1. Introduction
- It is common for phonologists to argue that particular constraints are phonetically grounded (or phonetically motivated).

E.g. *[+voice, -sonorant], *[+high, -ATR]

What is phonetic grounding?
  i. Maximize the distinctiveness of contrasts
  ii. Minimize articulatory effort
  iii. Maximize rate of transmission

What is the significance of phonetic grounding?
- Reassures us that a constraint is plausibly universal (cf. Kager 1998).
- Helps to guide research.
- Constrains or simplifies the phonological constraint set.
- Goal: replace a large set of highly specific constraints (*[+voice, -sonorant], *[+high, -ATR], etc.) with three highly general constraints.
  Alternatively: derive the large set of constraints from these three general meta-constraints (cf. Hayes 1999).
- Only possible if phonetic grounding is explicitly formulated in phonological theory.
- Case study: An analysis of some typological generalizations about vowel reduction.

2. Phonological vowel reduction
- Vowel contrasts are neutralized in unstressed syllables, e.g. Standard Italian:

(1) Primary stressed: Elsewhere:
   i  u  i  u
   e  o  e  o
   a
   a

[i] viño  ‘wine’  vinífero  ‘wine-producing’
[e] peska  ‘fishing’  peskaβ̥  ‘to fish’
[ə] bellf  ‘beautiful’  (bellf  ‘pretty’)
[a] majo  ‘hand’  manuɑl  ‘manual’
[ɔ] mui̯eʃ  ‘soft’  (moli̯eʃf ‘softly’)
[o] noñe  ‘name’  norniñeʃ  ‘to name, call’
[u] kuʃa  ‘care’  kuraʃ  ‘to treat’

- Vowel reduction (other than reduction to a single vowel) primarily eliminates height contrasts, not back/rounding contrasts (cf. Crosswhite 1999).

(2) (a) i  u  (b) i  u  (c) i  u
    e  o  e  o  a
    a
    a

- (a) reduces to (b): e.g. Standard Italian, Brazilian Portuguese, Slovene
- (b) reduces to (c): e.g. Standard Russian, S. Italian, Catalan dialects
- (a) reduces to (c): e.g. E.Catalan

- No examples in which front rounded or central vowels are allowed in stressed syllables but excluded from unstressed syllables.
  E.g. Scots Gaelic (Borgström 1940):

(3) Stressed: i  u  Unstressed: i  u
    e  o  a
    a
    a

Mantuan Italian (Miglio 1996):

(4) Stressed: i  y  u  Unstressed: i  y  u
    e  o  e  a
    a
    a

3. Outline of an analysis of vowel reduction

Two questions:
- Why do languages often allow fewer vowel contrasts in unstressed syllables?
- Why does vowel reduction eliminate F1 (height) contrasts, not F2 (back, round) contrasts?

- Dispersion theory of contrast (Flemming 1995, 2001) – vowel inventories involve an optimal balance between the desiderata for efficient communication:
  i. Maximize the distinctiveness of contrasts
  ii. Minimize articulatory effort
  iii. Maximize number of vowels

- Unstressed vowels are usually shorter than stressed vowels, so it is more effortful to achieve distinct vowel qualities in unstressed position.
- Where the difference between stressed and unstressed vowels is large enough, it may be optimal to select a smaller number of vowel contrasts in unstressed position.
4. Effort in vowel production
- Faster movements are more effortful (Nelson 1983, Perkell et al 2002)
- In a CVC sequence, the articulators have to move to and from the position for the vowel.
- Vowel targets are often not reached (‘undershoot’ – Lindblom 1963).
- Undershoot can be analyzed as a consequence of minimizing effort by avoiding fast articulator movements.
- Faster movement is required where:
  - the distance between C and V is greater.
  - V is short.
- Both situations tend to lead to increased undershoot (Lindblom 1963).
- The driving force in phonetic and phonological vowel reduction is the difficulty of moving far from adjacent consonants during a short vowel.

5. A model of vowel reduction
- Vowels are selected from a space of possible vowels modeled on Liljencrants and Lindblom (1972) (L&L), so as to minimize a cost function.

