Phonological Systems and Complex Adaptive Systems
Dynamique du Langage Lab, CNRS, Lyon
July 6, 2005

Abby Cohn
Cornell University
acc4@cornell.edu

GRADIENCE AND CATEGORIALITY IN SOUND PATTERNS

1. Goal: Explore the nature of gradience vs. categoriality in the domain of linguistic sound systems and consider the implication of these patterns for the nature of phonetics vs. phonology

2. Phonology is most basically a system of contrasts, crucial to the conveyance of linguistic meaning.

   In what ways is phonology categorical —mirroring its function as defining contrast, and to what degree is phonology inherently gradient in its representation, production, perception, acquisition, social realization, and change over time?

3a. The physical realization of sounds, understood as abstract units, is continuous in time and space.

b. One crucial aspect of acquisition of a sound system is understanding how phonetic differences are marshalled into defining abstract categories.

c. Intraspeaker and interspeaker variation signal speaker identity, community identity and attitude, while simultaneously conveying linguistic meaning through minimally contrasting elements.

d. The results of many diachronic changes, understood to be "regular sound change" in the Neogrammarian sense, are categorical, yet how do changes come about?

The nature of phonetics vs. phonology

4. The relationship between phonology and phonetics, a fairly standard view:

   phonology = discrete, categorical
   ≠
   phonetics = continuous, gradient

   (For recent discussions of this view, see e.g. Keating 1996, Cohn 1998, 2003, Ladd 2003, also individual contributions in Burton-Roberts et al. 2000 and Hume and Johnson 2001.)

5.

a. Gradient phonetics	b. ~~Categorical phonetics~~
c. ~~Gradient phonology~~	d. Categoric phonology

6. Recent work calls this into question and suggests that b. and c. also exist.

7. It is particularly evidence claiming that there is gradient phonology that has led some to question whether phonetics and phonology are distinct.

8. Categorical vs. gradient?

   Pierrehumbert et al. (2000, p. 287) ". . . this assertion [that the relationship of quantitative to qualitative knowledge is modular] is problematic because it forces us to draw the line somewhere between the two modules. Unfortunately there is no place that the line can be cogently drawn. . . .

   In short, knowledge of sound structure appears to be spread along a continuum. Fine-grained knowledge of continuous variation tends to lie at the phonetic end. Knowledge of lexical contrasts and alternations tend to be more granular."

9. Evidence for a. categorical phonology & d. gradient phonetics

10. Generative phonetics: Growing out of Pierrehumbert's (1980) study of English intonation, gradient phonetic patterns are understood as resulting from phonetic implementation, through a mapping of categorical elements (usually understood as distinctive features) to continuous events. Gradient patterns are the result of transitions between targets and interpolation through phonologically unspecified domains.

11. An example: Nasal vowels in French vs. anticipatory nasalization in English (Cohn 1993) [A]

12. A modular view of grammar such as that espoused by Chomsky and Halle (1968, SPE) frames our modeling of more categorical and more gradient aspects of such phenomena as belonging to distinct modules (e.g. phonology vs. phonetics).

13. Such approaches have had many successes and have greatly advanced our understanding of phonological patterns and their realization. Results are seen most concretely in the success of many speech-synthesis-by-rule systems both in their modeling of segmental and suprasegmental properties of sound systems. (See Klatt 1987 for a review.)

14. An alternative to two separate modules is a unidimensional approach:
    -- Articulatory phonology (Browman and Goldstein 1992 and work cited therein), both phonology and phonetics understood as constellations of gestures.
    -- Some constraint-based views (e.g. Flemming 2001, Kirchner 2001, Steriade 2001, see also Hayes et al. 2004), constraints that manipulate phonological categories and those that determine the fine details of the phonetic realization constitute a single class.

15. The question of whether phonology and phonetics should be understood as distinct modules needs to be approached as an empirical question. What sort of approach gives us the best fit for the range of more categorical vs. more gradient phenomena?

16. A caveat: Just because it is difficult to know exactly where to draw the line (cf. Pierrehumbert et al. 2000), this does not mean there are not two separate domains of sound structure.

    The fact that it is difficult to draw a line is explained in part from the conception of *phonologization* (Hyman 1976).

17. Recent work suggests that phonology and phonetics are not the same thing, but that the distinction might be more porous than assumed following strict modularity (e.g. Pierrehumbert 2002 and Scobbie 2004). Pierrehumbert (2002, p. 103) states: ". . . categorical aspects of phonological competence are embedded in less categorical aspects, rather than modularized in a conventional fashion."

18. Evidence for b. categorical phonetics

a. Discontinuities in the phonetics – precisely the fundamental insight in Stevens (1989) Quantal Theory

b. Some examples, Huffman (1990) articulatory landmarks in patterns of nasalization, Kingston (1990) coordination of laryngeal and supralaryngeal articulations = binding theory, Keating (1990) high jaw position in English [s] [B]

c. There are many ways to model steady state patterns within the phonetics without calling in question any of the basic assumptions of the dichotomous model of phonology and phonetics.

