of retroflexion

Two (or more) degrees of retroflexion

- Apical post-alveolar, e.g. Hindi, vs. Sublaminal post-alveolar, e.g. Telugu (Ladefoged and Bhaskararao 1983)
- Phonologically: both [+coronal, -anterior, -distributed]?



X-ray tracings of the apical retroflex ɖ in Hindi and the sub-apical retroflex ɖ in Tamil and Telugu.

Vowel quality

- Similar front vowels of Danish (dotted) and English (solid) (Disner 1978, 1983).
- Danish vowels are systematically higher than their English counterparts.

Disner, S. (1978) "Vowels in Germanic Languages." *UCLA Working Papers in Phonetics* 40.

Disner, Sandra F. (1983). "Vowel quality: The relation between universal and language-specific factors." *UCLA Working Papers in Phonetics* 58. Ph.D. dissertation, University of California, Los Angeles.

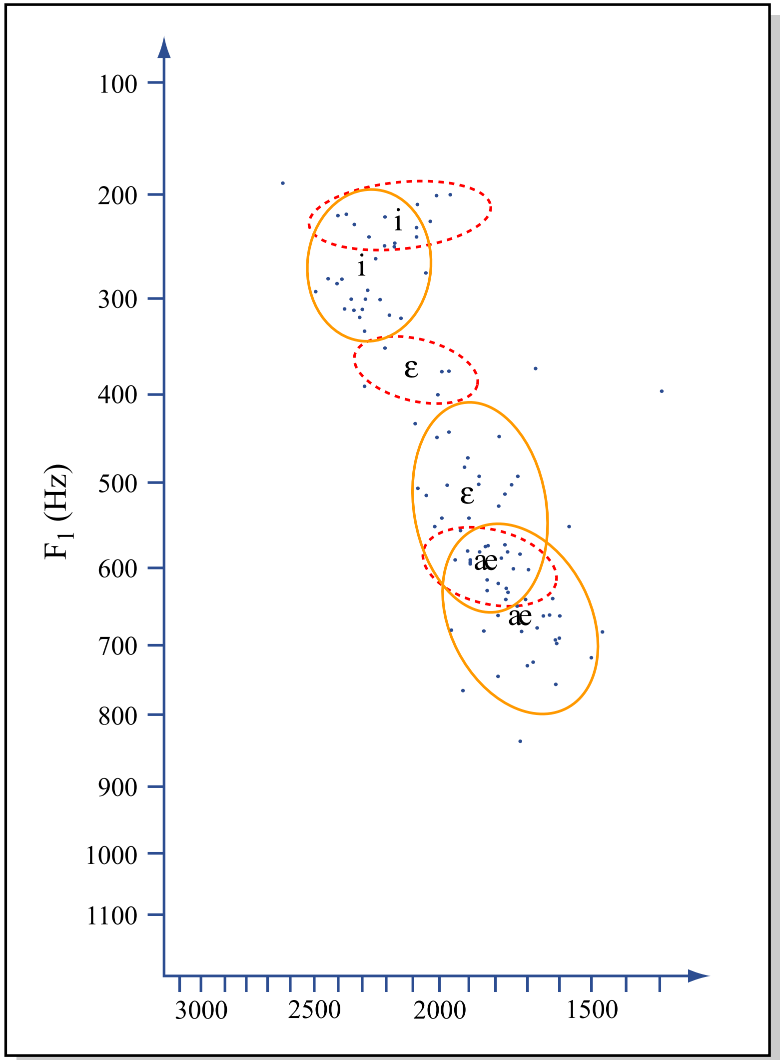


Image by MIT OpenCourseWare. Adapted from Disner (1983).

Cross-linguistic variation in contextual phonetic effects

Voicing effects on vowel duration.

- Vowels are shorter before voiceless obstruents than before voiced obstruents or sonorants in many languages (Chen 1970)
  - E.g. English [ɛ] is shorter in longer in ‘bet’ than in ‘bed’ and ‘ben’ (ratio is approx. 0.8).
- Language-specific variation (Keating 1985):
  - Effect is greater in English
  - No effect in Polish, Czech, Saudi Arabic
  - Effect conditioned by underlying voicing in Russian, German, English

Cross-linguistic variation in contextual phonetic effects

- Coarticulation
  – e.g. Nasalization adjacent to nasals (Cohn 1990, 1993).

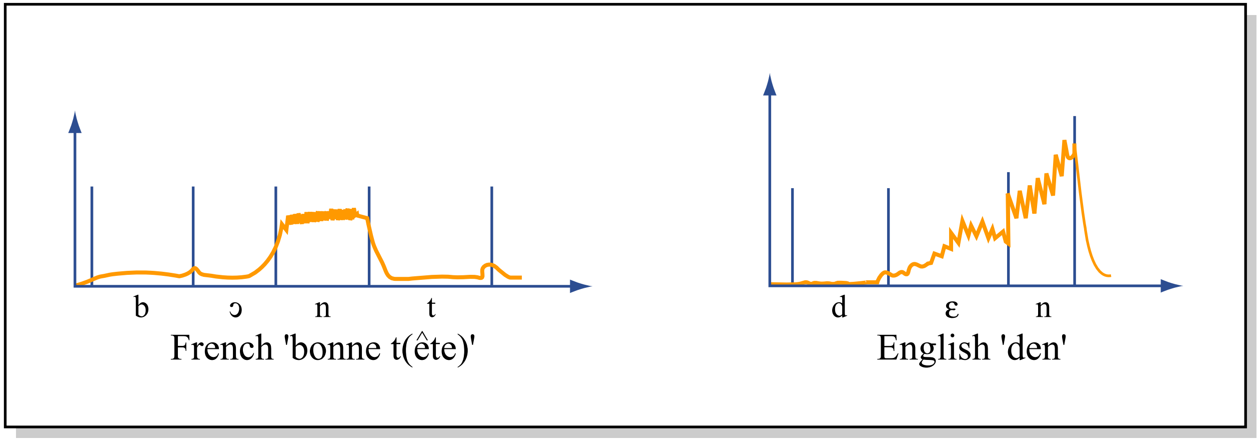
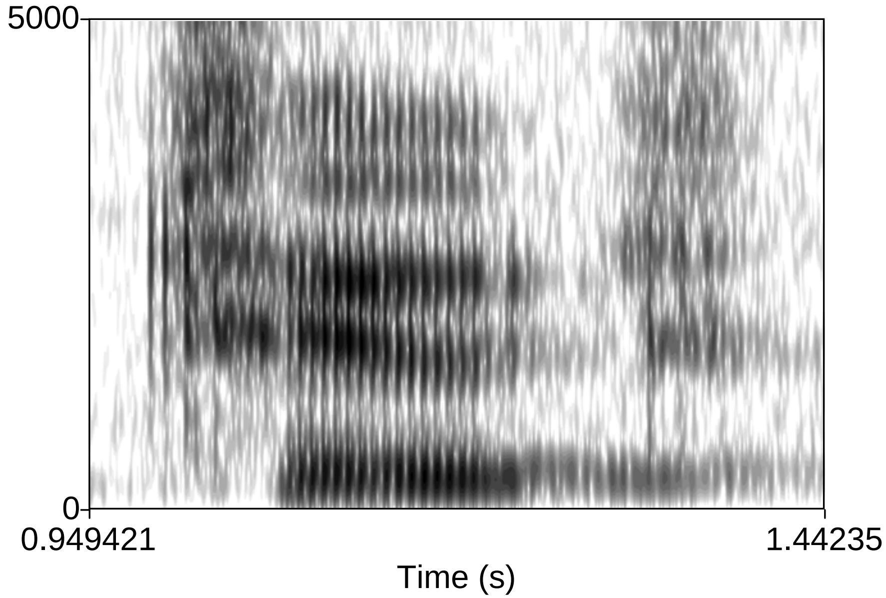


