

## The Power of Weighted Constraints

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Prince and Smolensky (1993/2004) adopt constraint ranking because of concerns about the power of weighted constraints (cf. Harmonic Grammar; Legendre *et al.* 1990, Smolensky and Legendre 2006). However, there has been little explicit comparison of the sets of linguistic patterns the two theories generate (cf. Prince 2002, Legendre *et al.* 2006a). The conclusion here is that HG is a viable theory of phonological typology if it incorporates proposed amendments to OT that make it properly local. I also discuss some of the advantages of HG over OT: it is compatible with scalar constraints, and it can better model gradual learning and gradient acceptability.

### 1. Pairwise Ranking vs. Weighting

#### 1.1 Optimization and trade-offs

I adopt a version of weighted constraint evaluation suggested as a strawman by Prince and Smolensky (1993/2004: 236); see also Flemming (2001), Prince (2002), Keller (2006) and Pater, Potts and Bhatt (2006):

(1) *Candidate evaluation by weighted constraints*

- a. Multiply violation scores by weights
- b. Sum weighted violation scores = harmony (H)
- c. Candidate is optimal *iff* H score is lower than every other candidate

(2) *A weighted constraint tableau*

| Weight     | 2            | 1            | H |
|------------|--------------|--------------|---|
| Input      | Constraint 1 | Constraint 2 |   |
| ☞ Output 1 |              | *            | 1 |
| Output 2   | *            |              | 2 |

One might think that a weighted constraint system could generate the following pattern by weighting NoCODA appropriately w.r.t. Max (cf. Prince and Smolensky 1997, Prince 2002):

(3) A word can have at most one coda; a second coda is deleted

That this is impossible can be shown by considering the weighting conditions under which each outcome is optimal.

(4)

| /batan/  | MAX | NoCODA |
|----------|-----|--------|
| ☞ ba.tan |     | 1      |
| ba.ta    | 1   |        |

(5)

| /bantán/ | MAX | NoCODA |
|----------|-----|--------|
| ban.tan  |     | 2      |
| ☞ ba.tan | 1   | 1      |

Inconsistent weighting conditions:

(6) /batan/ → [ba.tan]      $w(\text{MAX}) > w(\text{NoCODA})$   
 /bantán/ → [ba.tan]      $2 * w(\text{NoCODA}) > w(\text{NoCODA}) + w(\text{MAX})$   
     $= w(\text{NoCODA}) > w(\text{MAX})$

Morals:

(7) *Optimization ≠ Numerical cut-off*

As in OT, optimality is relative to the input; there is no numerical upper bound on well-formedness

(8) *Nature of trade-offs*

Here violations of NoCODA and MAX trade off one-to-one; to get a difference between OT and HG, we need *asymmetric trade-offs* in constraint violations between candidates (Prince 2002)

An example of an asymmetric trade-off:

(9) *Weighting ≠ Ranking*

| Weight     | 1.5          | 1            | H   |
|------------|--------------|--------------|-----|
| Input      | Constraint 1 | Constraint 2 |     |
| Output 1   |              | 2            | 2   |
| ☞ Output 2 | 1            |              | 1.5 |

To find differences between OT and HG, we can look for examples of the violation pattern in (9) - cases where one violation of one constraint trades-off against multiple violations of another. We'll look at these simple pairwise trade-offs before moving on to (slightly) more complicated interactions.

It is worth emphasizing that asymmetric trade-offs are a necessary, but not sufficient, requirement for an HG/OT difference. If (9) represented the entire set of candidates and constraints, both theories would produce two languages, one where Output 1 is optimal, and one where Output 2 is optimal. This may seem obvious, but as we'll see in section 3, this point has sometimes been ignored in earlier comparisons of OT and HG.

## 1.2 Gradient Alignment

Legendre *et al.* (2006a) show how the interaction of the following constraints yields distinct results in HG and OT

### (10) ALIGN-HEAD-R

Assess one violation mark for every syllable intervening between the main stress and the right edge of the word

### WEIGHT-TO-STRESS

Assess one violation mark for every unstressed heavy syllable

The following tableaux show how a weighting creates a system that places stress on a heavy syllable if it is at most 3 syllables away from the right edge, and on the final syllable if the heavy syllable is further away

### (11) A problem for HG

|                |     |            |          |
|----------------|-----|------------|----------|
| <i>Weight:</i> | 3.5 | 1          | <b>H</b> |
| /bantana/ma/   | W-S | ALIGN-HD-R |          |
| ban.ta.na.má   | 1   |            | 3.5      |
| ☞ bán.ta.na.ma |     | 3          | 3        |

|                   |     |            |          |
|-------------------|-----|------------|----------|
| <i>Weight:</i>    | 3.5 | 1          | <b>H</b> |
| /bantana/ma/      | W-S | ALIGN-HD-R |          |
| ☞ ban.ta.na.va.má | 1   |            | 3.5      |
| bán.ta.na.va.ma   |     | 4          | 4        |

Further weightings will create an infinite number of further systems, with the upper limit bounded only by word length. Stress systems are well-studied typologically, and while many examples of three-syllable windows have been found, not a single example of a stress window of any larger size exists.