Is there gradient phonology?

19. Evidence for c. gradient phonology

20. Definition: Most basically, we understand *gradient* and *gradience* in opposition to *categorical* and *categoriality*. A *gradient* (n.) in its original sense is a mapping from one continuous variable to another, i.e. a slope.

    It has also shifted to mean the continuous nature of a single variable.

21. Different uses of the term *gradience*: At least three senses of *gradience* have been prevalent in the recent phonetics/phonology literature—temporal/spatial gradience, variability, and gradient well-formedness (also used within Optimality Theory to refer to constraint satisfaction)

22. Temporal/spatial gradience — change in phonetic space through time

23. Variability: *Gradience* is also often used to refer to variable realizations or outcomes of sound patterns, understood as unpredictable or as stemming from various sociolinguistic and performance factors.

- It is not necessarily the case that temporal/spatial gradience and variability go hand in hand. There are well documented cases where they do not, that is, cases of variability that involve quite distinct categorical realizations, e.g. the allophones of /t/ and /d/ in English (Zue and Laferriere 1979). There are also patterns of temporal/spatial gradience that are highly systematic, as numerous studies of coarticulation and phonetic implementation show.

NB: What is sometimes interpreted as variability may in fact result from methodological approaches that are not fine-tuned enough in their characterization of conditioning factors or prosodic context. If these factors are not taken into consideration, one would conclude that there is variability, while the variation may in fact be systematic.

24. Gradient well-formedness: Speaker/hearers make relative judgements about the well-formedness of various sound structures.

- In the case of phonotactics, this is understood as resulting from stochastic generalizations across the lexicon. (See Frisch 2000 for a review and individual contributions in Bod, Hay and Jannedy 2003.)

- In such cases, it is the judgment about well-formedness or grammaticality that is gradient, not a physical event in time and space such as in the first sense.

25. Manifestation of *gradience* in different aspects of the phonology: Contrast, phonotactics, and alternations, both morphophonemics and allophony

26. Contrast (lexical): Some phonetic differences in the acoustic signal result in two distinct lexical items, i.e. minimal pairs. This is also the basis upon which inventories of sounds are defined.

27. Is contrast all or nothing? Or might it too be gradient in the sense of exhibiting gradient well-formedness?

- Some sounds contrast in some positions, but not others (positional neutralization), e.g, /a/ - /O/ in American English, only before coronals and in open syllables. What is the nature of realization of these sounds before non-coronals?

- The functional load of some contrasts is very limited, e.g. /θ/ vs. /ð/ in English (***th**igh vs. **th**y, **e**ther vs. **ei**ther, Be**th** vs. **eth***, that is [ð]).

- Is contrast realized the same way in these cases as in the more robust cases?

NB: Two different senses of the term contrast: Underlying or lexical contrast, and surface contrast, that is, identifiable phonetic differences independent of meaning, relevant in terms of comparisons of phonological categories across languages, also sometimes discussed in the case of near-neutralization.

28. Phonotactics: Allowable sound combinations or sequences

- Phonotactics can be defined by segmental context, prosodic position (often best characterized in terms of syllable structure); or morpheme- or word-position.

- Under many approaches to phonology, phonotactic patterns are understood to be categorical in nature. Combinations of sounds are understood to be either well-formed or ill-formed.

- Often phonotactic and allophonic patterns closely parallel each other and following most generative approaches to phonology, phonotactic patterns are captured with the same formal mechanisms as phonological alternations (thereby avoiding a "duplication" problem, e.g. Kenstowicz and Kisseberth 1977).

29. Recent work by a wide range of scholars (e.g. Pierrehumbert 1994, Vitevich et al. 1997, Frisch 2000, Bybee 2001, and Hay et al. 2003) suggests that phonotactic patterns can be gradient, in the sense that they do not always hold 100% of the time.

- Phonotactic patterns may reflect the stochastic nature of the lexicon and speaker/hearers are able to make judgments about the relative well-formedness of phonotactic patterns.

30. An example: phonotactics of English clusters, Pierrehumbert (1994)

-- How can we account for the distribution of medial clusters (in English)?

/mpr/, /ndr/ but not */rpm/ or */rdn/.

-- generative phonology predicts: medial clusters = possible codas + possible onsets

-- stochastic syllable grammar, that is "the likelihood of medial clusters derived from the independent likelihoods of the component codas and onsets" (p. 174) "The combination of a low-frequency coda and a low-frequency onset is expected to be a low-frequency occurrence." (p. 169)

-- systematic analysis of dictionary:

roughly 50 morpheme medial clusters

possible codas 147 + possible onsets 129

if freely combined = 18, 963

– restrictions ~ 8708

-- "It turned out that almost all the occurring triconsonantal clusters were among the 200 most likely combinations, and that a stochastic interpretation of syllable grammar effectively ruled out a huge number of possible clusters, eliminating the need for many idiosyncratic constraints in the grammar." (p. 169)

31. Recent work in psycholinguistics shows that speakers have access in at least some situations to very fine details including both speaker-specific and situation-specific information. (See Beckman 2003 and Pierrehumbert 2003 for review.)