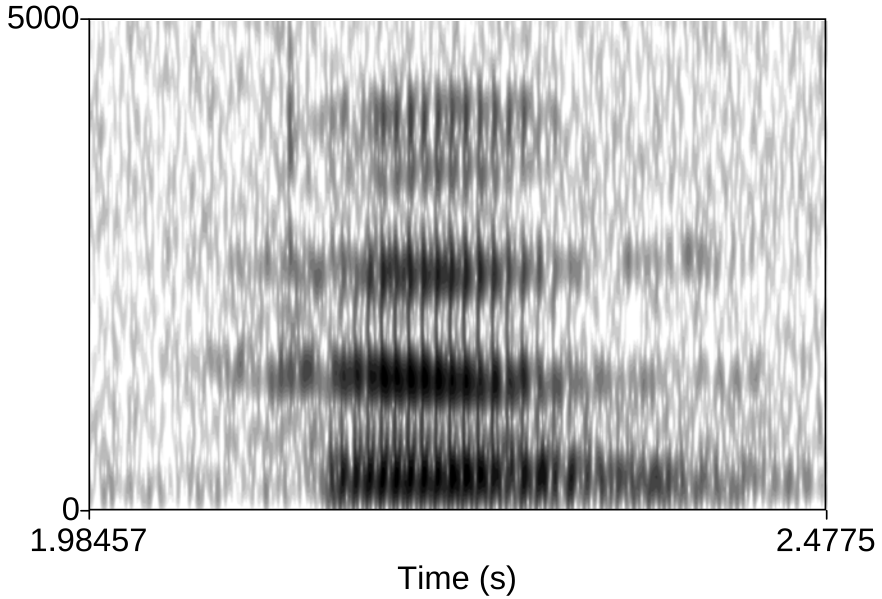
Image by MIT OpenCourseWare. Adapted from Abigail Cohn. "Phonetic and Phonological Rules of Nasalization." Ph.D. dissertation, University of California, Los Angeles, 1990. And Cohn, Abigail. "Nasalization in English: Phonology or Phonetics?" *Phonology* 10 (1993): 43-81.

Language-specific variation in coarticulation

- Fronting of vowels adjacent to alveolars and dentals.



