COPiL CAMBRIDGE OCCASIONAL PAPERS *in* LINGUISTICS
Volume **14(1)**, Article 5: pp. 145–179, 2022 | ISSN: 2050-5949

Modelling Unnatural Classes of Harmonic Vowels in Substance-Free Phonology*

Ariwan Kai Addy Suhairi
University of Cambridge

Abstract Vowel harmony systems often contain neutral vowels, which fail to harmonise in some way or other (van der Hulst 2016), e.g. by being transparent or antiharmonic. This dissertation identifies a problem in formulating the structural description of harmony rules in certain languages: although the set of neutral vowels can be described as a featurally natural class, the set of harmonic vowels cannot; there is no way of identifying the set of harmonic vowels without also including non-harmonic vowels. The primary goal of this dissertation is thus to provide an account of this problem. In the context of the substance-free Search and Copy theory (SCT) proposed by Samuels (2009), two possible solutions are suggested. One is to introduce union operators into the phonological component, allowing rules to target featurally unnatural classes of segments through set union: $A \cup B$, even if $A \cap B = \{\emptyset\}$ (i.e. A and B do not form a natural class). The alternative is to allow simultaneous (in addition to ordered) rule application; together with the assumption that Search is distance-sensitive (Nevins 2010), this proposal predicts that rules can consist of multiple *competing* Search operations, allowing us to derive unnatural-class behaviour. The typological and computational consequences of both proposals are also considered.

1 Introduction

Vowel harmony (VH) is a crosslinguistically widespread phenomenon, where multiple vowels in a phonological domain share the same value for a feature (van der Hulst 2016). This dissertation focuses exclusively on harmonic *alternations*, where morphemes alternate depending on their phonological environments.[1] For example, Turkish suffix vowels harmonise for [±back] and [±round], as seen in the genitive /-In/ (Clements & Sezer 1982):

* I owe a great intellectual debt to Bert Vaux and Bridget Samuels; this work is directly inspired by theirs. Samuel Andersson and Ollie Sayeed have also contributed many useful comments. Thanks also to Luca Gál for native-speaker intuitions, and Reddit user u/idsardi for insightful discussion of TSL grammars.

[1] VH also occurs as a phonotactic constraint on stems; I do not discuss this here.

(1) Turkish [±back] and [±round] harmony nucleus

Root	GEN.SG	*Gloss*
ip	ip-in	'rope'
kɨz	kɨz-ɨn	'girl'
jyz	jyz-yn	'face'
son	son-un	'end'

Vowel harmony is of interest to phonological theory for various reasons, such as the seemingly long-distance nature of harmony (Nevins 2010), along with the heterogenous behaviour of segments within harmony systems. Various generative accounts of VH have been proposed, ranging from derivational approaches involving autosegmental spreading (Clements & Sezer 1982) or Search-and-Copy (Mailhot & Reiss 2007), to representational licensing-based accounts (van der Hulst 2018). This study adopts the derivational Search-based framework (henceforth Search-Copy Theory; SCT) of Samuels (2011).

1.1 Neutrality

Vowels may also be NEUTRAL to harmony processes; I use the term in a broad sense, denoting vowels that fail to participate in VH in some way.[2] Neutrality can be viewed from the perspective of the trigger or target of harmony:

(2) Trigger neutrality

a. **Transparent** segments appear to be invisible to harmonic processes, allowing features to 'spread' through them. For example, Hungarian /i, e, ɛ/ seem to be irrelevant to the computation of [+back] harmony (section 2.1), where harmony is instead determined by a preceding non-transparent vowel: [yvɛg-nɛk] 'glass-DAT' ∼ [pɔpiːr-nɔk] 'paper-DAT'

b. **Antiharmonic** segments are opaque and inert to harmony; they do not seem to propagate their harmonic features. For example, Karchevan Armenian /i, e, ɛ/ are antiharmonic for [±back] harmony with suffixes (section 3.2.1). Alternating suffixes are [+back] following these vowels, even if the stem contains preceding [-back] harmonic vowels, e.g. /birgædiɾ-U-n/ 'together-DAT-DEF' [birgædiɾun], but not *[birgædiɾyn] (cf. /byn-U/ 'nest-DAT' [byny]).

(3) Target neutrality

a. **Invariant** segments fail to alternate in harmony processes. I assume that the contrast between invariant and alternating suffixes can be derived with reference to Archiphonemic Underspecification (Inkelas 1995, Samuels 2009): alternating segments are left underspecified by the learner, while invariant segments are prespecified.

[2] As van der Hulst (2016) notes, 'neutrality' is often used to imply *neutralisation* of a harmonic contrast in such vowels. I do not assume this to be the case; segments which are *not* neutralised for the harmonic feature may be neutral in VH (or vice versa); see section 3.3.

1.2 Unnatural classes in harmony

Neutral segments must somehow be treated as exceptions from harmony. Following Mailhot & Reiss (2007), I assume that neutral vowels are exceptional because they fail to meet the structural description of VH rule(s) in some way.[3] For example, Wolof (Niger-Congo) has [±ATR] harmony; /i u/ are transparent, while /e o ɛ ɔ ə a/ are harmonic. The neutral vowels are [+high], and harmonic vowels are [-high]; the ATR harmony rule simply targets [-high] segments. However, harmonic vowels do not always form a natural class. For example, Finnish (Uralic) has transparent /i e/, but harmonic /y ø æ u o ɑ/. While the neutral vowels form the natural class [-low, -back, -round], the harmonic vowels do not; there is no set of features P such that every Finnish vowel except /i, e/ is a superset of P. This presents a non-trivial problem for any derivational account of vowel harmony and neutrality:

(4) How do we formulate VH rules to target unnatural classes of harmonic vowels?

While the analysis developed here is Search-based, the problem also arises in autosegmental spreading approaches, where we must identify the class of spreading, i.e. harmonic, vowels.[4] The goal of this dissertation is thus twofold: (i) to evaluate current approaches to the problem in (4) in rule-based theories, and (ii) to propose a solution. Under the assumption that a unified account (even if it overgenerates somewhat) is preferable to one with multiple components, I attempt to provide a general account of unnatural classes in harmony.

In the remainder of this section, I discuss the SCT formalism, along with other basic assumptions. Section 2 evaluates rule-ordering accounts (Mailhot & Reiss 2007, Leduc, Reiss & Volenec 2020), which employ multiple rules to target harmonic vowels; I argue that these proposals fail because the ordering of rules causes fatal ordering paradoxes. Section 3 discusses analyses based on underspecification and/or contrast, namely Dresher's (2009) Modified Contrastive Specification and Visibility Theory as discussed by Nevins (2010); it is argued that neither approach provides a universal account of neutrality in a substance-free theory. In section 4 I discuss two possible accounts of the problem in (4). Both proposals allow the phonology to target unnatural classes simultaneously, one through set union and the other by allowing simultaneous and competing rule application. Section 5 concludes and suggests future lines of research.

1.3 Search and Copy

I begin by outlining the formalism assumed in this work, Search & Copy Theory

[3] Another option, considered in section 3, is to treat them as being representationally distinct.

[4] This does not seem to be the case in representational approaches like RcvP (van der Hulst 2018), or Optimality Theory (Prince & Smolensky 1993), where we can stipulate that the neutral vowels are excluded from spreading, e.g. by having a highly-ranked OT constraint blocking spreading, that dominates the constraint(s) enforcing VH.