- Thus, it is not that surprising that speakers are sensitive to degrees of well-formedness in phonotactic patterns and that these parallel in some cases distributions in the lexicon.

32. Are phonotactic patterns and other aspects of phonology (contrast and allophony) as closely associated as has been assumed in the generative phonological literature?

- Perhaps while similar and in some cases overlapping, phonotactics and other aspects of phonological patterning are not necessarily the same thing.

- This suggests that the standard generative phonology approach is reductionist in that it collapses distributional generalizations across the lexicon with other aspects of what is understood to be phonology.

33. Evidence suggests that we have access to finer details in at least some situations/tasks and some of these finer details may play a role in characterizing lexical entries. Thus, it cannot be, as often assumed following theories of underspecification in generative phonology, that lexical representations consist only of highly sparse contrastive information.

34. Two important caveats:

- Just because we are sensitive to finer details does not mean that we cannot abstract across the lexicon.

- Pierrehumbert (2003) argues that some phonotactic knowledge is not tied to frequency and indeed is true abstraction across the lexicon,
"In light of such results, I will assume, following mainstream thought in linguistics, that an abstract phonological level is to be distinguished from the lexicon proper." (p. 191).

- This suggests that we have access to both fine-grained and coarse-grained levels of knowledge and that they co-exist (see Beckman 2003 and Beckman et al. 2004).

35. Morphophonemic alternations: The surface form of a morpheme is systematically conditioned by phonological context
- Morphophonemic alternations are at the very core of what most phonologists think of as phonology. Most alternations are understood to be quite categorical in nature, often involving the substitution of distinct sounds in particular environments.

- If these sorts of cases are shown to involve gradience, this would strike at the core of our understanding of the phonology, since these are the least disputable candidates for "being phonology".

36. Steriade (2000) argues that there are phonetic paradigm uniformity effects, where non-contrastive phonetic details may be marshaled to indicate morphological relatedness.

"This paper aims to show that paradigmatic uniformity is enforced through conditions that govern both phonological features and properties presently classified as phonetic detail, such as non-contrastive degrees in the duration of consonant constrictions, non-contrastive details in the implementation of the voicing contrast, and degree of gestural overlap. . . There is a larger agenda behind this argument: the distinction between phonetic and phonological features is not conducive to progress and cannot be coherently enforced." (p. 314)

37. This very strong claim rests on two cases:

- Schwa deletion in French (see Barnes and Kavitskaya 2002 for critique)

- Flapping in American English: militaristic: military; but capi**D**alist: capi**D**al (as observed by Withgott 1983)

38. Two crucial assumptions:

p. 321 ". . . we suggest that PU [Paradigm uniformity] r(STRESS) should characterize not only stress identity between syllables but also the use of individual stress correlates (such as duration, pitch accents, vowel quality) to flag the stress profile of the lexical item to be accessed."

p. 322 "The difference between [ɾ] and [t]/[d] is a function of closure duration. . . . The extra-short duration of [ɾ] is a candidate for a never-contrastive property. . . "

-- Based on acoustic study, 12 speakers one repetition each, judgments based on impressionistic listening, Steriade concludes that PU (Stress: Duration) is responsible for observed base-derivative correspondence.

39. Steriade's (2000) claim that paradigm uniformity effects in American English flapping constitute evidence of subphonemic effects on morphology is called into question by Riehl's (2003a&b) experimental results

Riehl's study: 6 subjects, 12 repetitions each, acoustic analysis of closure duration, VOT, and voicing duration, perceptual classification by 3 listeners

For 4 pairs X 6 speakers (24 possible cases of paradigm uniformity):
7 cases uniform or nearly uniform (11/12 repetitions)
17 cases with variation within forms and within pairs

-- In cases of variation, stops usually earlier in the recording, flaps later (arguably shift from more formal to more casual speech)

-- Perception of flaps correlates best with VOT, not closure duration

40. This does not mean that there is no morphological influence on flapping, but suggests that the pattern may not be that strong. There is also a lack of compelling evidence to show that these effects are best understood as subphonemic paradigm uniformity.

41. Does this mean that there are not gradient effects in the domain of morphophonemics?

42. Allophony: Particular phones are in complementary distribution and are thus argued to be variants of the same underlying phoneme.

- Based on the definitions of SPE, allophony is understood to be part of phonology, due to its language-specific nature.