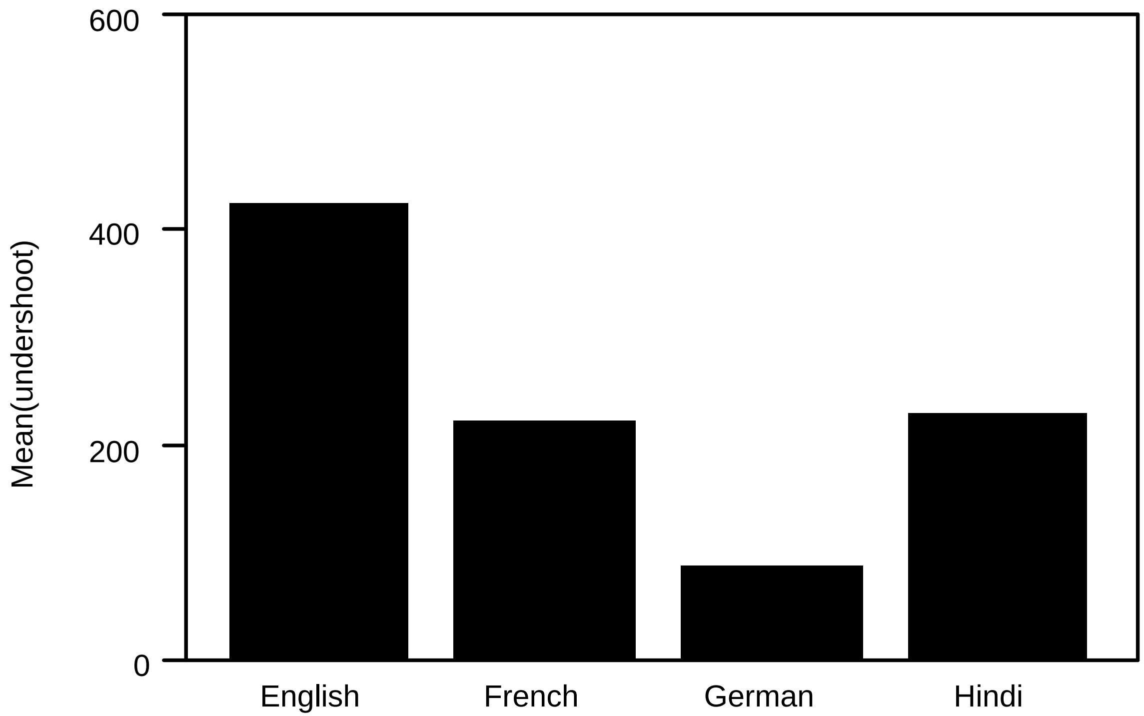
toot



who

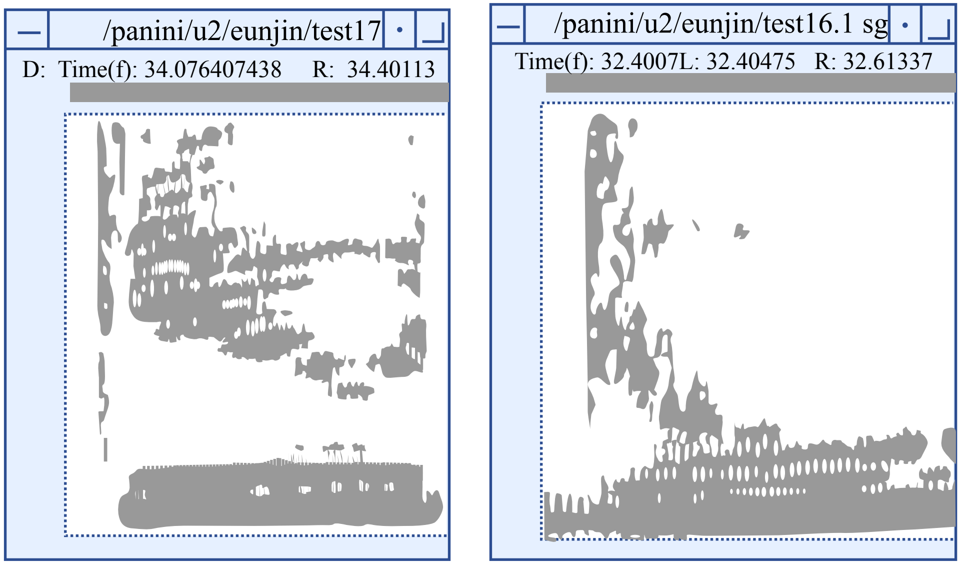
Language-specific variation in coarticulation

- Fronting of vowels adjacent to alveolars and dentals.



Language-specific variation in coarticulation

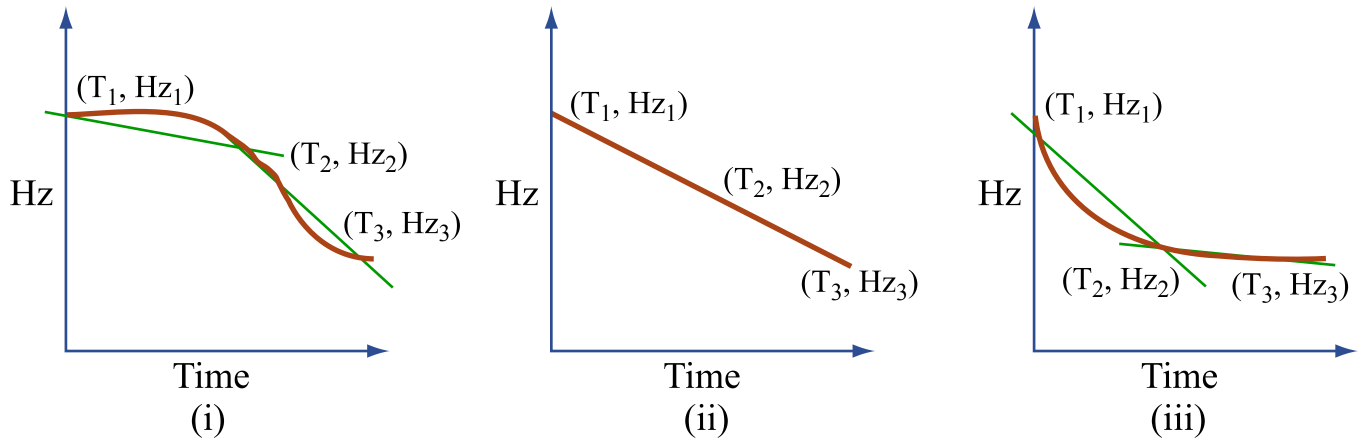
- The shape of the F2 trajectory in /du/ sequences (Oh 2000).



Sample spectrograms of [du] in native English (left) and French (right) speech.

Image by MIT OpenCourseWare. Adapted from Oh, Eunjin. *Non-native Acquisition of Coarticulation: The Case of Consonant-Vowel Syllables*. Ph.D. dissertation, Stanford University, 2000.

The shape of the F2 trajectory in /du/ sequences (Oh 2000).



Quantifying the distinct trajectory shapes: Slope change values.

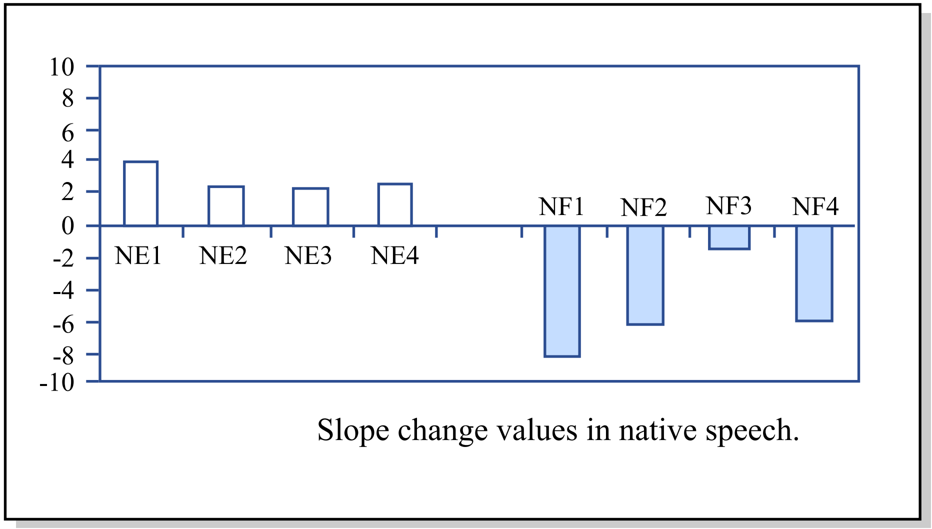
(i) $\left(\dfrac{Hz_2 - Hz_1}{T_2 - T_1}\right) - \left(\dfrac{Hz_3 - Hz_2}{T_3 - T_2}\right) > 0$

(ii) $\left(\dfrac{Hz_2 - Hz_1}{T_2 - T_1}\right) - \left(\dfrac{Hz_3 - Hz_2}{T_3 - T_2}\right) = 0$