Instead of abandoning weighting, another way of avoiding this result is to abandon gradient alignment, a move independently proposed in OT (Eisner 1998, Kager 2001, McCarthy 2003; see also Gordon 2002 on problems with syllable-counting ALIGN-HEAD). McCarthy (2003) derives the absence of this constraint type from two principles:

### (12) a. *Categorality*: Constraints assign a single mark for each locus of violation

b. *Locality*: Constraints are limited to mentioning two constituents: the locus of violation, and its context (McCarthy 2003: 80, based on Smolensky p.c.)

I adopt a version of locality theory, which is sufficient to rule out gradient alignment, while allowing other types of gradient constraints, which are compatible with HG. The proposed constraint schema enforcing locality is given in (13) (something like this is

implicit in most research in autosegmental and metrical phonology; see Eisner 1998 for a related proposal in OT, which does however allow a reformulation of ALIGN-HEAD)

### (13) \*XY

Assign a violation mark to every minimal string containing XY, where X and Y are adjacent elements on some phonological tier

X and Y may contain information about projections onto higher tiers (perhaps only immediately adjacent tiers, as in 16, though see text below 14). They can also be indexed for position in a domain (morphological and/or prosodic). Note that in HG, a double-sided context (e.g. intervocalic spirantization. constraints against long lapses) can be analyzed as the result of two single-sided constraints (see e.g. Flemming 2001), thus eliminating some counterexamples to (13).

Here I will show how ALIGN-HEAD-R can be replaced in a theory respecting (13). As in much research in metrical phonology, I will derive apparently non-local effects from elaborated representations. I adopt a grid to represent prominence in the metrical representation (Liberman 1975, see esp. Hayes 1995 on prominence):

### (14) *Metrical representation of prominence distinctions*

|    |     |
|----|-----|
|    | x   |
| x  | x   |
| CV | CVC |

Since languages differ in terms of the prominence distinctions they make (syllable weight, vowel sonority), language-specific constraints relate these factors to grid projections. For present purposes, I will take the representations in (14) as given.

Stress is directly marked on the prominence-based grid with an 'o'; grid elements with different phonetic interpretations co-exist on a single plane (cf. Hayes 1995). The rightmost heavy pattern favors (15a) over (15b):

|      |                  |                  |
|------|------------------|------------------|
| (15) | o                | o                |
|      | x x              | x x              |
|      | x x x x          | x x x x          |
|      | a. ban.tán.na.ma | b. ban.tán.na.ma |

We thus need a constraint violated by (15b). One possibility is an 'End-rule' constraint (Prince 1983; see also Gordon 2002, Hayes and Wilson 2006; cf. Bakovic 1998, McCarthy 2003a for a prosodic alternative):

### (16) END-RIGHT x]<sub>FINAL</sub>

Assign a violation mark to a grid element that is not dominated by 'o' and that is final on its tier

To distinguish a language that stresses the rightmost heavy, and one that stresses the rightmost syllable, END-RIGHT is parameterized to grid level:

(17) END-BASE-R

Assign a violation mark to a grid element that is not dominated by 'o' and that is final on the lowest tier

END-PEAK-R

Assign a violation mark to a grid element that is not dominated by 'o' and that is final on the highest tier

With further parameterization to yield 'left' versions of the constraints in (18), we have a constraint set that would get both 'default-to-same' and 'default-to-opposite' stress systems (cf. Gordon 2000)

*Problem:* how do we get the apparently gradient effect displayed when END-PEAK-RIGHT is dominated by NONFINALITY, as in Prince and Smolensky's (1993/2004) analysis of Hindi (see also Walker 1997)? That is, if final stress is not an option, what prefers (18a) to (18b), since both violate END-PEAK-R?

(18)

|   |   |   |  |   |   |   |
|---|---|---|--|---|---|---|
|   | o |   |  | o |   |   |
| x | x | x |  | x | x | x |
| x | x | x |  | x | x | x |

a. dan.bán.tan b. dán.ban.tan

One possibility: final syllables project differently from non-final syllables, perhaps due to some type of final consonant 'extrametricality' (note that final length is perceived as less prominent due to compensation for final lengthening; Nootboom and Doodeman 1980; see Lunden 2006 for related discussion):

(19)

|   |   |   |  |   |   |   |
|---|---|---|--|---|---|---|
|   | o |   |  | o |   |   |
| x | x |   |  | x | x |   |
| x | x | x |  | x | x | x |

a. dan.bán.tan b. dán.ban.tan

Another possibility is that the following constraint bans a final lapse at the highest grid level:

(20) \*xx]<sub>FINAL</sub>

Assign a violation mark to an adjacent pair of grid marks at the highest grid level in which the second is the final element on the tier and neither is dominated by o

While further work is needed, it appears that a theory in which constraints obey the locality restriction in (13) is sufficiently expressive to provide a reanalysis of systems that have been previously analyzed using head alignment (and some that challenge it, if the 'default-to-opposite' analysis goes through)

For present purposes, the important point is both HG and OT generate just the two desired patterns with END-BASE-R and END-PEAK-R

(21) Unattested set of optima

| /bantinama/    | END-BASE-R | END-PEAK-R |
|----------------|------------|------------|
| ban.ta.na.má   |            | 1          |
| ☞ bán.ta.na.ma | 1          |            |

| /bantinama/       | END-BASE-R | END-PEAK-R |
|-------------------|------------|------------|
| ☞ ban.ta.na.va.má |            | 1          |
| bán.ta.na.va.ma   | 1          |            |

These obviously require contradictory ranking conditions:

(22) ☞ bán.ta.na.ma      w(END-PEAK-R) > w(END-BASE-R)  
 ☞ ban.ta.na.va.má      w(END-BASE-R) > w(END-PEAK-R)

Legendre *et al.*'s (2006a) alignment example is to my knowledge the only published case of an unattested language generated by HG but not OT.

We now turn to two further cases of pairwise asymmetric trade-off. One favors the greater power of HG, the other is problematic for both HG and OT.

### 1.3 Scalar Constraints

Prince and Smolensky's (1993/2004) analysis of Berber syllabification invokes H-Nuc 'a higher sonority nucleus is more harmonic than one of lower sonority'. McCarthy (2003a: 82) translates it into now-standard OT formalism as follows:

(23) H-Nuc

Assign a nucleus one violation-mark for each degree of sonority lower than that of a

Unlike Alignment, McCarthy's argument against scalar gradience (building on Prince and Smolensky's 1993/2004 reanalysis of Berber in terms of a fixed ranking) is not that it overgenerates, but that it *undergenerates* in OT.

Consider a language like English, in which nuclei allow sonorant consonants, but no obstruents.

Abstracting from the English stress facts, we can use a simple three-degree scale:

(24) Sonority scale

Vowel = 2    Sonorant Consonant = 1    Obstruent Consonant = 0

The tableaux in (25) show the effects of the two rankings of H-NUC and the faithfulness constraint violated by epenthesis, DEP (McCarthy and Prince 1999).

(25) *The failure of scalar constraints in OT*

a. H-NUC >> DEP

| /ta/ | H-NUC | DEP |
|------|-------|-----|
| ☞ta  |       |     |
| ta.ə |       | 1   |

| /t/  | H-NUC | DEP |
|------|-------|-----|
| tl   | 1     |     |
| ☞təl |       | 1   |

| /ts/ | H-NUC | DEP |
|------|-------|-----|
| ts   | 2     |     |
| ☞təs |       | 1   |

b. DEP >> H-NUC

| /ta/ | DEP | H-NUC |
|------|-----|-------|
| ☞ta  |     |       |
| ta.ə | 1   |       |

| /t/ | DEP | H-NUC |
|-----|-----|-------|
| ☞tl |     | 1     |
| təl | 1   |       |

| /ts/ | DEP | H-NUC |
|------|-----|-------|
| ☞ts  |     | 2     |
| təs  | 1   |       |

OT generates only a language that permits all degrees of violation of the constraint (e.g. Berber), and one that tolerates no violation (e.g. French), but not a language that permits an intermediate degree of violation (e.g. English). In HG, however, an appropriate weighting of H-NUC and DEP will yield an inventory of intermediate size:

(26) *An intermediate inventory in HG (impossible in OT)*

|     | 3   | 2     | H |
|-----|-----|-------|---|
| /t/ | DEP | H-NUC |   |
| ☞tl |     | 1     | 2 |
| təl | 1   |       | 3 |

|      | 3   | 2     | H |
|------|-----|-------|---|
| /ts/ | DEP | H-NUC |   |
| ts   |     | 2     | 4 |
| ☞təs | 1   |       | 3 |

HG does not generate the 'gapped' inventory:

(27) *An impossible inventory in HG (and OT)*

| /t/  | DEP | H-NUC |
|------|-----|-------|
| tl   |     | 1     |
| ☞təl | 1   |       |

| /ts/ | DEP | H-NUC |
|------|-----|-------|
| ☞ts  |     | 2     |
| təs  | 1   |       |

The inconsistent weighting conditions:

- (28) ☞təl     w(H-NUC) > DEP  
 ☞ts         w(DEP) > 2w(H-NUC)

OT analyses of scalar phenomena are of course possible, but they require separate constraints for every step of a scale. In terms of the structure of the constraint component, the HG analysis is clearly more elegant. See Flemming (2001) for arguments for the use of scalar HG for phonetic trade-offs (cf. Boersma 1998:211).