43. Is allophony necessarily categorical in nature or are there gradient aspects of allophony?

- Many cases of what was understood as allophony in categorical terms have been shown based on instrumental studies to be gradient, e.g. anticipatory nasalization in English (Cohn 1990, 1993), consonant cluster reduction in English, *perfect memory* (Browman and Goldstein 1990)

44. Three issues:

- Based on impressionist description, allophony appears to be quite categorical in nature. But both the tools we use (careful listening) and the symbols available to us (phonetic transcription which is discrete in nature) bias our understanding of these patterns as categorical.

- There has been a wide body of work arguing for a rethinking of the SPE definition of what is phonology and what is phonetics. Much work has identified the language-specific nature of phonetic patterns (e.g. Chen 1970, Keating 1985, Cohn 1990, Kingston and Diehl 1994), leading to a rethinking of where we draw the boundary between phonetics and phonology. Under these approaches many cases that have been thought of as phonological have been reanalyzed as phonetic.

- This still leaves us with the question of where to draw the line and whether we should draw a line.

45. Gradience in allophony in a different sense: Bybee (2001) and Jurafsky et al (2001) among others argue that lexical (token) frequency affects allophony in the sense that more frequent words are observed to be shorter and phonologically reduced.

- If what we think is allophony falls along a continuum rather than in two or three discrete categories, and if there is a strong correlation between the realization of a particular non-contrastive property and frequencies of particular lexical items in the lexicon, then this would be difficult to model in standard generative phonological models.

46. One of Bybee's widely cited cases:

    schwa deletion: *every* [Ø], *memory* [ɹ], *mammary* [ɚɹ]

    claim: "sound change is lexically and phonetically gradual, schwa deletion before [r] is more complete in high frequency words" (as stated by Lavoie 1996)

    NB: original study (Hooper 1976, 1978) was done based on speaker self-characterization

47. Lavoie (1996) tried to replicate Bybee's finding with a more systematic study, including acoustic measurements

    test items, correlation with absolute frequency? [C]

48. Schwa deletion in English does not show the expected correlation with frequency.

49. Are there cases where the phonology is based on frequency?

    -- Yes, when the frequency difference correlates with function vs. content word difference

    -- e.g. Lavoie (2002) reduction and phonetic realization of *for* vs. *four*

    -- Bybee argues that it is frequency that differentiates function words and content words, yet these frequency effects can also be understood to follow from the prosodic difference between content and function words.

50. Cohn et al. (2005) investigation of the phonetic durations of heterographic pairs of homophonous English nouns that differ in token frequency.

- Homophonous pairs grouped into three categories based on the magnitude of the frequency difference between the members of each pair, as determined by relative frequencies in five large corpora: Large Difference pairs (e.g., *time ~ thyme, way ~whey*), Medium Difference pairs (e.g., *pain ~ pane, gate, gait*), and Little or No Difference pairs (e.g., *son ~ sun, peace~ piece*).

- No systematic differences were found for individual speakers or across speakers.

- The lack of positive correlation between duration and token frequency calls into question the hypothesis that greater frequency leads to shorter duration.

- These results are interesting in light of Jurafsky's (2003) observation that evidence for frequency effects are better documented in comprehension than production. On the production side, effects are much more robustly documented for latency in lexical access than in phonetic duration differences.

- These results and observations highlight the need for a better understanding of the locus of frequency effects in the lexicon and in speech production.

51. Conclusions and implications

- Is there gradience in the phonology? Yes and no.

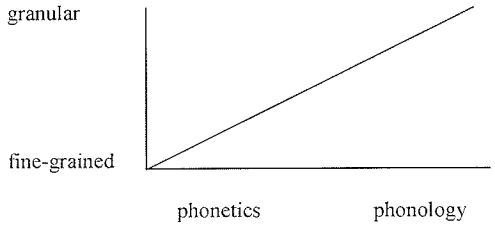
- The clearest evidence for gradience among the cases that we considered is gradient wellformedness, as documented in the case of phonotactics. It was less clear that there was a convincing empirical basis for the specific claims made by Steriade in terms of subphonemic effects in paradigm uniformity and those made by Bybee regarding frequency effects in allophony.

52. However the shakiness of the specific cases does not answer the question of whether there is gradience in phonology in the areas of morphophonology and allophony. In both cases, the conclusion about whether there is gradience in the phonology depends in part on the definition of phonology and how we understand phonology in relationship to phonetics.

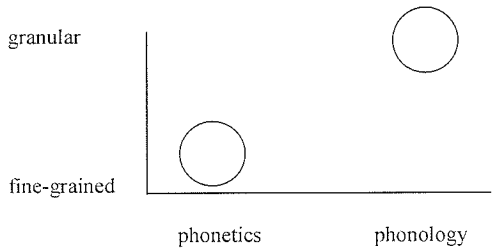
53. Are phonetics and phonology distinct domains?