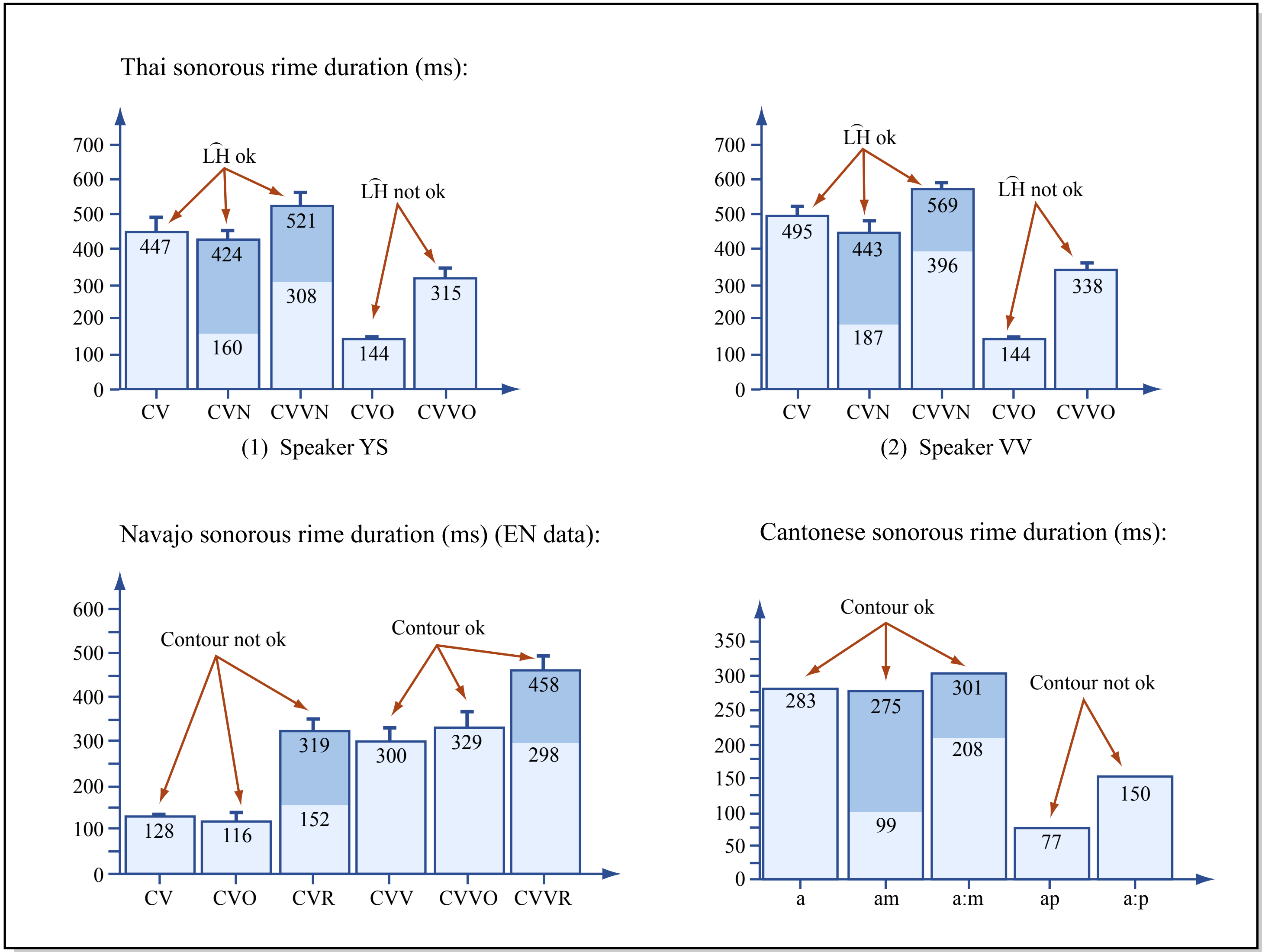
(iii) $\left(\dfrac{Hz_2 - Hz_1}{T_2 - T_1}\right) - \left(\dfrac{Hz_3 - Hz_2}{T_3 - T_2}\right) < 0$

Image by MIT OpenCourseWare. Adapted from Oh, Eunjin. *Non-native Acquisition of Coarticulation: The Case of Consonant-Vowel Syllables*. Ph.D. dissertation, Stanford, 2000.

The shape of the F2 trajectory in /du/ sequences (Oh 2000).



Vowel duration (Zhang 2001)



Vowel duration before geminates

- Italian: vowels are ~25% shorter before geminates than before singletons (Esposito & Di Benedetto (1999).
  - Preceding vowel duration is a cue to the geminate/singleton contrast.
- Japanese: vowels are generally longer before geminates (Isei-Jaakkola 2004).

m<u>a</u>ma	81 ms	m<u>a</u>maa	90 ms
m<u>a</u>mma	75 ms	m<u>a</u>mmaa	122 ms
p<u>a</u>pa	66 ms	p<u>a</u>paa	66 ms
p<u>a</u>ppa	81 ms	p<u>a</u>ppaa	88 ms

Summary

- There is language-specific variation in matters of relatively fine phonetic detail.
- Standard phonological representations cannot encode all of this detail.
- Therefore - either:
  - phonological representations need to be enriched, and/or
  - we should posit a phonetic realization component of grammar
- Phonetics is as much a part of grammar as phonology or syntax.

Implications for phonology

- Phonological patterning depends on the phonetic properties of sounds.
  - e.g. distribution of place contrasts and phonetic cues to place.
- These phonetic properties are themselves the products of grammar, so an analysis that takes these properties as given is incomplete.
- What happens if the relevant properties are subject to language-specific variation?
- Modular feed-forward models of phonetics-phonology (Pierrehumbert 1980, Keating 1990, Cohn 1990 etc):
  - Phonology and phonetic implementation are separate modules.
  - The output of the phonology is passed to phonetic implementation.
  - No other information passes between the modules (no feedback).