(SCT).[5] This theory is SUBSTANCE-FREE: phonological computation does not make any reference to phonetically-based notions like markedness and sonority, with consequences for the explanation of VH. However, following Hale & Reiss (2008), I assume that there is a finite (and presumably innate) set of features.[6]

1.3.1 Formalism

SCT decomposes the rules of classical generative phonology (Chomsky & Halle 1968) into three primitive operations, Search, Copy and Delete. Search allows two phonological entities to establish a Probe-Goal relationship:

(5) Search algorithm:
Search($\Sigma, \zeta, \gamma, \delta$), where ζ, γ are features, and if indexed, are segments with those features; Σ is the domain of rule application; and δ is the direction of the search.[7]

a. Find all x in Σ subsumed by ζ and index them: $\zeta_0, \zeta_1, ...\zeta_n$

b. For each $i \in \{0, ...n\}$,

i. Proceed from ζ_i through Σ in the direction δ until an element subsumed by γ is found.

ii. Label this γ_i.

c. Return all coindexed pairs of standards and goals, (ζ_i, γ_i)

---

5 For more detailed discussion, see Samuels (2009: ch.3); I follow Samuels in assuming that SCT is a theory of *all* phonological rules, rather than just VH, unlike Mailhot & Reiss (2007), Nevins (2010).

6 This stands in contrast to the feature-emergentist approach (Mielke 2008, Odden 2019, Samuels, Andersson, Sayeed & Vaux 2022). On this view, there can be no coherent notion of a phonologically 'unnatural' (or natural) class (Sayeed 2018), especially in Odden's (2019) approach, where features are induced solely from phonological activity. *Any* set of segments that patterns together in a phonological process is by definition a natural class; the modelling of harmony and neutrality becomes trivial, since features are effectively diacritics. This gives up the restrictiveness (and arguably explanatory power) of feature theory, though whether this is good or bad depends on one's theoretical perspective. I choose not to adopt this approach, though it may be worth considering.

7 Some further elaboration on the parameters of Search may be useful:

(i) a. Σ is the domain of rule application; usually the phonological word.

b. ζ, γ are features, and if indexed, are segments bearing those features. ζ_i, for example, is the *standard*, which initiates a Search; γ_i is its target.

c. δ is the direction of Search, either LEFT or RIGHT. Not all rules involve unidirectional Search; I assume that such rules involve two Search operations, each with a different value for δ.

d. β is the beginning point of Search; in most cases of VH, this is its standard (ζ). Samuels (2009) decouples the starting-point parameter from the standard in order to model various infixation processes, though it can also be applied to VH; see footnote 8 for discussion.

Note that terminates once it finds a *relevant intervener* (γ_i), enforcing a (relativised) minimality requirement on phonological processes (Mailhot & Reiss 2007).[8]

After Search finds its target γ_i, Copy and/or Delete may apply.[9]

(6) Copy and Delete algorithms:

a. Copy(γ_i, ζ_i, αF, C)
   i. Identify αF on γ_i and assign αF to ζ_i if the set of conditions C on γ_i is satisfied OR
   ii. Identify αF on ζ_i and assign αF to γ_i if the set of conditions C on γ_i is satisfied

b. Delete(γ_i, ζ_i, αF, C)
   i. Identify αF on ζ_i and remove αF from ζ_i if the set of conditions C on γ_i is satisfied OR
   ii. Identify αF on ζ_i and remove αF from γ_i if the set of conditions C on γ_i is satisfied.

I assume that Copy is subject to the requirement that segments be featurally CONSISTENT; that is, a segment cannot be simultaneously [+F] and [-F] (Bale, Papillon & Reiss 2014). If Copy would produce a non-consistent output, it fails to apply.[10]

1.3.2 Modelling VH in SCT

Traditional donor-centric analyses based on autosegmental spreading assume that donor segments spread their harmonic feature to their targets. By contrast, SCT takes a recipient-based approach, where a segment initiates a Search for a relevant target, after which Copy applies. For example, the Turkish [±back] harmony process (1) is formulated in (7):

[8] Some suffixal harmony patterns are apparently determined exclusively by the *first* stem vowel; non-initial vowels are irrelevant, despite bearing the relevant harmonic features. Eastern Meadow Mari has such a pattern (Walker 2011), as does Kazan Tatar (Henry 2018). While Burness, McMullin & Nevins (2020) argue that these patterns are problematic for relativised locality, SCT has at least two ways of modelling this pattern. Since the starting-point of Search can differ from its initiator, we can simply stipulate the starting point of Search in these languages as the left edge of the word. The search proceeds rightward, identifying the initial vowel as γ_i, as intended. Alternatively, (Samuels 2009: p178: fn18) suggests that γ may be divided into two subparameters, one specifying the position of the target and one specifying its featural content, e.g. {γ: INITIAL, [+vocalic]}.

[9] Both processes are bidirectional, to account for non-VH processes; only the first type of Copy is relevant here. Also, Delete applies only in feature-changing harmony processes, which I do not discuss.

[10] Compare the related operation Unify; Bale et al. (2014) propose that the output of Unify is undefined if its output is non-consistent. The consequence of this is that rules can apply vacuously (i.e. not effecting any change), because unification fails. It seems to me that Unify and Copy are generally interchangeable for current study; I use Copy.

(7) Turkish [±back] harmony

a. Search($\Sigma, \zeta, \gamma, \delta, \beta$):
   i. Σ: word
   ii. ζ: [+vocalic]
   iii. γ: [+vocalic, αback][11]
   iv. δ: L
   v. β: %

b. Copy [αback] from γ_i to ζ_i.

Any [+vocalic] segment initiates a leftward Search for a vowel with a [αback] specification, and Copies this specification. However, only underspecified [Øback] segments end up Copying [αback] from γ_i; Copy to segments which already have [αback] is ruled out by the requirement of CONSISTENCY. As mentioned above, alternating vowels are left underspecified for [±back], through Archiphonemic Underspecification.

1.3.3 Neutrality

Another important insight of SCT is that vowel neutrality is (in principle) derived without reference to exceptional properties on segments (e.g. underspecification), but rather by stipulating conditions on the application of Search & Copy.

(8) a. **Transparent** vowels are simply ignored by VH, since they fail to meet the structural description of Search. For example, in the [±ATR] harmony system of Wolof (Niger-Congo), where /i u/ are transparent, and /e o ɛ ɔ ə a/ harmonic, we can assume that Search looks for a [-high] vowel (Samuels 2009), easily accounting for this pattern.

b. **Antiharmonic** vowels are valid targets of Search, but fail to satisfy the structural description of Copy. As a result, antiharmonic vowels are invalid (or defective) targets for Copy. In order to get the surface pattern of antiharmony, we also need to specify that a default feature-filling rule applies at the end of the derivation.

This gives us a typology of segments based on whether they are valid targets of Search and/or Copy (Table 1). The unnatural-class problem already mentioned in (4) can also be restated in SCT terms. We assume that transparent segments are ignored by Search, which targets *harmonic* segments. Crucially, this is impossible (under current assumptions) if the harmonic segments do not form a featurally natural class.

[11] I abstract away from the participation of laterals; see Clements & Sezer (1982), Mailhot & Reiss (2007) for more discussion.

Type of V	**Target of Search**	**Target of Copy**
Harmonic	✓	✓
Antiharmonic	✓	✗
Transparent	✗	✗
(Impossible)	✗	✓

Table 1 Behaviour of segments in harmony systems.

2 Rule Ordering

It has been proposed, especially within the SFP literature, that unnatural classes of harmonic vowels arise from multiple ordered rules (Mailhot & Reiss 2007, Leduc et al. 2020). Consider again the Finnish vowel inventory, with transparent /i e/[12] and harmonic /y ø æ u o ɑ/. The harmonic vowels can be classified as the complement of the natural class characterising /i e/; by DeMorgan's Law, ¬[-low, -round] = [+low] ∪ [+round]. We may then posit two rules, one targeting [+low] and the other targeting [+round]. Segments that are not [+low] OR [+round] are ignored by Search, and are thus treated as transparent by the harmony rule.