- A modular view of the grammar necessarily leads us to a mapping approach between the phonology and phonetics view. On the other hand, focusing primarily on the gray area, cases that are particularly difficult to classify, and defining similarity as "duplication" lead us to a unidimensional view.

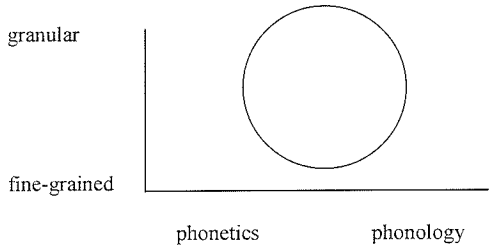
54. a. Continuum between phonetics and phonology (x-axis) and fine-grained and granular (y-axis) dimensions of speech



b. distribution of data, modular approach



c. distribution of data, unidimensional approach



55. The nature of modularity. Hale and Reiss (2000, p. 162) state "The modular approach to linguistics, and to science in general, requires that we both model the interactions between related domains, and also sharply delineate one domain from another."

- Is there strict modularity? Does modularity entail sharp delineation? Could there be modularity that is not rigid?
- Does a division of labor contribute to both descriptive adequacy and explanatory adequacy?

56. The status of Occam's Razor, or the principle of parsimony.

- Not only is there redundancy within domains, but there appears to be redundancy across domains, so "duplication" is not a problem, but in fact an intrinsic characteristic of language.

57. The relationship between phonetics and phonology is a multifaceted one.

- It reflects phonetic constraints that have shaped synchronic phonological systems through historical change over time.
- Synchronically, phonological systems emerge as a balance between the various demands placed on the system, but the evidence suggests that phonology cannot be reduced to the sum of these influences.
- Phonetics and phonology also need to be understood in relationship to the lexicon. There are parallels and overlaps between these three areas, but none of them is properly reduced to or contained in the others.
- Language patterns are fundamentally fluid. There is evidence of phonologization, grammaticalization, lexicalization, and so forth. Similar patterns can be observed across these domains.
- To reach a fuller understanding of the workings of the sound system and the lexicon, we need be willing to reconsider widely held assumptions and ask in an empirically based way what is the connection between these domains of the linguistic system.

References

Barnes, J. and D. Kavitskaya (2002) Phonetic analogy and schwa deletion in French, presented at the Berkeley Linguistic Society.

Beckman, M. (2003) Input representations (inside the mind and out). *WCCFL 22 Proceedings*, ed. M. Tsujimura and G. Garding. Somerville, MA: Cascadilla Press, pp. 101-125.

Beckman, M., B. Munson, and J. Edwards (2004) Vocabulary growth and developmental expansion of types of phonological knowledge. LabPhon 9 preconference draft.

Bod, R., J. Hay and S. Jannedy (2003) *Probabilistic Linguistics*. Cambridge, MA: The MIT Press.

Browman, C. and L. Goldstein (1990) Tiers in articulatory phonology, with some implications for casual speech. In J. Kingston and M. Beckman (eds.). 341-376.

Browman, C. and L. Goldstein (1992) Articulatory Phonology: an overview. *Phonetica* 49: 155-180.

Burton-Roberts, N., Carr, P. & G. Docherty (2000) *Phonological Knowledge: Conceptual and Empirical Issues*. New York: Oxford University Press.

Bybee, J. (2001) *Phonology and Language Use*. Cambridge: CUP.

Chen, M. (1970) Vowel length variation as a function of the voicing of the consonant environment. *Phonetica* 22: 129-159.

Chomsky, N. and M. Halle (1968) *The Sound Pattern of English*, Harper and Row, New York.

Cohn, A. (1990) *Phonetic and Phonological Rules of Nasalization*. PhD dissertation, UCLA. Distributed as UCLA Working Papers in Phonetics 76.

Cohn, A. (1993) Nasalization in English: Phonology or phonetic. *Phonology* 10: 43-81.

Cohn, A. (1998) The phonetics-phonology interface revisited: Where's phonetics? *Texas Linguistic Forum* 41: 25-40.

Cohn, A. (2003) Phonetics in phonology and phonology in phonetics. Paper presented at 11th Manchester Phonology Meeting, Manchester, UK.

Cohn, A., J. Brugman, C. Clifford, and A. Joseph (2005) Phonetic Duration of English Homophones: An Investigation of Lexical Frequency Effects, presented at LSA, 79th meeting, Oakland, CA.

Flemming, E. (2001) Scalar and Categorical Phenomena in a Unified Model of Phonetics and Phonology. *Phonology* 18: 7-44.

Frisch, S. (2000) Temporally organized lexical representations as phonological units. In M. Broe and J. Pierrehumbert (eds.) *Papers in Laboratory Phonology V: Acquisition and the Lexicon*. Cambridge, England: Cambridge University Press, pp. 283-298.