Maximize the distinctiveness of contrasts
- Distance between V_i and V_j:
  \[ r_{ij} = \sqrt{a \cdot (x_i - x_j)^2 + (y_i - y_j)^2} \]
  where \( x_i \) is F2 of V_i in Bark, \( y_i \) is F1 of V_i in Bark, \( a = 0.3 \) (reduces the distinctiveness of F2 differences relative to F1).
- Overall distinctiveness cost of a vowel system (cf. L&L:842):
  \[ E = \frac{1}{n! \prod_{i=1}^{n-1} r_{ij}} \]
  where \( n \) is the number of contrasting vowels in the system.

Maximize the number of contrasts
- Implemented as a negative ‘cost’, -\( w_v n \)
- Total cost = \( E - w_v n \)

Articulatory effort
- Cost is minimized subject to a limit on the maximum effort that may be expended to realize a vowel.
- Effort is proportional to the distance between vowel V_i and ‘consonant target’, approximated by distance, \( d_i \) in F1[F2 space (kHz):
  \[ d_i = T \sqrt{(F1_i - F1_C)^2 + (c(F2_i - F2_C))^2} \]
  where \( F1_i, F2_i \) are the formants of V_i in kHz, \( F1_C, F2_C \) are the formant targets for the consonant context, \( T \) is a scaling factor that is inversely proportional to vowel duration, \( c < 1 \) (models assimilation of consonants to vowel F2).
- A vowel inventory is selected so as to minimize cost, subject to the constraint that that \( d_i < \) threshold for all vowels in the inventory.
- In practice, minimize \( E \) for \( n = 1-8 \), and select the inventory with the lowest total cost.
- As vowel duration decreases, the same values of constants can result in a reduction in the optimum number of vowels.
- Vowel reduction can be derived from relatively direct formulations of basic ‘phonetic grounding’ constraints (given vowel duratons).
- The model derives both phonetic (non-neutralizing) and phonological (neutralizing) reduction.

5.1 Alternative models
- A more direct implementation of dispersion constraints includes effort in the cost function, allowing it to be balanced with distinctiveness:
  \[ \text{Total cost} = E + w_e \max(d_j) - w_v n \]
  where \( \max(d_j) \) is the maximum distance between consonant target and a vowel. \( w_e \) is a weighting factor
- Yields qualitatively similar results.

6. Vowel reduction neutralizes height contrasts
- In most contexts, the primary effect of reducing vowel duration is to make low vowels more difficult because most consonants can substantially assimilate to F2 of vowel, but cannot assimilate to F1 (cf. Lindblom 1963).
- Raising low vowels leaves less room for F1 contrasts.
- Other evidence for the relationship between F1 and duration:
  - Low vowels are longer than higher vowels, other things being equal (Lehiste 1970).
  - Westbury and Keating (1980): vowels with lower jaw positions had longer durations.
  - Van Son and Pols (1990): in Dutch low vowels, F1 is positively correlated with duration in read speech. Correlations weak for F2 and for F1 in other vowels (except [yl]).
- This effect is incorporated into the model as a lower effort cost for F2 distance between vowel and consonant (\( c \) in (4) above).
- This formulation can be derived from the well established generalization that F2 at the release (or closure) of a stop is linearly related to F2 at the center of the vowel (Lindblom 1963a, Klatt 1987):

\[ F2_o = k(F2_v-F2_c)+F2_c \]

where \( F2_o \) is the frequency of F2 at the onset of the vowel 
\( F2_v \) is the frequency of F2 at the center of the vowel 
so: \( F2_v-F2_o = (1-k)(F2_v-F2_c) \) as in (7), substituting \( c=(1-k) \)

(9) can be derived from constraints similar to those above (Flemming 2001b).

6.1 Positional Faithfulness
- Analyses of vowel reduction in terms of ‘positional faithfulness’ lead to the incorrect expectation that reduction should eliminate all kinds of ‘marked’ vowels (e.g. Beckman 1998:129). Special status of height must be stipulated.