Similarly, antiharmonic vowels are excluded by stipulating conditions on multiple Copy operations, as exemplified by Mailhot & Reiss's (2007) analysis of Kyrgyz [round] harmony, where alternating suffixes harmonise for [round] (and [±back]). However, while [+high] suffix vowels Copy [+round] from all rounded vowels /y ø u o/, [-high] suffix vowels fail to Copy from /u/, e.g. [utʃ-tu] ∼ [utʃ-kɑ] 'tip-ACC/DAT', cf. [konok-ko] 'guest-DAT'. This can be modelled by postulating one Search with two Copy operations, each with different conditions:

(9) Round harmony ([-high] vowel version):
  a. Search **left** for γ : [αround, +vocalic]
  b. Copy [αround] from γ_i to ζ if:
    i. γ is [-high], OR
    ii. γ is [-back]

Copy fails if γ_i is [+high, +back] /u/ (or /ɨ/), and a default rule fills in [-round] at the end of the derivation.

All else being equal, a solution based on rule ordering is ideal. The theoretical device of extrinsic rule ordering is already required elsewhere, and so we derive transparency for free, without adding any computational power to the phonological component. It has also been argued that a language may have multiple rules underlying the surface phenomenon of harmony (Kiparsky 1973, Vaux 1995); for example,

[12] I include only the features that seem relevant to the description of the vowel inventory. Note also that [±back] and [round] are redundant with each other in this case.

stem-level harmony and suffix harmony must often be distinguished. This proposal is only somewhat different, in that it is argued that a single 'type' of harmony (here suffix harmony) involves multiple ordered rules.

However, this solution produces potential violations of relativised minimality, in that non-transparent vowels may be skipped.[13] This is especially the case if the language contains disharmonic stems that participate in vowel harmony. Stem-level disharmony can be schematised as follows:

(10) Disharmonic stems

a. [a…ä] OR

b. [ä…a]

Here, [a] represents a non-neutral [αF] vowel, and [ä] a non-neutral [-αF] vowel. Consider a toy grammar with two rules: Rule 1 targets segments like [ä] but not [a], and Rule 2 targets [a] but not [ä]. If Rule 1 is ordered before 2, in a stem that is [ä…a], Search (in Rule 1) will target [ä] while skipping the intervening harmonic vowel [a]. Samuel Andersson (p.c.) notes that this involves skipping of a relevant intervener, hence violating relativised locality; however, this follows only if we are tied to the conception of VH as involving a single rule. As Mailhot & Reiss (2007) note, if locality constraints are shown to be derived from conditions on rules, there is no violation of relativised locality in the phonology, since the VH process involves more than one ordered rule. Nevertheless, this surface locality violation is somewhat suspicious, and it is unclear whether such a pattern is actually attested.

In this section, I evaluate two previous rule-ordering accounts of transparent vowels: Mailhot & Reiss (2007) on Hungarian, and Leduc et al. (2020) on Votic. In Votic, the rule-ordering analysis is capable of generating the correct surface forms, but this is dependent on the assumption that the lexicon contains at most one of the two kinds of disharmonic stems given above. If both kinds of disharmony are attested, then ordering paradoxes arise; I suggest that this is the case in Hungarian and Finnish, both of which have various disharmonic loan stems that participate in harmony (Ringen & Heinämäki 1999, Törkenczy 2011).

2.1 Hungarian

Hungarian (Uralic) has [$\pm$back] harmony in suffixes (as well as in most native stems).[14] Mailhot & Reiss (2007) (henceforth M&R) propose that that transparency phenomena in Hungarian [$\pm$back] harmony can be modelled by appealing to ordered rules.

[13] Notice that there is no potential locality violation in the Kyrgyz analysis, since we only have multiple Copy; there is only one Search, and it is local.

[14] Some suffixes also show [round] harmony in addition to [$\pm$back] harmony. The rounding harmony system is generally simpler; for example, it does not show any transparency effects (Törkenczy 2011), and I do not discuss it here.

-back		+back	
-round	+round	-round	+round
i iː	y yː		u uː
eː ɛ	øøː		o oː
		ɑː	ɔ

Table 2 Hungarian vowel inventory.

The surface inventory of Hungarian vowels is given in Table 2.[15] The front unrounded vowels /i iː eː ɛ/ are neutral, and co-occur with [+back] vowels in stems.[16] It should be noted that /eː ɛ/ and /ɑː ɔ/ are often treated as being minimal length pairs, but other feature specifications (e.g. tongue root for /eː ɛ/ also differ Törkenczy 2011), though these are not always treated as phonological differences.

2.1.1 *Suffix harmony*

Many Hungarian suffixes show [±back] harmony, illustrated here with the dative suffix /-nAk/ [nɔk ∼ nɛk].[17] The following data is largely adapted from Törkenczy (2011); Fr = front harmonic, B = back harmonic, N = neutral. For ease of exposition, I schematise stem + suffix sequences as follows:

(11) $/V_n \ldots V_3 - V_2 - V_1 + V_{suff}/$

The [±back] value of the harmonising suffix vowel V_{suff} is determined by the preceding vowel, V_1, if it is harmonic:

(12) a. **V_1 is Fr, suffix is [-back]**

[ørøm-nɛk] ‘joy’
[ʃofør-nɛk] ‘chauffeur’

b. **V_1 is B, suffix is [+back]**

[ɔblɔk-nɔk] ‘window’
[biːroː-nɔk] ‘judge’

Complications arise if V_1 is neutral. If the first non-neutral vowel to its left is Fr, then the suffix will surface as [-back], e.g. [yvɛg-nɛk] ‘glass-DAT’. Any number of

15 The short low back vowel written as *a* (here /ɔ/) is variably transcribed as [ɔ, ɒ, ɑ]. Törkenczy (2011) notes that *a* is more rounded than [ɑ], but less so than [ɔ, ɒ]. I also assume that the vowel /ɛ/ is [-low], following M&R.

16 Note that /eː ɛ/ are not entirely neutral; while transparent to vowel harmony, they do alternate with /ɑː ɔ/ respectively in suffixes. Furthermore, it has been argued that the neutral vowels do not seem to be ‘equally’ transparent; see Ringen & Kontra (1989) and Rebrus & Törkenczy (2016) for further discussion.

17 There are various other alternating vowels; Törkenczy identifies at least 9, with varying degrees of productivity. The question of how exactly to represent these vowels underlyingly arises, but I do not deal with it here.

neutral vowels can intervene, so stems of this form can be represented as [Fr-B$*$] (where $*$ is a Kleene star). If the second closest vowel to the suffix (V2) is [+back], i.e. the stem is [B-N], there is some variation:

(13) a. **V_2 is back, suffix is [+back]**

[pɔpiːr-nɔk] ‘paper’
[kɑːveː-nɔk] ‘coffee’

b. **V_2 is back, suffix is [-back]**

[kodɛks-nɛk] ‘codex’

c. **V_2 is back, suffix vacillates**

[dʒungɛl-nɔk] ‘jungle’
[dʒungɛl-nɛk] (id.)

If V_2 is neutral and V_3 is [+back] ([B-N-N] stem), some stems exhibit **vacillation**: both [+back] and [-back] alternants can appear, e.g. [ɔnɔliziʃ-nɔk ∼ ɔnɔliziʃ-nɛk] ‘analysis-DAT’. Other stems take [+back] suffixes, e.g. [novɛmbɛr-nɛk] ‘November-DAT’. If the stem only contains neutral Vs, the suffix vowel will usually be [-back], e.g. [filːeːr-nɛk] ‘penny-DAT’. This pattern is apparently productive, since loan stems consisting solely of neutral vowels also take [-back] suffixes, e.g. [kviːn-nɛk] ‘Queen’. However, there are a number of ‘antiharmonic’ neutral stems that always select [+back] alternants, e.g. [hiːd-nɔk] ‘bridge’;[18] These are usually treated as exceptions; Mailhot & Reiss (2007) do not consider them in their analysis.

In general, we can say that the neutral vowels show some degree of transparency. However, an explanation should be found for cases like [ɔnɔliziʃ-nɛk], where two neutral vowels in a row sometimes trigger [-back] harmony. It is possible that Search has a maximum distance in Hungarian, as Nevins (2010) suggests; if Search fails to find a target after a traversing more than two syllables, it terminates. The presence of the [-back] specification on the suffix in such cases (and in purely neutral stems like [filːeːr-nɛk] may be attributed either to a default rule, or a more general harmony rule that Searches and Copies [±back] from any vowel.