Example: Neutralization of major place contrasts

	_V (_L)	**_#**	**_(N) _T (_F)**
Spanish **Japanese**		neutralization	assimilation
Diola Fogny			assimilation
English, **Russian**			

V = vowel; L= glides & liquids; N = nasals, T = stops, F = fricatives

Jun (1995), DeLacy (2001), Steriade (2001)

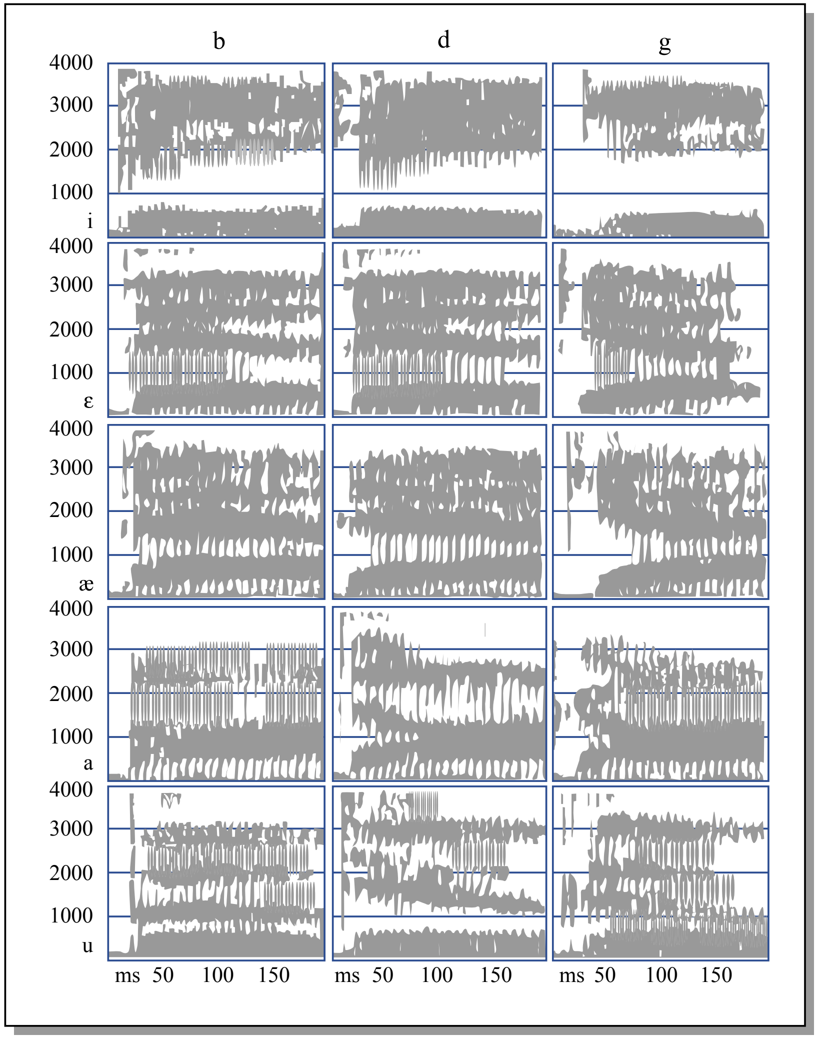
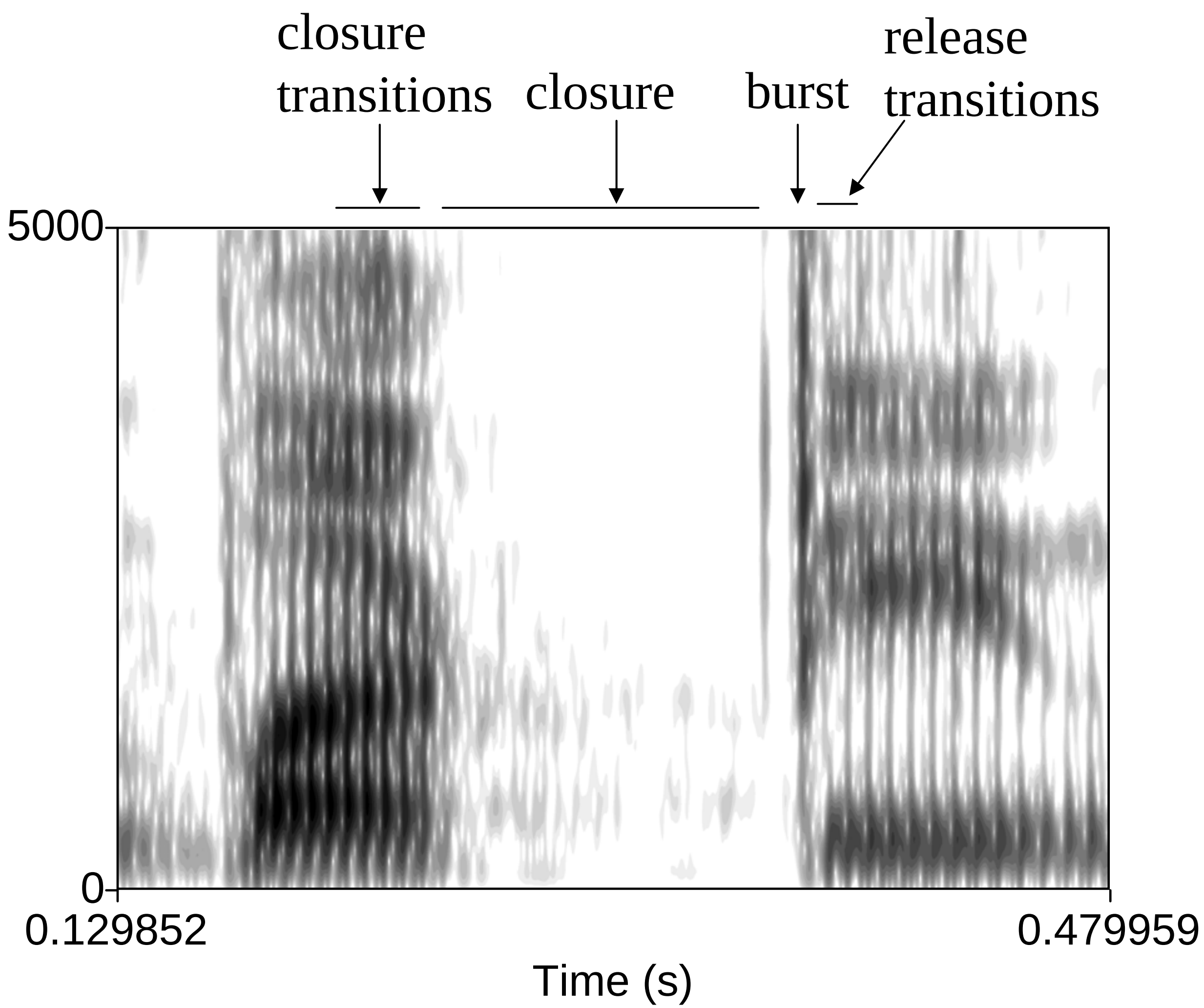


Image by MIT OpenCourseWare. Adapted from Ladefoged, Peter. *Phonetic Data Analysis*. Malden, MA: Blackwell, 2003.

Main cues to stop place:

- Release burst
- Formant transitions

Components of a stop



Major place neutralization

- Preferred environments for major place contrasts are contexts with more/better cues to place contrasts (Steriade 1999 etc).