1.4 *Multiple violations of a single categorical constraint*

As the NoCODA and MAX example in (4) and (5) showed, violations of pairs of categorical constraints normally trade-off one-to-one. However, McCarthy (2006a,b) draws attention to the fact that ONSET can demand an unlimited number of LINEARITY violations

(29) LINEARITY

Assign a violation mark for each precedence relation in the input that is reversed in the output

As shown in (30), with the ranking ONSET >> LINEARITY, an input segment at the right edge of the word will appear at the left edge in the output in order to satisfy ONSET, regardless of the number of LINEARITY violations this incurs. The optimal form (31b) incurs five violations of Linearity because [k] follows all of the other segments in the input, and precedes them in the output:

(30) *Non-local metathesis*

| anatak    | ONSET | LINEARITY |
|-----------|-------|-----------|
| a. anatak | 1     |           |
| b. kanata |       | 5         |

As McCarthy notes, this pattern of long-distance metathesis is unattested.

At first glance it might seem that this is a problem with strict domination, but it is in fact aggravated in HG, since varying the weights of ONSET and LINEARITY can produce an infinite set of languages fitting the following description:

- (31) To satisfy ONSET, a segment is permitted to reverse precedence relations with *n* segments, where *n* is any non-negative integer.

McCarthy (2006a,b) shows that the adoption of harmonic serialism solves this problem; this holds for both OT and HG.

(32) *Gen/Eval interaction in Harmonic Serialism*

- a. Gen performs a single operation at a time
- b. Each operation must result in harmonic improvement according to Eval

To illustrate the workings of harmonic serialism, I'll use a tableau format that incorporates the derivational process.

(33) *Tableaux conventions for Harmonic Serialism*

- a. Representations ordered according to the order of operations with the UR/Input at the top, followed by a fully faithful parse (McCarthy 2006b). The last representation in the SR/Output.
- b. Each representation differs from the immediately preceding one in terms of one operation (one 'basic' faithfulness violation in McCarthy 2006b,c)
- c. Each representation is more harmonic than the immediately preceding one
- d. A representation that violates b. or c. is indicated with a bomb.

The attested pattern:

(34) *Local metathesis in standard OT and harmonic serialism*

| atka      | ONSET | LINEARITY |
|-----------|-------|-----------|
| a. atka   | 1     |           |
| ☛ b. taka |       | 1         |

Ruling out the unattested pattern:

(35) *A violation of gradualness in non-local metathesis in harmonic serialism*

| anatak      | ONSET | LINEARITY |
|-------------|-------|-----------|
| a. anatak   | 1     |           |
| ☛ b. kanata |       | 5         |

(36) *Violations of harmonic improvement*

| a. anatak | ONSET | LINEARITY |
|-----------|-------|-----------|
| anatak    | 1     |           |
| ☛ anatka  | 1     | 1         |

| b. anatak | ONSET | LINEARITY |
|-----------|-------|-----------|
| anatak    | 1     |           |
| ☛ naatka  | 1     | 1         |

For expository ease I have presented McCarthy's solution to the Onset/Linearity problem in terms of OT, but the violations of harmonic improvement in (36) would hold equally in Harmonic Grammar. As we will see, the gradualness requirement has important consequences for typology in HG.

## 2. Independence in Constraint Conflict

Another type of asymmetric trade-off:

(37) *Weighting ≠ Ranking*

| Weight     | 1.5  | 1    | 1    | H   |
|------------|------|------|------|-----|
| Input      | Con1 | Con2 | Con3 |     |
| Output 1   |      | 1    | 1    | 2   |
| ☛ Output 2 | 1    |      |      | 1.5 |

Shigeto Kawahara has brought the following Japanese loanword phonology example to my attention (Nishimura 2003, Kawahara to appear):

(38) *An attested cumulative constraint interaction*

- a. Pairs of voiced obstruents are parsed faithfully [bagii] 'buggy'
- b. Voiced geminates are parsed faithfully [reddo] 'red'
- c. Voiced geminates are devoiced in the context of another voiced obstruent [beddo] 'betto'

(39) *Cumulative effect of OCP-VOICE and \*VCE-GEM*

| Weight        | 1.5    | 1         | 1        | H   |
|---------------|--------|-----------|----------|-----|
| /beddo/ 'bed' | ID-VCE | OCP-VOICE | *VCE-GEM |     |
| [beddo]       |        | 1         | 1        | 2   |
| ☛ [betto]     | 1      |           |          | 1.5 |

| Weight          | 1.5    | 1         | 1        | H   |
|-----------------|--------|-----------|----------|-----|
| /bagii/ 'buggy' | ID-VCE | OCP-VOICE | *VCE-GEM |     |
| ☛ [bagii]       |        | 1         |          | 1   |
| [bakii]         | 1      |           |          | 1.5 |

| Weight        | 1.5    | 1         | 1        | H   |
|---------------|--------|-----------|----------|-----|
| /reddo/ 'red' | ID-VCE | OCP-VOICE | *VCE-GEM |     |
| ☛ [reddo]     |        |           | 1        | 1   |
| [retto]       | 1      |           |          | 1.5 |

This pattern can be captured in standard OT by increasing the size of the constraint set (see Nishimura 2003 for a Local Conjunction analysis of this case, and Kawahara to appear for one employing geminate-specific faithfulness). However, given the set of constraints in (39), no ranking will produce this pattern.