Hale, M. and C. Reiss (2000) Phonology as cognition. In Burton-Roberts, N., Carr, P. & G. Docherty (eds.) *Phonological Knowledge: Conceptual and Empirical Issues*. New York: Oxford University Press. pp. 161-184.

Hay, J. Pierrehumbert, J. and M. Beckman (2003) Speech perception, wellformedness, and the statistics of the lexicon. In J. Local, R. Ogden, and R. Temple (eds.) *Phonetic Interpretation: Papers in Laboratory Phonology VI*. Cambridge: CUP.

Hayes, B., R. Kirchner, and D. Steriade (2004) *Phonetically Based Phonology*. Cambridge: CUP.

Hooper, Joan B. (1976) "Word Frequency in Lexical Diffusion and the Source of Morphophonological Change." In Christie, W. (ed.) *Current Progress in Historical Linguistics*. Amsterdam: North Holland, 95–105.

Hooper, Joan B. (1978) "Constraints on Schwa Deletion in American English." In Fisiak, J. (ed) *Recent Developments in Historical Phonology*. The Hague: Mouton, 183–207.

Huffman, M. (1990) Implementation of Nasal: Timing and Articulatory Landmarks. *UCLA Working Papers in Phonetics 75*.

Hume, E. and K. Johnson (2001) *The Role of Speech Perception in Phonology*. San Diego: Academic Press.

Hyman, L. (1976) Phonologization. In A. Juilland (ed.) *Linguistic Studies Offered to Joseph Greenberg*. Vol. 2 Saratoga: Anma Libri, pp. 407-418.

Jurafsky, D. (2003) Probabilistic modeling in psycholinguistics: Linguistic comprehension and production. In R. Bod, J. Hay and S. Jannedy (eds.) *Probabilistic Linguistics*. Cambridge, MA: The MIT Press, pp. 39-95.

Jurafsky, D. Bell, Gregory and Raymond (2001) Probabilistic relations between words: Evidence from reduction in Lexical Production, in Bybee and Hopper (eds) *Frequency and the emergence of linguistic structure*. Amsterdam: John Benjamins.

Keating, P. (1985) Universal phonetics and the organization of grammars. In V. Fromkin (ed) *Phonetic Linguistics: Essays in Honor of Peter Ladefoged*. Orlando: Academic Press, pp. 115-132.

Keating, P. (1990) The window model of coarticulation: articulatory evidence. In Kingston and Beckman (eds.). 406-434.

Keating, P. (1996) The Phonology-Phonetics interface. *UCLA Working Papers in Phonetics* 92: 45-60.

Keating, P. (1988) The window model of coarticulation: articulatory evidence. *UCLA Working Papers in Phonetics* 69: 3-29.

Kenstowicz, M and C. Kisseberth (1977) *Topics in Phonological Theory*. New York: Academic Press.

Kingston, J. (1990) Articulatory binding. In J. Kingston and M. Beckman (eds.). 406-434.

Kingston, J. and M. Beckman (1990) Papers in Laboratory Phonology I: Between the Grammar and the Physics of Speech. Cambridge: Cambridge University Press.

Kingston, J. and R. Diehl (1994) Phonetic knowledge. *Language* 70: 419-454.

Kirchner R. (2001) *An Effort-Based Approach to Consonant Lenition*. New York, NY: Routledge. [1998 UCLA Ph.D dissertation].

Klatt, D. (1987) Review of text-to-speech conversion for English. *JASA* 82.3: 737-793.

Ladd, D. R. (2003) "Distinctive phones" in surface representation. Written version of paper presented at LabPhon 8, to appear in the Proceedings.

Lavoie, L. (1996) Lexical frequency effects on the duration of schwa—Resonant sequences in American English. Poster presented at LabPhon 5, Chicago, IL June 1996.

Lavoie L. (2002) Some influences on the realization of *for* and *four* in American English. *JIPA* 32: 175-202.

Pierrehumbert, J. (1980) *The Phonology and Phonetics of English Intonation*. MIT Ph.D. dissertation.

Pierrehumbert, J. (1994) Syllable structure and word structure: A study of triconsonantal clusters in English. In Keating (ed.) Phonological Structure and Phonetic Form: Papers in Laboratory Phonology III, Cambridge: CUP, pp. 168-188.

Pierrehumbert, J. (2002) Word-specific phonetics. In Gussenhoven and Warner (eds) *Laboratory Phonology* 7. Mouton de Gruyter, pp. 101-139.

Pierrehumbert, J. (2003) Probabilistic Phonology: Discrimination and Robustness. In R. Bod, J. Hay and S. Jannedy (eds.) *Probabilistic Linguistics*. Cambridge, MA: The MIT Press, pp. 177-228.

Pierrehumbert, J., Beckman, M. E and Ladd, D. R. (2000) Conceptual foundations in phonology as a laboratory science. In Burton-Roberts, N., Carr, P. and Docherty, G. (eds) *Phonological Knowledge: Conceptual and Empirical Issues*, New York: Oxford University Press, 273-304.