2.1.2 Mailhot and Reiss's analysis

M&R propose that Hungarian [±back] harmony involves two extrinsically ordered rules:

(14) a. Search for a [+round] V and Copy [±back].

b. Search for any V and Copy [±back].

However, there is a clear issue with the analysis: it treats the low unrounded vowel /ɑː/ as transparent, since it is [-round] and should thus be ignored by Rule (14a).

[18] Törkenczy (2011) also cites the stem /feːrfi/ ‘manly’, which exhibits vacillation in some suffixes, like the dative, but consistently antiharmonic with others.

M&R provide a counterexample to their own analysis, [kɑːveː-nɔk] 'coffee-DAT'. Under M&R's analysis, Rule (14a) should fail to apply, since /kɑːveː/ contains no [+round] Vs; Rule (14b) applies, and its Search terminates on the first V, /eː/. We thus expect Copy of [-back] from /eː/, yielding the illicit form *[kɑːveː-nɛk].

It might be possible to salvage the analysis if the two harmony rules instead target [+round] and [+low].[19]

(15) a. Harmony with round vowels (RVH):
Search for a [+round] V and Copy [±back]

b. Harmony with [+low] vowels (LVH):
Search for [+low] V and Copy [±back]

The ordering of RVH and LVH is important, but to determine this we would need disharmonic sequences containing sequences of [+round, -back] and [+low, +back] vowels in either order:

(16) Disharmonic sequences in Hungarian

a. /{y, yː, ø, øː}…{ɑː, ɔ}/

b. /{ɑː, ɔ}…{y, yː, ø, øː}/

Törkenczy (2011) gives only one example of (16a): *pönálé* [pøːnɑːleː] 'penalty', a fairly transparent loan form; he does not provide any examples of harmony with this stem. A Google search for *pönálénak* ([+back] VH) returns 7 results, while *pönálének* ([-back] VH) returns none, suggesting that this stem causes [+back] harmony. Notice that the ordering must be LVH ≫ RVH; RVH ≫ LVH wrongly predicts that suffixes should be [-back] after (16a)-type stems, since RVH ignores intervening /ɑː/. However (16b)-type stems can also be found, e.g. *amatőr* [ɔmɔtøːr] 'amateur', again a loan. Google search suggests that these forms take [-back] suffixes: 99,300 for *amatőrnek* vs. 8 for *amatőrnak*. Hence, we need the ordering RVH ≫ LVH, else we would expect [+back] harmony. But this is contradictory to the ordering required for forms like *pönálé*; an ordering paradox results.

2.2 Votic

Votic is a severely endangered Finnic language spoken in Ingria (Northern Russia); it exhibits widespread [±back] harmony in stems and harmonic suffixes (Leduc et al. 2020). The vowel inventory is given in Table 3; the vowel /ɨ/ is only attested in Russian loanwords, and does not participate in harmony (Blumenfeld & Toivonen 2016). The vowel /i/ is neutral: it can freely co-occur with both [-back] and [+back] harmonic vowels in stems, does not alternate when it occurs in suffixes,[20], and is transparent in [±back] harmony. Leduc et al. (2020) (henceforth LRV) argue that the transparency of /i/ can be derived via rule ordering, without relying on theoretical devices like underspecification and Visibility Theory (see section 3).

[19] If /ɛ/ is [+low], then we can instead target [+round] and [+back].
[20] Harmonic vowels can also be invariant in suffixes.

-back		+back	
-round	+round	-round	+round
i	y	(ɨ)	u
e	ø	ə	o
æ		ɑ	

Table 3 Votic vowel inventory (length contrasts not represented).

2.2.1 Suffix harmony

Some Votic suffixes alternate for [±back]; in most cases, their [±back] value is determined by that of the preceding (non-neutral) vowel:[21]

(17) a. Vowel harmony controlled by preceding stem vowel.

vævy	vævy-æ	'rope-PART'
sɑvːə	sɑvːə-ɑ	'girl-PART'
ø	ø-heː	'night-ILL'
so	so-həː	'marsh-ILL'
væsyː	væsyː-nːy	'tired-PST.ACT'
ɑrvɑ	ɑrvɑ-nːʊ	'guess-PST.ACT'

b. /i/ is transparent to suffix harmony.

tʃæs	tʃæs-i-næː	'hand-COM'
pəlʲv	pəlʲv-i-nɑː	'knee-COM'
pehm	pehm-iː-seː	'soft-ILL.PL'
vətːim	vətːim-iː-səː	'key-ILL.PL'

If the stem only contains /i/, alternating suffixes will surface as [-back], e.g. [siːli-æ] 'hedgehog-PART'. We can thus generalise that Votic [±back] harmony Searches for a vowel that is *not* /i/, and Copies [αback]; this cannot be modelled as a natural class, since there is no set of features P such that every Votic vowel but /i/ is in P.

2.2.2 Leduc et al.'s analysis

LRV thus argue that Votic [±back] harmony consists of ordered rules:[22]

(18) Votic harmony rules[23]

a. Harmony with non-high vowels (NHVH):
Search for a [-high] V and Copy [±back]

b. Harmony with high round vowels (HRVH):
Search for a [+high, +round] V and Copy [±back]

[21] LRV postulate three alternating vowels, /A/ [ɑ∼æ], /E/ [ə∼e], /U/ [u∼y].
[22] They also reject underspecification accounts, following Blumenfeld & Toivonen (2016).
[23] I substitute Copy for Unify; see footnote 10 for discussion.

LRV argue that this specific ordering is supported by the existence of disharmonic forms like /tytːær-ikːo-A/ ‘girl-DIM-PART’ [tytːærikːoɑ]. The inverse ordering would wrongly identify /y/ in the initial syllable as γ_i, and thus copy [-back], giving *[tytːærikːoæ]. A default rule assigning [-back] applies if neither NHVH nor HRVH find a target, i.e. the stem only contains /i/.

This approach effectively treats the high rounded vowels /y,u/ as partially transparent, since NHVH ignores them. As a result, we might expect ordering paradoxes to arise in stems that contain the reverse ordering of vowels from [tytːærikːoɑ]; that is, disharmonic sequences of [-high, αback] … [+high, -αback]. For example, in the notional form /toky-A/, the rule ordering above would identify o as the target of the first Search (rather than intervening /y/); as a result, it would Copy [+back], and we would (counterintuitively) find [toky-ɑ] instead of [toky-æ]. However, LRV argue that this is not a problem for two reasons, (i) that there are no disharmonic /toky/-type stems in the lexicon, and (ii) Votic does not contain any suffixes with invariant /u, y/. Both facts taken together mean that Votic lacks any disharmonic sequences of {[-high, αback]…[+high, -αback]}, either in stems or in stem + suffix sequences. Interestingly, LRV claim that ‘ordering arguments can only be made on the basis of forms that match the /tyko/ pattern’: the absence of /toky/-type sequences is systematic, rather than accidental. It also suggests that they would reject (hypothetical) evidence from wug-test experiments conducted using the /toky/ pattern.[24]

2.3 Finnish

Finnish (Finnic) has a well-studied system of [±back] harmony. The surface vowel inventory in Table 4 is adapted from Ringen & Heinämäki (1999).

-back		+back	
-round	+round	-round	+round
i	y		u
e	ø		o
æ		ɑ	

Table 4 Finnish vowel inventory (length contrasts not represented).

Finnish shows vowel harmony in both stems and suffixes. Native (non-compound) stems require non-neutral vowels to agree for [±back]. Loan stems may be disharmonic, containing both [+back] and [-back] harmonic vowels (Ringen & Heinämäki 1999); however, these forms still participate in suffix harmony (Kiparsky 1973). The neutral vowels /i e/ can occur with [+back] and [-back] harmonic vowels in both native and loan stems, and are transparent in suffix harmony.