Because this asymmetric trade-off pattern involves violations of pair of markedness constraints trading-off against a single competing faithfulness constraint, there are strict restrictions on the types of gang effect that can be captured.

(40) *A putative gang effect*

A vowel undergoes backness harmony *iff* it is nasal

Constraints at issue:

- (41) \*V-NAS Assign a violation mark to a nasal vowel  
 AGREE-BACK Adjacent vowels agree in [+/-back]  
 IDENT-BACK A vowels' input and output backness features are identical

The desired optima and constraint violations:

(42) *An unattested pattern of vowel harmony*

| /idũ/   | ID-BACK | *V-NAS | AGR-BACK |
|---------|---------|--------|----------|
| ☞ [idỹ] | 1       | 1      |          |
| [idũ]   |         | 1      | 1        |

| /idu/   | ID-BACK | *V-NAS | AGR-BACK |
|---------|---------|--------|----------|
| [idy]   | 1       |        |          |
| ☞ [idu] |         |        | 1        |

The pattern in (42) requires inconsistent weightings:

- (43) /idũ/ → [idỹ] w(AGR-BACK) > w(ID-BACK)  
 /idu/ → [idu] w(ID-BACK) > w(AGR-BACK)

Where markedness constraints conflict with different faithfulness constraints, a gang effect cannot be produced in HG. In this respect, and many others, it has very little of the power of OT with Local Conjunction (Legendre, Sorace and Smolensky 2006, Pater 2006):

(44) *The unattested pattern in OT with local conjunction*

| /idũ/   | *V-NAS&AGR-BACK | ID-BACK | *V-NAS | AGR-BACK |
|---------|-----------------|---------|--------|----------|
| ☞ [idỹ] |                 | 1       | 1      |          |
| [idũ]   | 1               |         | 1      | 1        |

| /idu/   | *V-NAS&AGR-BACK | ID-BACK | *V-NAS | AGR-BACK |
|---------|-----------------|---------|--------|----------|
| [idy]   |                 | 1       | 1      |          |
| ☞ [idu] |                 |         | 1      | 1        |

A remaining restrictiveness problem for HG: if IDENT-BACK were replaced by MAX, the pattern of violation marks instantiates the asymmetric trade-off pattern: violations of the two markedness constraints are traded off against a violation of MAX.

(45) *An unattested pattern of vowel deletion*

| /idũ/  | MAX | *V-NAS | AGR-BACK |
|--------|-----|--------|----------|
| ☞ [id] | 1   |        |          |
| [idũ]  |     | 1      | 1        |

| /idu/   | MAX | *V-NAS | AGR-BACK |
|---------|-----|--------|----------|
| [idy]   | 1   |        |          |
| ☞ [idu] |     |        | 1        |

However, if we adopt Harmonic Serialism, this problem also disappears. The following solution builds on McCarthy's (2006c) Harmonic Serialist analysis of Wilson's (2003) C1-deletion generalization. IDENT-NASAL is replaced with a MAX constraint:

- (46) MAX-NASAL An input [nasal] feature is preserved in the output

Violation of principles of harmonic serialism in unattested mapping:

(47) *Violation of gradualness*

| /idũ/  | MAX | MAX-NASAL | *V-NAS | AGR-BACK |
|--------|-----|-----------|--------|----------|
| [idũ]  |     |           | 1      | 1        |
| ☞ [id] | 1   | 1         |        |          |

(48) *Violation of harmonic improvement*

| /idũ/   | MAX | MAX-NASAL | *V-NAS | AGR-BACK |
|---------|-----|-----------|--------|----------|
| [idũ]   |     |           | 1      | 1        |
| ☞ [idu] |     | 1         |        | 1        |

The derivational step in (48) must violate harmonic improvement because of the weighting condition imposed by the presence of nasal vowels in the inventory:

- (49) /dũ/ → [dũ] \*[du] MAX-NASAL > \*V-NAS

*A remaining issue:* Note that the problem with MAX in (45) was that a single violation of the faithfulness constraint could result in the satisfaction of two unrelated markedness constraints. This problem gets even worse if the Null Parse (Prince and Smolensky 1993/2004) violates only a single constraint (see Wolf and McCarthy 2007), since any set of markedness constraints can gang up to yield a null parse. It's worth thinking about alternatives...