\( I-DENT \) - STRESSED SYLL(F) >> I-DENT(F)

\( I-DENT \) - STRESSED SYLL(HIGH) >> *MID >> I-DENT(HIGH)

why not? I-DENT-STRESSED SYLL(ROUND) >> *[-BK, +RD] >> I-DENT(ROUND)

- Same problem arises in some positional markedness approaches, e.g. Crosswhite (2001);

(11) LIC-NONCORNER/STRESS: Vowels other than [i, a, u] are licensed only in stressed positions.

- Short low vowels are the immediate problem, not non-peripheral vowels.

7. When are F2 contrasts neutralized?
- The model above predicts F2 contrasts could be neutralized if:
  - duration is very short
  - duration is short and \( c \) is high (close to 1).
- both situations arise:
  a. Very short vowels - reduction to schwa
    - Very short vowel duration makes it difficult to maintain either F1 or F2 contrasts, E.g. English schwa: 34 ms (Kondo 2000), Dutch schwa: 47 ms (Koopmans-van Beinum 1994).
    - Model predicts that the end-point of reduction should be a highly context-dependent vowel quality, assimilated to the surrounding context, not a mid-central vowel. This is confirmed for English (Kondo 1994) and Dutch (van Bergem 1994, Koopmans-van Beinum 1994).

b. Vertical vowel systems
- Neutralization of F2 contrasts can occur where vowel duration is short and consonant contrasts place strong constraints on F2 at consonant edge.
- E.g. Marshallese (Bender 1968, Choi 1992):
  - Extensive palatalization and velarization contrasts, e.g. ['tJç] ‘ignite’, ['tÏç] ‘sugar cane’
  - Contrastively palatalized and velarized consonants cannot assimilate much to F2 of adjacent vowel, i.e. \( c \) is close to 1 (cf. Richey 2001).
  - F2 contrasts among long vowels, but only F1 contrasts among inter-consonantal short vowels:

(12) long: i  ı  u  short: ı
  e  ő  o
  - a  -  a

- F2 of medial short vowels is an almost linear interpolation between preceding and following consonants (Choi 1992), i.e. they are assimilated to context.
- NW Caucasian languages such as Kabardian are comparable (Kuipers 1960, Choi 1991).

8. Phonetic reduction should be a precondition for neutralizing reduction
- If neutralization of height contrasts is a consequence of avoiding effortful low vowels, then raising of ‘low’ vowels should accompany neutralizing reduction.
  - In many cases, the lowest vowel of reduced inventories is commonly transcribed as [i], [ã], [ı], e.g. Russian, Bulgarian, Catalan, Portuguese.
  - Acoustic data show reduction in these and other cases (e.g. Italian).

9. Vowel reduction should be conditioned by duration, not stress
- The model predicts that lack of stress should not in itself condition vowel reduction.
  - Stress should only condition reduction via its effects on vowel duration.
  i. Languages that do not use substantial duration differences to realize stress should not have vowel reduction (e.g. K‘ekchi: Berinstein 1975, Toba Batak: Podesva and Adisasmito-Smith 1999).
  ii. Other factors that influence vowel duration should be able to affect patterns of reduction.
    - Brazilian Portuguese (e.g. Mattoso Camara 1972):
      - Primary stressed syllables: i, e, ì, a, ì, o, u
      - Pre-stress syllables: i, e, a, o, u
      - Final unstressed vowels: i, a, ù
10. Summary

General:
- Realizing the full implications of the observation that many phonological constraints are “phonetically grounded” depends on explicitly formalizing this notion.
- Formalizing phonetic grounding involves quantitative models.

Specific:
- Phonetic and phonological vowel reduction are motivated by the difficulty of producing short low vowels.
- Together with facts about consonant production, this helps to explain why vowel reduction generally neutralizes height contrasts before it neutralizes back or round contrasts.
- Interesting predictions:
  - Vowel reduction depends on duration, not stress.
  - Phonetic reduction is a prerequisite for phonological reduction.

References


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