[24] The feasibility of such experiments is of course minimal, since Votic is nearly extinct.

2.3.1 Suffix harmony

Some suffixes alternate for backness; the [±back] value of an alternating vowel is determined by the closest non-neutral vowel:

(19) a. Essive /-nA/

pøytæ-næ	'table-ESS'
poutɑ-nɑ	'fine weather-ESS'
mɑkːɑrɑ-nɑ	'sausage-ESS'
koti-nɑ	'house-ESS'
pɑpːi-nɑ	'priest-ESS'

b. Adessive /-lːA/

kædæ-lːæ	'hand-ADD'
vero-lːɑ	'tax-ADD'
tie-lːæ	'road-ADD'
velje-lːæ	'key-ADD'

Forms ending in neutral vowels, like [koti-nɑ] and [pɑpːi-nɑ], show that the suffixal /A/ Copies [+back] from the preceding [+back] vowel of the stem, ignoring the neutral /i/. We can also observe that if the stem contains only neutral vowels, the suffix surfaces in its [-back] form, as in the adessive forms [tie-lːæ] and [velje-lːæ]. This could be interpreted as /i e/ being able to serve as targets of Search and Copy in certain limited environments, or the effect of a default rule filling in [-back].

2.3.2 Rule-ordering analysis

As noted in the introduction to this section, the harmonic vowels /y ø æ u o ɑ/ do not form a natural class; at best, we can identify [+round] /y ø u o/ and [+low] /æɑ/. The rule-ordering approach would thus involve multiple ordered Searches targeting each class:

(20) Finnish vowel harmony rules

a. Harmony with low vowels (LVH):
Search for a [+low] V and Copy [±back]

b. Harmony with round vowels (RVH):
Search for a [+round] V and Copy [±back]

On the assumption that disharmonic stems do not exist (or if disharmony is limited as in Votic) this would probably give the right (surface) results. As noted above, however, Finnish has a number of (loan) stems that are disharmonic for [±back]. In these cases, the multiple-rule approach produces locality/ordering paradoxes: regardless of how the Search operations are ordered, incorrect results are derived in some cases. Sample derivations for each ordering are given in Table 5, using the

Ordering 1: LVH ≫ RVH		
UR	/ɑnaly:si-A/	/tyrɑn:i-A/
LVH	ɑnaly:si-ɑ	tyrɑn:i-ɑ
RVH	—	—
SR	*ɑnaly:siɑ	[tyrɑn:iɑ]
Comments	/y/ skipped	
Ordering 2: RVH ≫ LVH		
UR	/ɑnaly:si-A/	/tyrɑn:i-A/
RVH	ɑnaly:si-æ	tyrɑn:i-æ
LVH	—	—
SR	[ɑnaly:siæ]	*tyrɑn:i-æ
Comments		/ɑ/ skipped

Table 5 Sample derivations with both possible orders of LVH and RVH.

partitive forms of /ɑnaly:si/ 'analysis' and /tyrɑn:i/ 'tyranny'.[25] We can see that an ordering paradox arises. Both orderings are incapable of generating the correct results; this is because the rule-ordering analysis incorrectly treats certain harmonic vowels as transparent. If LVH ≫ RVH, intervening /y/ in /ɑnaly:si/ is skipped; if RVH ≫ LVH, intervening /a/ is /tyrɑn:i/ is skipped. The rule-ordering analysis thus fails to provide an adequate account of Finnish [±back] harmony.

2.4 Summary

In the languages discussed above, the harmony process can be stated informally as in (21):

(21) Alternating vowels Search and Copy from the closest HARMONIC vowel.

Ordered-rule analyses cannot retain this generalisation; as I noted in the beginning of this section, the multiple rule analysis involves the skipping of harmonic segments.[26]

As a result, the rule ordering account can only (weakly) generate the correct surface patterns if stem disharmony is limited, as it is in Votic, in the sense that

[25] These examples were brought to my attention by Samuel Andersson. Note also that there is some variation in how individual speakers treat disharmonic loan stems; speakers may treat /y ø/ as transparent. See Ringen & Heinämäki (1999) for more discussion; different speakers clearly entertain distinct rule analyses. Importantly, however, we never find skipping of low vowels, contrary to the predictions made by the ordering RVH ≫ LVH discused below.

[26] Also, rule-ordering analyses predict the existence of surface locality violations in disharmonic stems, where harmonic vowels can be skipped. Such a language does not seem to exist; while arguments from absence are not airtight, this gap is suspicious.

at most one of the possible combinations of disharmonic vowels can be allowed (e.g. how Votic contains [tyko]-type sequences but not [toky]-type sequences). Languages like Finnish and Hungarian, with a rich inventory of disharmonic loan stems, cannot be analysed in terms of rule ordering, since fatal ordering paradoxes result. The success of the rule ordering analysis relies crucially on there being a gap in the lexicon; whether or not this gap is accidental or systematic (as Leduc et al. 2020 argue for Votic) is an empirical question. The analysis proposed in section 4 avoids this ordering paradox by ensuring that Search targets the set of harmonic vowels simultaneously.

3 Exceptional Segments

Neutral segments may also be analysed as *representationally* distinct from harmonic ones, rendering them non-participants in vowel harmony. They may be UNDERSPECIFIED for the harmonic feature (Dresher 2009, Shen 2016), causing them to pattern differently in harmony processes. Alternatively, they may be fully specified, but lack either CONTRASTIVE or MARKED values of the harmonic feature. Visibility Theory (Calabrese 2005, Nevins 2010) proposes that rules can specifically target such feature-values, rendering neutral segments 'invisible' to harmony. Either proposal may be embedded in our approach (with some modifications); the goal of this section is thus to evaluate both solutions to (4) from the perspective of substance-free SCT. I argue that neither underspecification nor VT are viable as universal accounts of harmony and neutrality, suggesting that independent explanations should be found.

3.1 Underspecification

Feature underspecification has often been used to explain neutrality (van der Hulst 2016). Assume, for example, that neutral vowels are underspecified for the harmonic feature [αF]. This will have several consequences, depending on our formulation of the VH rule:

(22) a. **Transparency**: if Search looks for a segment that is [αF], neutral segments will be treated as irrelevant, rendering them transparent.[27]

b. **Antiharmony**: assuming a local Search that looks for the closest vowel and Copies [$\pm$F], nothing will be Copied if the target of Search lacks [F] altogether. Antiharmonic vowels are assigned [αF] while alternating vowels are assigned [$-\alpha$F], giving rise to surface antiharmony.

The contrast between invariant and alternating segments is also explained with reference to Archiphonemic Underspecification, as mentioned in section 1.

[27] Note that the 'missing feature' [G] that Search looks for, and which transparent segments lack, need not be the harmonic feature [F], as in Wolof (discussed in section 1), so underspecification of neutral vowels is not always needed in SCT.

3.1.1 Opportunistic underspecification

Underspecification analyses must provide a principled account of when and why segments may be underspecified for features. Failure to do so results in opportunistic invocation of underspecification. For example, Shen (2016) attempts to analyse Uyghur (Turkic) [±back] VH in a SFP approach similar to the one adopted here.[28] Uyghur has a surface vowel inventory similar to that of Finnish (section 2.3); like Finnish, the unpaired vowels /i, e/ are transparent to [±back] harmony.[29] Stems containing only neutral vowels are somewhat more complicated. While they usually take [+back] suffixes, e.g. [deŋiz-lɑr] 'sea-PL', some take [-back] suffixes, e.g. [tʃiʃ-lær] 'tooth-PL'. This variation is apparently arbitrary, and is independent of etymological factors (Mayer & Major 2018).