### 3. The insufficiency of asymmetric trade-offs

An asymmetric trade-off is a necessary, but not sufficient, criterion for establishing a difference between HG and OT. This is especially relevant when we are considering interactions between multiple constraints. The following two tables use alternative sets of constraints that have been posited for OT analyses of coda devoicing.

(50) *Asymmetric trade-offs that do not lead to OT/HG differences*

| /bat/ | *VOICE | IDENT-[VOICE]-ONSET | IDENT-[VOICE] |
|-------|--------|---------------------|---------------|
| bat   | 1      |                     |               |
| pat   |        | 1                   | 1             |

| /tab/ | *VOICE | *CODA-VOICE | IDENT-[VOICE] |
|-------|--------|-------------|---------------|
| tab   | 1      | 1           |               |
| tap   |        |             | 1             |

The constraints that pair up in assessing two violations to a single candidate are in a specific-to-general or stringency relationship. A weighting that requires violations of both constraints to overcome the third one produces exactly the same result as a ranking/weighting in which only the specific constraint is above the conflicting constraint (though see Pater, Jesney and Tessier 2007 for a learning application):

(51) *A vacuous gang effect*

| Weight | 1.5   | 1            | 1        | H   |
|--------|-------|--------------|----------|-----|
| /bat/  | VOICE | ID-VOICE-ONS | ID-VOICE |     |
| pat    |       | 1            | 1        | 2   |
| bat    | 1     |              |          | 1.5 |

More broadly, these cases serve to demonstrate that an asymmetric trade-off is not a sufficient criterion for an OT/HG difference.

Prince and Smolensky's (1993/2004) sole argument for strict domination is in fact based on a pairwise candidate comparison in their analysis of Lardil. The candidates, and constraint violations are shown in (52)

(52) *An asymmetric trade-off in Lardil (= P&S 1993/2004: (183 A))*

| /yiliyili/                     | FREE-V | ALIGN | PARSE | NoCODA |
|--------------------------------|--------|-------|-------|--------|
| i. <sup>☞</sup> .yi.li.yil.<i> |        | 1     | 1     | 1      |
| ii. .yi.li.yi.li.              | 1      |       |       |        |

Prince and Smolensky's commentary on the above (p. 144 in 2004 version):

(53) The relative harmonies of .yi.li.yil.<i> (183 A.i) and .yi.li.yi.li. (183 A.ii) pointedly illustrate the *strictness* of strict domination. Fully parsed .yi.li.yi.li. is less harmonic than truncated .yi.li.yil.<i> even though it violates only one constraint, while the truncated form violates three of the four lower ranked constraints...

However, the optimality of (53i) is in itself no illustration of strict domination, let alone an argument for it, since there is of course a constraint weighting that will produce this pattern. HG is a more powerful theory than OT (55):

(54) i. Given a set of constraints, any set of optima produced by some OT ranking can also be produced by some HG weighting.

ii. *It is not the case* that given a set of constraints, any set of optima produced by some HG weighting can also be produced by some OT ranking.

Since OT is the more restrictive theory, it makes predictions that are not shared by HG, as in the following example:

(55) "If FREE-V dominates each of ALIGN, PARSE, and NoCODA, then a candidate violating all three will necessarily be chosen as optimal relative to a candidate violating just FREE-V"

These sorts of predictions need to be tested typologically, or through psycholinguistic experimentation. As far as I know, this research remains to be done.

### 4. Doing HG

We have seen that weighted constraint systems do not overgenerate in the gross ways that they might be thought to. Evidence for overgeneration must come from more complex cases of constraint interaction. However, studying complex cases of interaction in HG can be difficult. We've thus far been looking at extremely simple patterns of constraint violation, involving at most three tableaux with just a few constraints and a couple of candidates at a time, each usually incurring a single violation. As we increase the number of each of these, it quickly becomes difficult to answer the question we've been posing:

(56) What weighting, if any, makes a particular set of candidates optimal?

Pater, Potts and Bhatt (2006) present an application of Linear Programming that can answer this question for larger problems; a web-based implementation called *HaLP* is provided by Potts, Pater, Bhatt and Becker (2006).

Given a file formatted according to OT-Soft conventions (Hayes, Tesar and Zuraw 2003), which includes tableaux containing candidates, their violations, and a set of specified optima, HaLP returns one of two outputs:

- (57) i. A set of constraint weights that give the optima the lowest score in each of their tableaux, along with html-formatted tableaux showing the scores incurred by each of the candidates
- ii. A verdict of infeasible, which indicates that the optima require contradictory weightings

*Demonstration of Lardil analysis, large made-up system.*

We are currently developing a version of HaLP that will return the equivalent of OT-Soft's factorial typology, and other useful analytic information (weighting conditions, infeasibility analysis).