_V	pa	burst, release transitions
V_T	ap˺ta	closure transitions
V_#	ap	closure transitions, burst

  - Release transitions are stronger cues to place than closure transitions (Fujimura et al 1978).
- General principle: a preference for more distinct contrasts

Questions:

- Why are stops audibly released in some contexts but not others?
  - What is the grammar of stop releases?
- Distribution of audible release of stops is language-specific. Does this affect the distribution of place contrasts?

Distribution of audibly released stops

English:

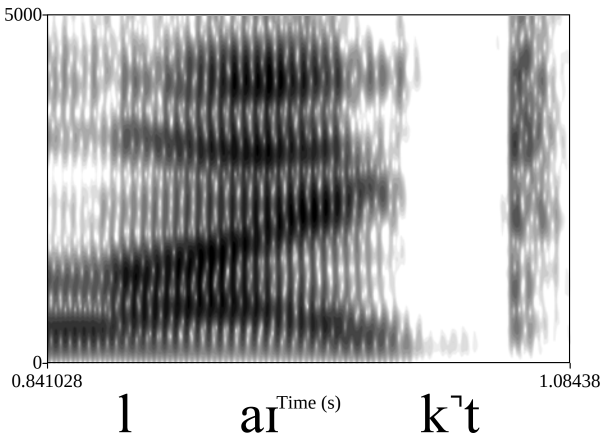
- no audible release of stops before non-approximants (word-internally)
- final stops can be released.

Korean:

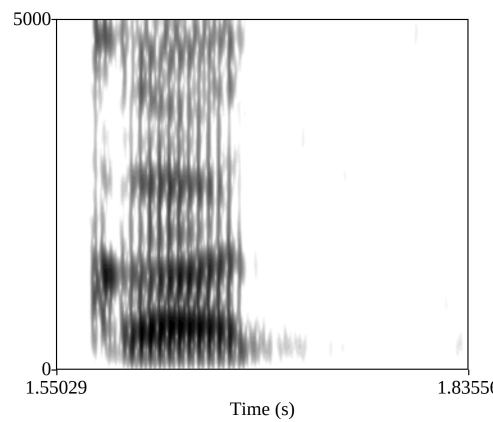
- no audible release of stops in clusters or word-finally.

Montana Salish:

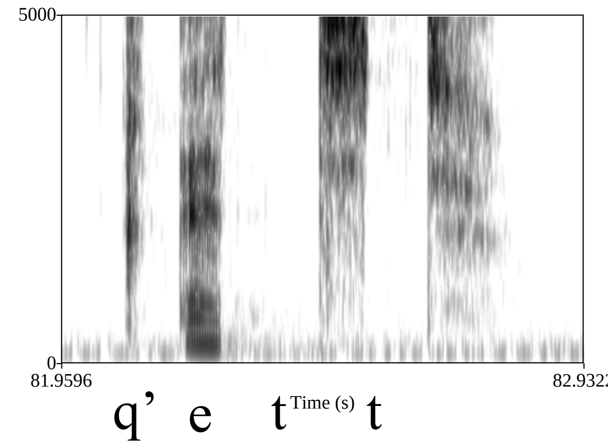
- stops are strongly released in all contexts.



Audio: 1_english.wav.



Audio: 1_korean.wav.



Audio: 1_salish.wav.

Implications for phonology

- The hierarchy above assumed that stops are not audibly released pre-obstruent but are released word-finally - this is not universal.
- Is the distribution of place contrasts sensitive to the actual distribution of stop releases in a language?
- Jun (2002): Yes - released preconsonantal stops are "resistant to phonological changes such as place assimilation" (Zoque, Tswana vs. Korean, Malayalam).
- This would be inconsistent with a model in which stop release is a matter of phonetic realization and phonology has no access to phonetic realization (modular, feedforward).
- Sensitivity of phonological patterns to language-specific details of phonetic realization would show that phonology must have access to those details.
  - As part of phonological representation (enriching phonology),
  - Or via some 'back-channel' from phonetics to phonology.

Implications for phonology

Models of phonetics/phonology that allow for effects of phonetic realization on phonology:

- ‘Unified’ phonetics-phonology (e.g. Flemming 2001, Zhang 2004).
  - Include all/relevant phonetic detail into phonological representations
  - Phonological constraints regulate phonetic detail in addition to distribution of contrasts, etc.
- Separate phonetic implementation and phonology, but phonetic implementation can affect phonology.
  - Steriade (1997:12) proposes that the ranking of *αvoice/X_Y constraints depends on the distinctiveness of voice contrasts, based on their language-specific phonetic realization (cf. Gordon 2004).
  - i.e. properties of phonetic implementation can affect ranking of phonological constraints.

Other cases

- Jun’s observations could be accommodated by adding the distinction between released/unreleased stops to phonological representations.
  - already proposed by McCawley 1967, Steriade 1993, etc.
- Other examples implicate language-specific details of segment durations in phonological patterning:
  - Zhang (2001, 2004): distribution of contour tones depends on sonorous rime duration.
  - Gordon (1999, 2004): distinction between heavy and light syllables depends on the loudness of the rimes of different syllable types.
    - loudness depends in part on duration.
  - Kawahara (2006): acceptability of devoicing a stop depends on extent of phonetic stop voicing.

The nature of phonetic implementation

One of the most explicit models of phonetic implementation: Pierrehumbert's (1980) analysis of English intonation

- Maps a sequence of H, L tones with numerical prominence values onto an f0 contour.
- General scheme: assign times/ f0 targets to tones, interpolate between targets.
- Examples of f0 assignment rules:

H-H scaling

$$/H^*_{i+1}/ = /H^*_i/ . \frac{\text{Prominence}(H^*_{i+1})}{\text{Prominence}(H^*_i)} \qquad \text{in } H^*_i(+L)\ (L+)H^*_{i+1}$$

Downstep

In H+L H_i and H L+H_i : $/H_i/ = k/H_i/$ where k is the downstep constant.

Upstep

in H-T%: /T/ = /H-/ + /T/

Constraint-based models of phonetic implementation

- Given an OT phonology, if phonological representations ar phonetically detailed, and there are constraints on those phonetic details, then we have an OT model of phonetic implementation.
- E.g. Gafos (2002) analyzes gestural coordination in an OT framework.