Riehl, A. (2003a) American English flapping: Evidence against paradigm uniformity with phonetic features. *Proceedings of the 15th International Congress of Phonetic Sciences*, pp. 2753-2756.

Riehl, A. (2003b) American English flapping: Perceptual and acoustic evidence against pardigm uniformity with phonetic features. To appear in the *Working Papers of the Cornell Phonetics Laboratory 15*. 271-337.

Scobbie, J. (2004) Flexibility in the Face of Incompatible English VOT Systems. Written version of *Lab Phon 8* paper.

Steriade, D. (2000) Paradigm uniformity and the phonetics-phonology boundary, in M. Broe and J. Pierrehumbert (eds.) *Papers in Laboratory Phonology V: Acquisition and the Lexicon*. Cambridge, England: Cambridge University Press, pp. 313-334.

Steriade, D. (2001) Directional asymmetries in assimilation: A directional account. In E. Hume and K. Johnson (eds.) *The Role of Speech Perception in Phonology*. San Diego: Academic Press, pp. 219-250.

Stevens, K. (1989) On the quantal nature of speech. *Journal of Phonetics* 17. 3-45.

Vitevitch, M., P Luce, J. Charles-Luce, and D. Kemmerer (1997) Phonotactics and syllable stress: Implications for the processing of spoken nonsense words. *Language and Speech* 40: 47-62.

Withgott, M. (1983) *Segmental Evidence for Phonological Constituents*. PhD dissertation, Univerity of Texas, Austin.

Zue, V. and M. Laferriere (1979) Acoustic Study of Medial /t, d/ in American English. *JASA* 66: 1039-1050.

A.

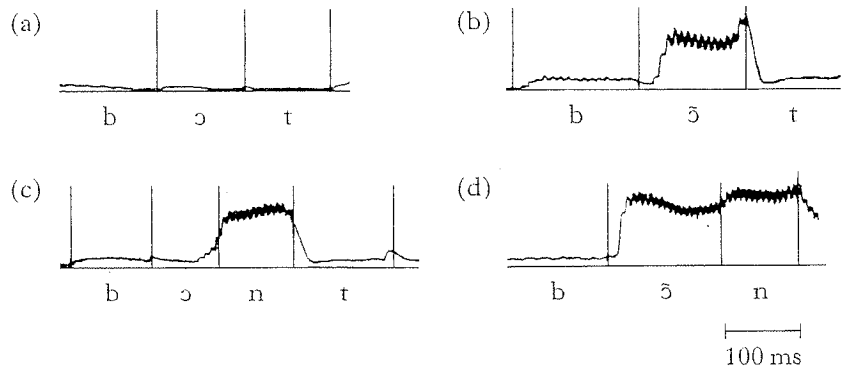
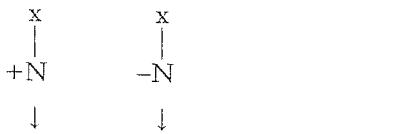


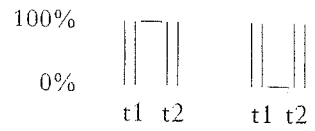
Figure 2
Nasal airflow traces for nasal and oral segments in French: (a) V *botte* /bɔt/ 'boot'; (b) Ṽ *bonté* /bɔ̃t(e)/ 'goodness'; (c) VN *bonne tête* /bɔnt(ɛt)/ 'good head'; (d) ṼN *bon nez* /bɔ̃#n(e)/ 'good nose'

(4) Phonological output:



Target assignment

Nasal airflow

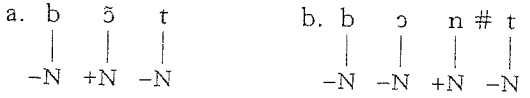


t = transition

(5) a. [−cont]/ — [+cont] > [+cont] (−C > +C)
b. If (a) doesn't apply, then [+nas] > [−nas] (+N > −N)

(6) *Sample derivations*

Phonological output:



Phonetic implementation: *(phonetic parameter: nasal airflow)*

Target assignment

Priority statements

–C > +C
+N > –N

+N > –N
+N > –N

Interpolation

(10) *Predicted outputs for VN patterns in English*

a. Phonological rule
b. Phonetic interpolation

Phonological output:

Phonetic implementation:

Target assignment and interpolation

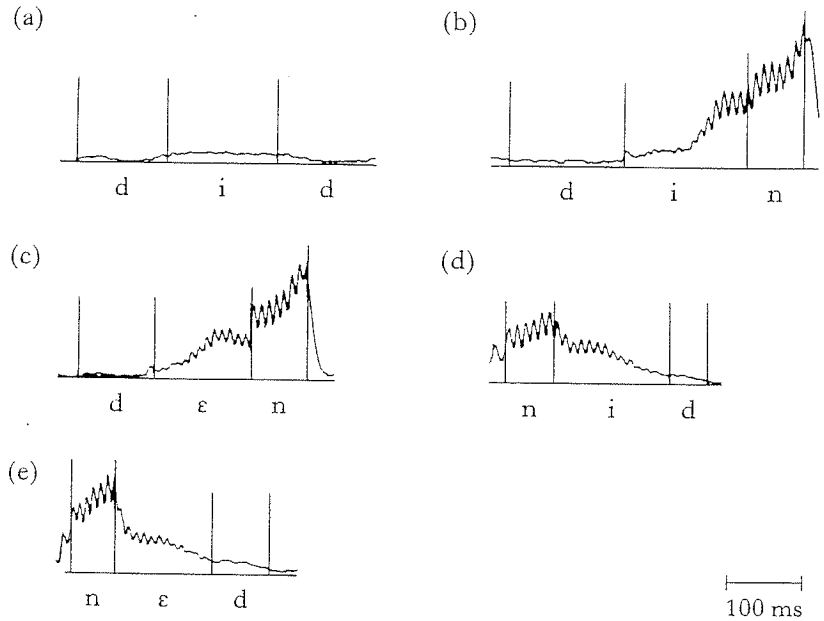


Figure 4
Nasal airflow traces for VN and NV in English: (a) V *deed* /did/; (b) VN *dean* /din/; (c) VN *den* /dɛn/; (d) NV *need* /nid/; (e) NV *Ned* /nɛd/

(11) *Sample derivations*

Phonological output:

a. d i n
−N +N

b. n i d
+N −N

Phonetic implementation:

Target assignment

Priority statements n/a n/a

Interpolation

B.

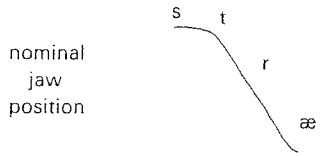


Figure 26.6 Vertical position of a point on the jaw in /stræ/, after Amerman et al. (1970).

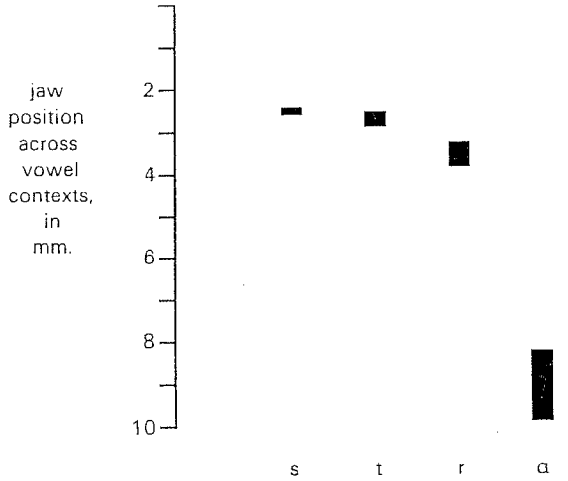


Figure 26.7 Range of mean extreme values for jaw position for four segments, from data of Keating et al. (1987).

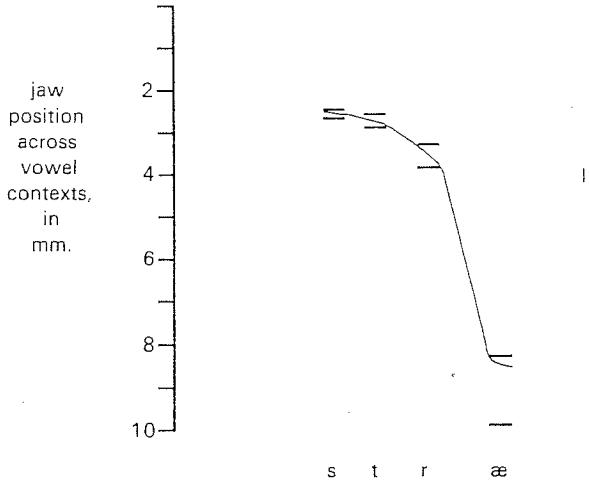


Figure 26.8 Sequence of schematic jaw windows for /stræ/, with contour.

C. Lavoie (1996)

Test items

- Frequencies from Francis & Kucera (1982)

Deleted* Schwa		Syllabic Resonant		Schwa + Resonant	
every	490	memory	91	mammary	0
delivery	19	ivory	14	livery	5
separate (adj.)	65	separate (verb)	14	lacerate	2
strawberry	2	raspberry	1	gooseberry	0
nursery	14	grocery	9	cursory	4
chocolate	9	desolate	6	particulate	3
family	314	simile	1	homily	0
chancellor	14	bachelor	10	jeweler	3
frightening	14	whitening	1	heightening	1

Correlation with absolute frequency?

- No inverse correlation between word's absolute frequency and schwa duration