## 5. Gradual learning in HG

One of the strengths of OT is that it has an associated learning algorithm, the Constraint Demotion Algorithm (CDA; Tesar and Smolensky 1998, 2000) that provably converges on a correct ranking. The Linear Programming implementation discussed in the previous section can be seen as convergent/correct learning algorithm for HG (see Pater *et al.* 2006 for further discussion).

Neither one of these is realistic as a model of human language acquisition, partly because they do not display the gradualness of that process. The Gradual Learning Algorithm (GLA; Boersma 1998, Boersma and Levelt 2000; Boersma and Hayes 2001) addresses this problem in OT by incorporating a numerical constraint scale (cf. Jarosz 2006, Tessier 2006). Each time the grammar is used, the numerical constraint values are converted to a ranking.

The GLA, like some versions of the CDA, and many other learners, is error-driven:

(58) *Error-driven learning*

**Parsing:** The input is submitted to the current grammar to generate an output

**Comparison:** If the resulting output differs from the learning datum, learning is triggered

**Learning:** The grammar is adjusted so as to prefer the correct form (the Winner) over the learner's output (the Loser)

Because it places constraints on a numerical scale, the GLA can adjust their values

gradually. It adjusts ranking values as in (60).

- (59) Subtract  $n$  from the ranking value of all constraints violated by the Winner, add  $n$  to all constraints violated by the Loser

It very similar to the Perceptron model (Rosenblatt 1962), a general-purpose error-driven learner whose update rule could be translated into the present context as in (61).

- (60) Add  $n*(x-y)$  to the value of every constraint  
Where  $0 > n > 1$ ,  $x$  = Loser's violation marks and  $y$  = Winner's violation marks

For those cases in which the Winner and Loser differ by no more 1 violation mark on each constraint, the update rules for the GLA and Perceptron are identical. There are two other differences:

- (61) i. The GLA assumes OT parsing, Perceptron uses an HG-like linear model  
ii. The GLA is demonstrably non-convergent (Pater to appear), Perceptron provably converges on a correct weighting

## 6. Gradient acceptability in HG

A longstanding argument for HG is that it provides a means of modeling gradient acceptability (Legendre *et al.* 1990, 2006, Keller 2006, Hayes and Wilson to appear) Two kinds of gradient acceptability (see Coetzee 2004 for discussion of phonological experimentation in these terms; note that I am not referring here to the relative frequency of forms in variation; a phonological example of gradient well-formedness would be what Frisch, Pierrehumbert and Broe 2004 call gradient phonotactics):

- (62) **Gradient ill-formedness** Two structures are absent from a language, and one is judged as worse than the other  
**Gradient well-formedness** Two structures exist in a language, and one is judged as worse than the other

A schematic example of gradient ill-formedness in OT terms (for 'Mark', substitute your favorite syntactic or phonological constraint):

(63) *No gradient ill-formedness in standard OT*

| /In-1/    | MARK | FAITH |
|-----------|------|-------|
| Out-1-X   | 1    |       |
| ☞ Out-1-Y |      | 1     |

| /In-2/    | MARK | FAITH |
|-----------|------|-------|
| Out-2-X   | 2    |       |
| ☞ Out-2-Y |      | 2     |

Standard OT only makes a distinction between grammatical and ungrammatical forms, so 'Out-1-X' and 'Out-2-X' are equivalently ungrammatical.

In Coetzee's (2004) rank-ordering model of OT, candidates can be compared across tableaux; this does allow an account of this type of case.

(64) *Gradient ill-formedness in rank-ordering OT*

|        |         | MARK | FAITH |
|--------|---------|------|-------|
| /In-1/ | Out-1-X | 1    |       |
| /In-2/ | Out-2-X | 2    |       |

Out-1-X > Out-2-X

In the standard HG analysis of gradient ill-formedness (see esp. Keller 2006) - Out-1-X receives a lower H-score than Out-2-X:

(65) *Gradient ill-formedness in HG*

| Weight    | 2    | 1     | H |
|-----------|------|-------|---|
| /In-1/    | MARK | FAITH |   |
| Out-1-X   | 1    |       | 2 |
| ☞ Out-1-Y |      | 1     | 1 |

| Weight    | 2    | 1     | H |
|-----------|------|-------|---|
| /In-2/    | MARK | FAITH |   |
| Out-2-X   | 2    |       | 4 |
| ☞ Out-2-Y |      | 2     | 2 |

Boersma (2004) points out a fatal flaw for this approach: because it does not relativize well-formedness to the input, in many cases ill-formed structures will receive lower (better) scores than well-formed ones. In the following schematic case, grammatical Out-1-Y receives a lower score than ungrammatical Out-2-X.