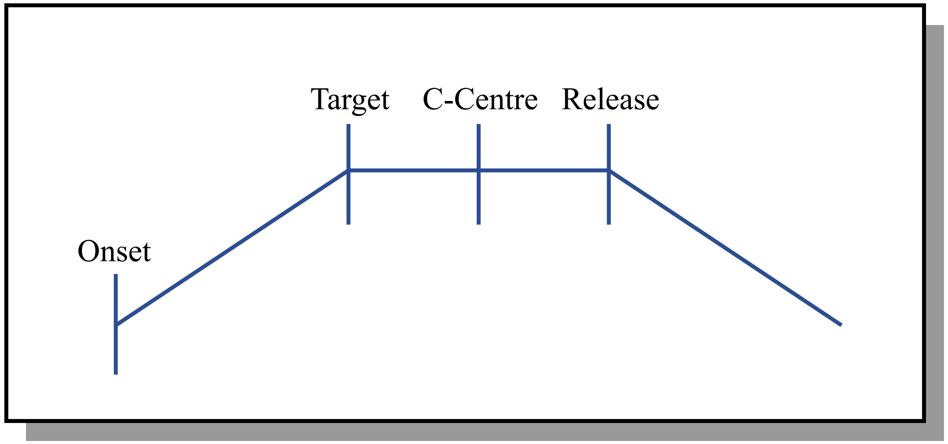


Image by MIT OpenCourseWare. Adapted from Gafos, A. "A Grammar of Gestural Coordination." *Natural Language and Linguistic Theory* 20 (2002): 269-337.

Overlap and stop releases

In consonant clusters, the presence or absence of stop releases can depend on the patterns of coordination between consonants.

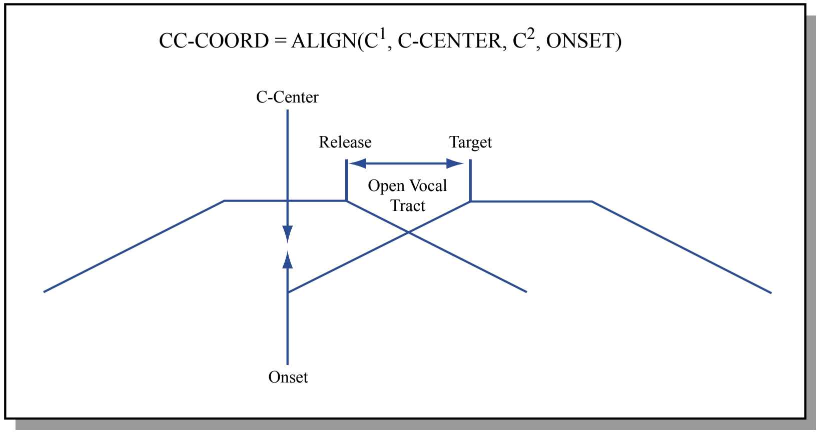


Image by MIT OpenCourseWare. Adapted from Gafos, A. "A Grammar of Gestural Coordination." *Natural Language and Linguistic Theory* 20 (2002): 269-337.

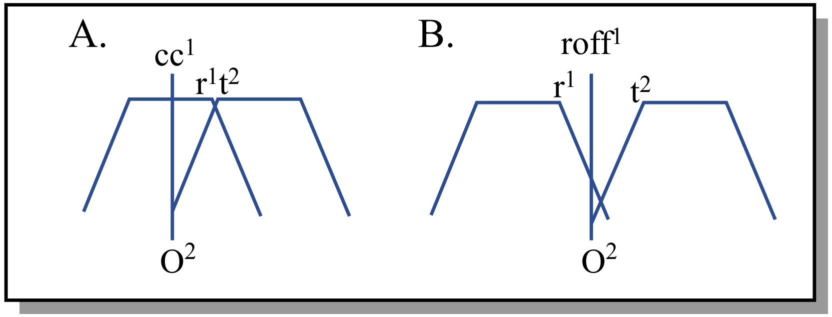


Image by MIT OpenCourseWare. Adapted from Gafos, A. "A Grammar of Gestural Coordination." *Natural Language and Linguistic Theory* 20 (2002): 269-337.

Constraint-based models of phonetic implementation

- Constraint-based models of phonetic implementation are interesting. whether or not phonetics is integrated with phonology.
- Offers an approach to the analysis of the typology of phonetic realization, unlike rule-based models.
  - Constraints are universal.
  - Prioritization of constraints is language-specific.
- Related proposals: Flemming (1997, 2001), Zsiga (2001).

Phonetic-phonological typologies

- It is common for phonetic explanations for phonological patterns to start from some observed phonetic facts about a language (‘stops are released in consonant clusters’).
- But these phonetic facts are as much in need of explanation as the distribution of contrasts.
- ‘Unified’ models of phonetics and phonology imply that the analyses of the distribution of contrasts and of the distribution of phonetic details can interact.
  - release of C1 in a C1C2 cluster could be motivated the constraint preferring distinct contrasts that motivates place neutralization.
  - i.e. release of a stop (phonetic detail) and neutralization of a place contrast (phonological) are alternative repairs for the same constraint violation (an insufficiently distinct contrast).
- Zhang (2001, 2004) develops a phonetic-phonological typology of positional effects on contour tones.

‘Too many solutions’

- Violations of a constraint can usually be repaired in many ways, in principle.
- E.g. *NT (Pater, Hayes): no sequences of a nasal followed by a voiceless obstruent.
  - /ampa/ -> [amba], [apa], etc, but not [aməpa]
- Steriade (2001) proposes that there is a universal preference for the phonetically minimal modification which can result in universally preferred repairs.
- Hypothesis: Part of the problem arises from a mischaracterization of the space of possible repairs resulting from incorrect formulation of constraints.
  - Correct constraints make crucial reference to phonetic detail
  - the space of alternative repairs includes modifications of phonetic detail.
  - these ‘phonetic’ modifications are often preferred since they are perceptually minimal.

‘Too many solutions’

- NT sequences are problematic because velum lowering associated with the nasal is liable to persist into the voiceless stop, and lowered velum vents air pressure, making rapid cessation of voicing more difficult.
- Two constraints
  - i. tendency to overlap gestures of adjacent segments, due to dispreference for rapid articulator movements.
  - ii. devoicing of a segment is more difficult if the velum is lowered.
- Direct repair (i) is to provide more time for the articulatory transition from velum open to velum closed (in turn solves (ii)).
  - E.g. lengthen the stop, raise the velum earlier, lengthen the whole cluster.
  - All seem to be attested in English (Hayes and Stivers, ms.)
- Vowel epenthesis does contribute the required time between nasal and stop, but it also (gratuitously) inserts a vowel - non-minimal repair.
- Formulating constraints in terms of coarse features creates a misleading impression of the nature of the markedness problem, and of the potential solutions.