In order to account for the transparency of /i/, along with the neutral stems that condition [-back] harmony, Shen (2016) sets up an underlying distinction between [Øback] /I/ (transparent) and [-back] /i/ (harmonic). This also accounts for derived transparency; the process of Low Vowel Raising (/æ, ɑ/ → [i] in medial open syllables) also produces transparent /I/. Shen's analysis thus involves the absolute neutralisation of the contrast between /i/ and /I/. Absolute neutralisation poses a nontrivial learning problem for the language-learner, who must acquire /i,I/ on the sole basis of their varying participation in vowel harmony: forms like [tʃiʃ-lær] and [deŋiz-lɑr] seem to be the only cues for the distinction.[30] Shen's invocation of underspecification is also opportunistic: /i e/ are analysed as underspecified simply because they are transparent (note that Shen explicitly rejects Contrastive Underspecification). To claim that transparency results from underspecification is somewhat circular, since underspecification is itself postulated on the basis of transparent behaviour (Kiparsky 1973). In the absence of a principled theory of underspecification, Shen's analysis loses explanatory force. In the following section I discuss one of the many theoretical approaches to underspecification, though it should be noted that this approach (as with most mainstream underspecification theories) does not allow for the same /i/-/I/ absolute neutralisation that Shen proposes.

3.1.2 Contrastive Underspecification

Various approaches to deriving feature specification and underspecification have been proposed in UNDERSPECIFICATION THEORY. I focus on Dresher's (2009) Modified Contrastive Specification (MCS) approach; Radical Underspecification relies on

[28] See Shen (2016: ch. 3) and Vaux (2000) for more detailed discussion of Uyghur VH, which is complex and shows cyclic/post-cyclic interactions with a widespread low-vowel raising process.

[29] Most analyses focus primarily on /i/; /e/ is severely restricted in distribution, occurring only in loanwords and as the output of an umlaut rule that raises short low vowels in initial syllables when followed by [i] (Shen 2016). Note also that the treatment of /i/ as unpaired abstracts away from surface phonetic reality; [ɨ] does occur as an allophone of /i/ as the result of C-V coarticulation (Hahn 1991).

[30] See also Kiparsky (1973) for other arguments against the use of absolute neutralisation as an explanatory device.

markedness, which has no status in SFP.[31] MCS employs a hierarchical notion of contrast, setting it apart from earlier Contrastive Underspecification approaches, e.g. Clements (1987), which relies on pairwise contrast; Dresher (2009) argues extensively against the pairwise approach to underspecification. Under the MCS approach, the child divides the segmental inventory into a contrastive hierarchy through application of the Successive Division Algorithm (SDA).[32] It is also argued that the Contrastivist Hypothesis holds throughout the phonology:

(23) Contrastivist Hypothesis (Hall 2007: p. 20):
The phonological component of a language L operates only on those features which are necessary to distinguish the phonemes of L from one another.

Contrast is thus explicitly tied to activity in phonological processes; importantly, anything that is inactive (hence underspecified) cannot be accessed by phonological rules. These features can only be filled in by post-phonological rules, similar to enhancement processes (Dresher 2018). We can thus derive the transparency of /i e/ in languages like Finnish and Uyghur by postulating the feature ordering [±round] ≫ ([±high], [±low]) ≫ [±back], as shown in Figure 1. Presumably, the neutrality of /i e/ leads the child learner to postulate such an ordering, leaving /i e/ unspecified for [±back].

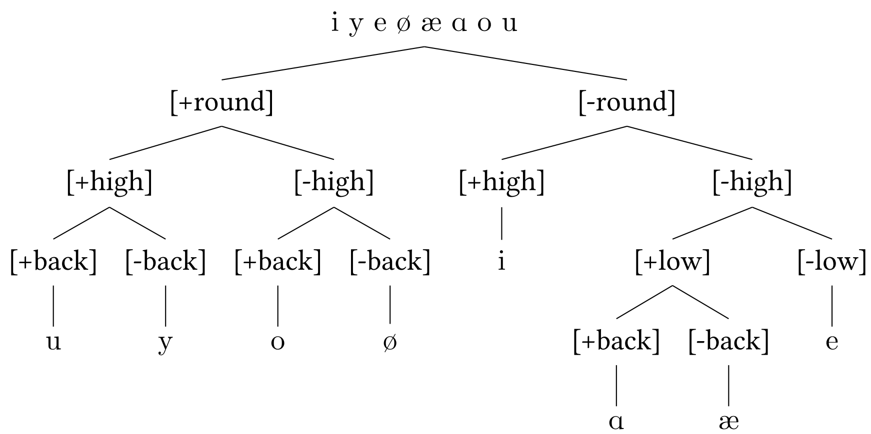

Figure 1 Contrastive feature tree for Uyghur.

3.2 Oops, I need that!

Nevins (2015) argues that underspecification analyses face what he terms the 'Oops, I need that' (OINT) problem: while we can assume that a segment is unspecified for [F] to account for its neutrality, other processes elsewhere in the phonology

[31] Samuels (2009) also argues that Radical Underspecification cannot account for systems where three-way contrasts [+F/-F/ØF] are required, e.g. Kalenjin [±ATR] harmony.

[32] Since the hierarchy is language-specific and emergent, this approach predicts that languages with similar surface inventories can exhibit very different phonological behaviour.

require [F] to be present. For example, the behaviour of transparent /i/ in Finnish and Votic outside of harmony suggests that they are [-back]. Finnish, for example, has assibilation t → s /__i applying in derived environments (Kenstowicz 1994); Nevins (2010) argues that the feature [-back] is essential for the statement of the rule. And Votic has various processes that seemingly require /i/ to be [-back]; these include /l/-fronting and /k/-palatalisation (Blumenfeld & Toivonen 2016, Hall 2017).

However, neither of these conclusions necessarily follow. In the case of Finnish, we can identify /i/ (and /e/) without reference to [±back]: [-low, -round, +high] are sufficient. Nevins (2010) argues that such an analysis is undesirable, since it obscures the phonetic basis of assibilation, i.e. the effect of the /i/'s [+high, -back] features on the realisation of the preceding stop. But there is no reason to assume that the phonetic justification of a rule must be preserved in its synchronic description (Reiss 2017b). This is particularly obvious in cases of 'rule telescoping', such as the postlexical sandhi rule /l/ → [ʁ] / V__V in some Sardinian dialects (Scheer 2015). In these examples, there is no clear synchronic phonetic justification for the alternation, yet such rules must clearly be allowed by the phonology. And since SFP assumes that phonetic properties of features are irrelevant to phonological computation, the argument from naturalness does not hold here.

Hall (2017) also proposes an MCS solution to the Votic problem relying on /i/ being [±coronal]. By ordering [±coronal] before all other vowel features, /i/ can be characterised as [Coronal, Øback]; the other vowels (which are harmonic) can be divided in terms of [±back] and other features.[33] This analysis seems to rely on the redundancy that is encoded by the feature [±coronal] and [-back], which usually code for similar phonetic properties. This analysis could also be extended to Finnish, with some minimal adjustments; [round] must still be ordered before [±back] to prevent e from being assigned [-back]. To the extent that we find Hall's [±coronal]-/i/ analysis convincing, the OINT problem does not arise for Votic and Finnish, since it is possible to state the various processes involving the neutral vowels without reference to [-back].

3.2.1 Karchevan Armenian antiharmony

A more serious OINT problem can be identified in the Karchevan dialect of Armenian, where the neutral vowels /i e ɛ/ pattern differently for the two processes of suffix-level [±back] harmony and epenthetic vowel harmony. The Karchevan dialect is spoken in the south of Armenia, close to the Iranian border (Vaux 1995). The vowel inventory of Karchevan is given in Table 6; the vowels /i e ɛ/ are neutral. The distribution of [ə] is often predictable, so it is usually omitted from underlying representations.[34] Karchevan Armenian exhibits stem-level harmony, where stem

[33] While it has been argued that vowels are [±dorsal] rather than [±coronal] (Howe 2004), we cannot assume this to be the case for Votic in the absence of patterns requiring [±dorsal] on vowels, since feature specifications are emergent.

[34] Note also that while this vowel is transcribed as [ə], I treat it as [+high] due to its behaviour. See Vaux (1998) for more discussion of epenthesis in Armenian.