(66) *A problem for the standard HG account of gradient well-formedness*

| Weight    | 3  | 2  | 1  | H |
|-----------|----|----|----|---|
| /In-1/    | C1 | C2 | C3 |   |
| Out-1-X   | 2  |    |    | 6 |
| ☞ Out-1-Y |    | 2  |    | 4 |

| Weight    | 3  | 2  | 1  | H |
|-----------|----|----|----|---|
| /In-2/    | C1 | C2 | C3 |   |
| Out-2-X   |    | 1  |    | 2 |
| ☞ Out-2-Y |    |    | 1  | 1 |

Here is a 'real-life' example using Lombardi's (1999) analysis of final devoicing (see Boersma 2004 for syntactic examples):

(67) *Ill-formed [pad] > well-formed [bam.bam]*

| Weight  | 3          | 2      | 1       | H |
|---------|------------|--------|---------|---|
| /pad/   | ID-ONS-VCE | *VOICE | *ID-VCE |   |
| ☞ [pat] |            |        | 1       | 1 |
| [pad]   |            | 1      |         | 2 |

| Weight      | 3          | 2      | 1       | H |
|-------------|------------|--------|---------|---|
| /bambam/    | ID-ONS-VCE | *VOICE | *ID-VCE |   |
| ☞ [bam.bam] |            | 2      |         | 4 |
| [pam.pam]   | 2          |        |         | 6 |

Boersma's critique of the standard HG approach also applies to OT rank-ordering, as can be seen in its application to the devoicing case:

(68) *Also a problem for OT rank-ordering*

|          |          | ID-ONS-VCE | *VOICE | *ID-VCE |
|----------|----------|------------|--------|---------|
| /pad/    | pad      |            | 1      |         |
| /bambam/ | ☞ bambam |            | 2      |         |

pad > bambam

A revised acceptability metric for HG that makes the assignment of well-formedness scores relative to the input:

(69)  $\text{Acceptability}(x) = H(y) - H(x)$

Where y is the most harmonic alternative candidate for the same input as x

Using this metric, well-formed structures get positive scores, and ill-formed ones get negative scores, as we can see by calculating the scores of the no longer problematic forms from the tableaux in (68).

(70)  $\text{Acceptability}([\text{pad}]) = H([\text{pat}]) - H([\text{pad}]) = 1 - 2 = -1$

$\text{Acceptability}([\text{bambam}]) = H([\text{pampam}]) - H([\text{bambam}]) = 6 - 4 = 2$

The degree of well-formedness correlates with the Acceptability score: greater well-formedness produces higher Acceptability scores, and greater ill-formedness produces lower Acceptability scores.

Furthermore, as shown in Pater (2007) and Coetzee and Pater (in prep.), gradual adjustment of constraint weights in gradual learning automatically yields weights that correlate with structural frequency, and can be used to predict the relative acceptability of unobserved forms.

OT accounts of gradient acceptability that are input-relative account only for one side of the ill-formed/well-formed divide, and require considerable elaboration of the core theory. For example:

- (71) a. The account of gradient well-formedness in Pater (2005) involves the postulation of lexically specific faithfulness constraints for every lexical item, and requires the calculation of the outcome of every possible indexation to determine degree of well-formedness for a nonce word. As Hayes and Wilson (to appear) point out, it does not extend to gradient ill-formedness.
- b. The account of gradient ill-formedness in Boersma (2004) involves the incorporation of numerical values of constraints, and the calculation of the percentage of times each candidate wins relative to the other candidates. This account does not extend to gradient well-formedness, since by definition attested (non-variable) forms win 100% of the time.

## 7. Conclusions

The advantages of OT over HG:

- (72) a. Linguistic analysis with ranked constraints is easier than analysis with weighted constraints
- b. Restrictiveness

Here I have shown that the restrictiveness of strict domination is in many cases vacuous, given inherent properties of OT and HG (74a.) and (74b.), and proposed amendments to OT/HG that render it properly local (74c.) and (74d.)

(73) *Other sources of restrictiveness*

- a. The structure of an optimization system (no numerical cut-off)
- b. Independence of constraint conflicts
- c. Constraint locality (and perhaps categorality)
- d. Harmonic Serialism's gradualness and harmonic improvement

Furthermore, I have shown that the added power of constraint weighting is of use in traditional linguistic analysis for scalar phenomena, and for attested gang effects. All of this suggests the following framework for further exploration/development:

(74) Local Harmonic Grammar with Harmonic Serialism

I have also argued that weighted constraints have advantages for modeling gradual learning, and gradient acceptability. More generally, linear and log-linear models of grammatical constraint interaction, like the model of HG discussed here, hold considerable appeal. They can generate both categorical and probabilistic distributions, and they are associated with learning models whose behaviour and mathematical properties are well understood. Recent phonological work using these models includes:

(75) Flemming (2001), Goldwater and Johnson (2003), Hayes and Wilson (to appear), Jäger (to appear), Wilson (2006)

These linear and log-linear models of grammar and learning have interesting differences, whose consequences should become clearer with further study.

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