Summary

- Phonetics is part of grammar like phonology or syntax.
  - resembles phonology in many ways
  - should be studied like phonology
- What is the form of phonetic realization
  - cf. phonology
- What is the typology of phonetic realization?
- What is its relation to phonology?

- Phonetics explains phonology
- what explains phonetics?
- what happens to phonetic explanation in the face of cross-linguistic phonetic variation.

References

- Chen, M. (1970) Vowel length variation as a function of the voicing of the consonant environment. *Phonetica* 22, 129-159.
- Cho, Taehong and Peter Ladefoged (1999). Variations and universals in VOT: evidence from 18 languages. Journal of Phonetics , 27, 207-229.
- Chomsky, Noam, and Morris Halle (1968). *The sound pattern of English*. Harper and Row, New York.
- Cohn, A. (1990) Phonetic and Phonological Rules of Nasalization. UCLA Working Papers in Phonetics 76.
- Cohn, A. (1993). Nasalization in English: Phonology or phonetics? Phonology 10, 43-81.
- de Lacy, Paul (2002). *The formal expression of markedness*. PhD dissertation, University of Massachusetts, Amherst.
- Disner, S. (1978) Vowels in Germanic Languages. UCLA Working Papers in Phonetics 40.
- Disner, Sandra F. (1983). *Vowel quality: The relation between universal and language-specific factors (UCLA Working Papers in Phonetics 58)*. Ph.D. dissertation, University of California, Los Angeles.
- Esposito A. and Di Benedetto, M. G. (1999) Acoustical and perceptual study of gemination in Italian stops. *Journal of the Acoustical Society of America* 106, 2051-2062.

References

- Flemming, E. (1997) Phonetic optimization: Compromise in speech production. *University of Maryland Working Papers in Linguistics 5: Selected phonology papers from H-OT-97*. 72-91.
- Flemming, E. (2001) Scalar and categorical phenomena in a unified model of phonetics and phonology. *Phonology* 18. 7-44.
- Fujimura, Macchi, and Streeter (1978). Perception of stop consonants with conflicting transitional cues: A cross-linguistic study. *Language and Speech* 21, 337-346.
- Gafos, A. (2002). A grammar of gestural coordination. *Natural Language & Linguistic Theory* 20, 269-337.
- Gordon, M. (1999). *Syllable weight: Phonetics, phonology, and typology*. Ph.D. dissertation, UCLA.
- Gordon, M. (2004). Syllable weight. Robert Kirchner, Bruce Hayes & Donca Steriade (eds). *Phonetically-Based Phonology*. CUP, Cambridge.
- Halle, M. & Clements, N. (1983). Problem Book in Phonology: A Workbook for Courses in Introductory Linguistics and Modern Phonology. MIT Press, Cambridge.
- Hayes, Bruce (1999). Phonetically driven phonology: the role of Optimality Theory and inductive grounding. In Darnell, Moravcsik, Newmeyer, Noonan, and Wheatley (eds.) (1999). 243-286.
- Hayes, Bruce and Tanya Stivers (1996). The phonetics of post-nasal voicing. Ms, UCLA.
- Isei-Jaakkola, T. (2004). *Lexical quantity in Japanese and Finnish*. Academic Thesis, University of Helsinki.
- Jun, Jongho (1995). *Perceptual and Articulatory Factors in Place Assimilation: An Optimality-Theoretic Approach*. PhD dissertation, UCLA.
- Jun, Jongho (2002). Positional faithfulness, sympathy and inferred input. Ms, Yeungnam University.

References

- Kawahara, S. (2006). A faithfulness ranking projected from a perceptibility scale: The case of [+voice] in Japanese. *Language* 82.3.
- Keating, P.A. (1985). Universal phonetics and the organization of grammars, *Phonetic Linguistics*, ed. V. Fromkin, Academic Press, 115-132.
- Keating, Patricia A. (1990). Phonetic representations in a generative grammar. *Journal of Phonetics* 18, 321-334.
- Ladefoged, Peter & Taehong Cho (2001) Linking linguistic contrasts to reality: The case of VOT. *UCLA Working Papers in Phonetics* 98, 1-9.
- Ladefoged, P.N. & Maddieson, I. (1996). *Sounds of the World's Languages*. Blackwell.
- Ladefoged, P.N. (2003). *Phonetic Data Analysis*. Blackwell.
- Ladefoged, Peter, and Peri Bhaskararao (1983). Non-quantal aspects of consonant production: A study of retroflex consonants. *Journal of Phonetics* 11: 291–302.
- McCawley, James D. (1967). The role of a system of phonological features in a theory of language. In Valerie Makkai (ed.) *Phonological Theory*. New York: Holt, Rinehart and Winston, 522-528.
- Oh, Eunjin (2000). *Non-native Acquisition of Coarticulation: The Case of Consonant-Vowel Syllables*. PhD dissertation, Stanford.
- Pater, Joe (1996). *NC. *Proceedings of the North East Linguistic Society* 26. Amherst: Graduate Linguistic Student Association, University of Massachusetts, 227-240.
- Pierrehumbert, Janet B. (1980). *The Phonology and Phonetics of English Intonation*. Ph.D. dissertation, MIT.
- Steriade, Donca (1997). Phonetics in phonology: the case of laryngeal neutralization. Ms, UCLA.

References

- Steriade, Donca. 2001. Directional asymmetries in assimilation. In E. Hume & K. Johnson (eds.), The Role of Perception in Phonology. New York: Academic Press. 219-278.
- Steriade, Donca (1993). Closure, release and nasal contours. Marie Huffman and Rena Krakow (eds) *Nasality: Phonological and phonetic properties*. Academic Press, New York, 401–470.
- Steriade, Donca (1999). Alternatives to syllable-based accounts of consonantal phonotactics. Osamu Fujimura, Brian D. Joseph, and Bohumil Palek (eds.) *Proceedings of LP '98: Item Order in Language and Speech*. Karolinum Press, Prague, 205-245.
- Zhang, Jie (2004). The role of contrast-specific and language-specific phonetics in contour tone distribution. Robert Kirchner, Bruce Hayes & Donca Steriade (eds). *Phonetically-Based Phonology*. CUP, Cambridge.
- Zhang, J. (2001). *The effects of duration and sonority on contour tone distribution*. PhD dissertation, UCLA.
- Zsiga, Elizabeth C. (2000). Phonetic alignment constraints: Consonant overlap and palatalization in English and Russian, *Journal of Phonetics* 28: 69 – 102.

24.964 Topics in Phonology: Phonetic Realization
Fall 2006