-back		+back	
-round	+round	-round	+round
i	y	ə	u
e ɛ	ø		o
æ		ɑ	

Table 6 Karchevan vowel inventory.

vowels share the same [±back] value; the neutral vowels /i e ɛ/ can co-occur with both [-back] and [+back] harmonic vowels. Some suffixes also harmonise for [±back]:

(24) a. Harmony with PL /-Aɾ/ [ɑɾ ∼ æɾ]

tsɑr-Aɾ	tsɑrɑɾ	'tree-PL'
onkʰ-Aɾ	onkʰɑɾ	'eyebrow-PL'
muts-Aɾ	mutsɑɾ	'big one-PL'
æts-Aɾ	ætsæɾ	'goat-PL'
gʲørn-Aɾ	gʲørnæɾ	'sheep-PL'
gʲyl-Aɾ	gʲylæɾ	'wolf-PL'

b. Neutral vowels are antiharmonic

izn-Aɾ	iznɑɾ	'OX-PL'
bern-Aɾ	bernɑɾ	'burden-PL'
dɛzn-Aɾ	dɛznɑɾ	'wild mint-PL'
biɾgædiɾ-U-n	biɾgædiɾun	'together-DAT-DEF'

The form /biɾgædiɾ-U-n/ [biɾgædiɾun], *biɾgædiɾyn shows that Search does not skip /i/ and Copy [-back] from preceding /æ/, i.e. that /i/ is antiharmonic.

Epenthetic VH can be illustrated with the definite article /-n/, which is realised as [ə ∼ i ∼ y] depending on the preceding vowel.[35] The data is summarised in Table 7; epenthetic vowels receive [-back] (and possibly [+round]) from [-back] vowels (including /i e ɛ/) in adjacent syllables, or adjacent palatalised Cs. If the word lacks vowels, or only has adjacent [+back] vowels, the epenthetic vowel surfaces as [ə]. The crucial point for our discussion is the participation of /i e ɛ/ in this process, vs. their neutrality in suffixal harmony. If they were to be unspecified for [±back], we would find *ə (rather than [i]) as the result of harmony. Therefore /i e ɛ/ cannot be treated as underspecified for [±back], despite being antiharmonic with suffixes.

It is a simple matter to ensure that i e ɛ are [-back], e.g. by ordering [±back] over all the other features in the contrastive hierarchy. By doing so, however, we lose our account of the neutral vowels being antiharmonic in suffix harmony.[36] It is worth

[35] Schwa-epenthesis occurs if addition of /-n/ produces illicit clusters; /-n/ deletes if not followed by a vowel.

[36] Of course, if antiharmony can be modelled via multiple (ordered) rules, as I argued in section 2 with respect to Kyrgyz, then this is not a problem.

Harmony trigger	UR	SR	Gloss
[-bk, -rd] V	/værd-n/	værdi	rose-DEF
	/beh-n/	behi	spade-DEF
	/vitsʰ-mndʒi/	vitsʰmindʒi	sixth (ordinal)
[-bk, +rd] V	/myrdʒym-n/	myrdʒymy	ant-DEF
	/bødzr/	bødzyr	high
[-bk] V	/hɑkʰ-n/	hɑkʰə	foot-DEF
	/joχtn-mndʒi/	joχtəməndʒi	seventh
	/jorku-məndʒi/	jorku-məndʒi	second
nothing	/χm-ɑts/	χəmɛts	drink-P.PTCP
palatal C	/knɑgʲ-n/	knɑgʲi	woman-DEF

Table 7 Karchevan Armenian epenthetic vowel harmony.

noting that Visibility Theory (discussed below) provides a comparatively simple account of this fact; Vaux (1995) argues that suffix harmony involves spreading of CONTRASTIVE [±back], excluding /i e ɛ/ (which are not pairwise-contrastive), while epenthetic VH involves spreading of ALL [±back].

3.2.2 *Hungarian low vowels*

There also seem to be cases where the SDA simply fails to derive the appropriate opposition between specified (harmonic) and underspecified (neutral) segments.[37] This seems to happen in Hungarian, where we want /i(ː) eː ɛ/ to be [Øback] due to their transparency. However, there does not seem to be a way to specify /ɑː ɔ/ as [+back] without also specifying /eː ɛ/ as [-back]. Let us consider a version of the Hungarian vowel inventory which abstracts away from quality differences in length pairs for space reasons (Table 8).

-back		**+back**	
-round	+round	-round	+round
i	y		u
e	ø		o
		ɑ	

Table 8 Simplified Hungarian vowel inventory.

[37] An obvious example would be in languages where a neutral segment is minimally paired with a harmonic one, e.g. how Kyrgyz /u/ minimally contrasts with /ɨ/ for [round].

I assume three height distinctions: [+high, -high, +low]. Adopting a two-way distinction [±high] incorrectly predicts a Turkic-like system, where /e ∼ ɑ/ are minimally paired, hence for /e/ to be the [-back] counterpart to /ɑ/, and be [-back] harmonic, which is not the case.[38] Therefore I assume that [back, high, low, round] are minimally required, giving $4! = 24$ possible permutations of feature orderings (and specifications). We can immediately eliminate a number of possible orderings, as schematised in Table 9.

Ordering	**Reason for rejection**
[±low] ≫ …	Fails to assign /ɑ/ a [±back] specification, since it is just [+low].
… ≫ [±low] ≫ (…) ≫ [±back]	Fails to assign /ɑ/ a [±back] specification, since it is just [+low].
[±back] ≫ …	Neutral vowels receive [±back] specifications.
… ≫ [±back] ≫ (…) ≫ [round]	Neutral vowels receive [±back] specifications.
… ≫ [±back] ≫ (…) ≫ [±high]	Assigns /i e/ [-back] before they can be distinguished with [±high].

Table 9 Possible divisions that do not work. Bracketed ellipses are optional features; ellipses are any other feature.

To summarise, [±back] must precede [low]; [±high] must precede [±back]; and [round] must precede [±back]. This leaves us with just 2 options (25).

(25) a. [±high] ≫ [round] ≫ [±back] ≫ [low]: this fails because ordering [low] this low in the hierarchy renders it irrelevant; the ordering treats /e ∼ ɑ/ as a [±back] pair.

b. [round] ≫ [±high] ≫ [±back] ≫ [low]: again, [low] is rendered irrelevant, and /e ∼ ɑ/ are treated as a [±back] pair.

It seems impossible to derive the neutrality of e and the activity of ɑ through feature ordering. Note that adding in more features does not seem to save the analysis, since this should predict even more orderings where [±back] is unnecessary to distinguish ɑ from other vowels. The Hungarian pattern thus seems to pose a real problem for attempts at explaining transparency by appeal to contrastive underspecification.[39]

[38] Though as noted in section 2.1, /eː/ and /ɑː/ do alternate in several suffixes.

[39] MCS does allow ‘prophylactic’ features, which are non-contrastive but must be specified solely for the purpose of preventing neutralisation (Dresher 2009: pp. 208-209). However, prophylactic features are inert to phonological computation, so they are not relevant here.

3.2.3 Summary

In general, underspecification theory does not provide a universal account of neutrality, as argued based on data from Karchevan Armenian and Hungarian. Note that this not inherently a problem for MCS;[40] it is only problematic for our attempts at modelling neutrality with MCS. As Dresher (2009: p. 175, fn. 16) notes (without further explanation), '[t]here are various reasons why segments may block harmony, not all derived from their contrastive status [...] targets may be restricted for reasons beyond their contrastive status'. In general, however, it seems that explanations for neutrality independent of contrastive underspecification must be found.

Furthermore, underspecification raises certain issues in SCT: in particular, how do we prevent underspecified neutral vowels from harmonising? We assume that all vowels of a featural class [$F_1 \ldots F_n$] initiate a Search for a harmonic feature [G]; non-alternating vowels are invariant because they are prespecified for [αG], and CONSISTENCY (see section 1.3.1) prevents copying of [-αG]. But this does not hold for underspecified neutral vowels, which we would expect to harmonise, e.g. Hungarian /i e ɛ/ → *[ɨ ɤ ʌ]. Lindblad (1990) and Finley (2008) propose that neutral vowels *do* undergo harmony, though the result is neutralised on the surface. Again, this raises learnability concerns, and I would consider this a point against the underspecification analysis.

3.3 Visibility Theory

Visibility Theory (Calabrese 1995, Vaux 1995, Nevins 2010 etc.) allows rules to target {ALL, CONTRASTIVE, MARKED} values of features. I focus primarily on Nevins' (2010) Search-based implementation; other accounts employ autosegmental spreading.[41] On this approach, segments are fully specified, but may have CONTRASTIVE or MARKED feature-values. Contrast is defined in a pairwise manner, and can be computed on a position-specific basis (Nevins 2010: p. 86):

> 'A segment S in position P is contrastive for the feature [F] iff there is a segment S_0 in the inventory that is featurally identical to S for all values except [F], and S_0 can occur in position P as well.'

On the other hand, marked specifications seem to come from two sources, (i) a UG-specific markedness component (cf. Calabrese's 2005 Markedness Module) and (ii) language-specific or 'logical' markedness.[42] I focus primarily on the use of

[40] Though see Samuels (2009: ch. 3) for arguments against MCS.

[41] There are some differences between this version of SCT and the one I adopt. Importantly, (i) Search and Copy must target the same feature, (ii) Search can only look for a single feature, and no further conditions on operations are allowed.

[42] This can be seen in the discussion of Finnish (Nevins 2010: pp. 109-111), where the default ('unmarked') value of [±back] is argued to be [-back], in contrast to Uyghur and other languages, where the default value is [+back]. The addition of logical and language-specific markedness arguably expands the concept of 'markedness' to the point that it fails to make any strong typological predictions, surely an undesirable consequence.

(pairwise) contrast in VT; given that my approach is substance-free, markedness has no theoretical status.

3.3.1 The treatment of neutrality in VT

Given a harmony rule targeting CONTRASTIVE or MARKED [F], and a segment S that lacks either type of [F], S will be treated as neutral. For example, Finnish lacks /ɨ ɤ/, so /i e/ are non-contrastive for [±back]; if Finnish [±back] harmony section 2.3 involves Search for CONTRASTIVE [±back], then the transparency of the neutral vowels is straightforwardly derived. The primary issue with VT (in the context of our substance-free approach) is that contrast is neither necessary nor sufficient to determine activity in VH. In some languages, non-contrastive vowels are harmonic, and in others the inverse pattern holds, where contrastive vowels are neutral. While it may be possible to explain some of the data by referring to either MARKED or ALL values of [F], some patterns resist explanation in these terms. To account for such cases, Nevins (2010) has to appeal to other factors like sonority, which have no theoretical status in a substance-free theory.

Non-contrastive but harmonic

In many languages, non-contrastive vowels nevertheless participate in harmony. For example, Khanty (Uralic) has unpaired but harmonic /i/ (van der Hulst 2016). In some cases this can easily be resolved by stipulating that harmony looks for ALL [F]. This approach obviously does not work if there are other segments that are also neutral; for example, Hungarian has harmonic low [+back] vowels /ɑː ɔ/, which lack [-back] counterparts, along with the neutral (transparent) /i(ː) eː ɛ/. Since the Hungarian VH rule is argued by Nevins (2010) to target CONTRASTIVE [±back], we predict the low vowels to be transparent. This is not the case, as discussed in section 2.1. Nevins (2010) argues that low vowels are 'sonority hurdles': in languages like Hungarian, they are sonorous enough to intervene for Search, even if they do not meet the structural description of the VH rule.

Contrastive but neutral

We also find neutral vowels that *are* contrastive for the relevant harmonic feature; the (in)activity of these vowels cannot be predicted from the structure of the segmental inventory.[43] In some cases we can postulate that Search looks for MARKED [F], but this is not always possible. For example, Mayak (Nilotic; South Sudan) exhibits bidirectional [±ATR] harmony. McCollum (2016) analyses eight phonemic vowels:

[43] Seto (Finnic) has been cited as such a case (Bowman 2013); this language has /i/ and /ɨ/, but /i/ is transparent to [±back] harmony. However, the contrast between /i ∼ ɨ/ is actually neutralised in non-initial positions (Kiparsky & Pajusalu 2001). As a result, a Search for contrastive [±back] would skip non-initial /i/; /i/ can only be contrastive in monosyllabic stems, which *do* take [-back] suffixes, as predicted by the VT approach. Note that positional contrast can also be derived in MCS, since multiple hierarchies can be defined corresponding to different phonological positions, e.g. initial vs. non-initial positions (Dresher 2009: pp. 190-196).

/i ɪ ɛ a ʌ ɔ ʊ u/, with additional surface [e o].[44] In regressive [±ATR] harmony, which is the most productive harmony pattern, the surface harmonic pairs are /ɛ-e/, /ɔ-o/, /ɪ-i/. Despite being minimally paired for [±ATR], /a-ʌ/ do not alternate with each other, though they *are* paired for progressive [±ATR] harmony, except in the singulative suffix [at̪ ∼ ʌt̪]].[45] Appealing to MARKED [±ATR] does not seem to work here, since [+low, +ATR] is a highly marked combination (Calabrese 2005: p. 366).

3.4 Exceptional segments: A summary

In this section, I have discussed attempts at deriving neutrality through underspecification (Dresher 2009) or feature (in)visibility (Nevins 2010); both accounts rely on some notion of contrast (and markedness in the case of VT). I argued that neither approach provides a universal account of neutrality. More generally, the concept of contrast has been criticised by some work in the substance-free tradition, particularly by Charles Reiss and colleagues (Shen 2016, Reiss 2017a, Leduc et al. 2020):

(26) SFP criticisms of contrast

a. Contrast is a functionalist notion based on the communicative use of language: it 'relates to the capacity of a phonological difference to communicate a difference in meaning' (Reiss 2017b: p. 435).[46]

b. Contrast complicates the grammar e.g. by requiring a separate module to determine contrastive values; an approach that can derive the empirical insights of contrast-based theories (without appealing to contrast) is simpler and thus more desirable (Reiss 2017a).

c. Contrast is invoked opportunistically, and on a language-specific basis; this is in direct response to VT approaches, which allow for non-contrastive features to be active (Reiss 2017a).

Perhaps the most important issue with these arguments is that the use of contrast does not simply boil down to 'simplif[ying] the description of particular languages' (Reiss 2017a: p. 30); as discussed at length in section 2, there is a clear empirical problem in the SFP treatment of transparency that goes beyond simplicity/elegance considerations. By hypothesis, appealing to 'contrast' provides us with a solution to this problem.[47]

---

[44] Note that these seem to be allophonic vowels produced by [±ATR] harmony, providing a counterexample to the idea that VH is 'structure preserving' (Kiparsky & Pajusalu 2003).

[45] This also poses problems for underspecification accounts, since they predict segments to behave consistently (i.e. neutral/harmonic) regardless of morphological context.

[46] This seems to be a rather distinct understanding of the term; see Dresher (2009: p. 20 onwards) for discussion.

[47] And there do seem to be many patterns where (non-)contrastiveness *does* seem to correlate with (in)activity, though I am unaware of any large-scale typological surveys of these patterns.

But in any case, contrast does not seem to be sufficient on its own; patterns like the Hungarian one remain problematic even if we adopt MCS or (substance-free) VT. My conclusion is somewhat more modest: given that the solutions I propose in the following section do not rely on contrast, but can generate these patterns, I assume that appeal to contrast is not necessary in our account of vowel harmony. This is compatible with the assumption that contrast has no intragrammatical status (Reiss 2017a), but further discussion of the role contrast plays is beyond the scope of this dissertation.

4 Modelling Unnatural Classes

In this section, I propose two ways of augmenting the rule component in order to achieve (27):

(27) Phonological rule(s) can target unnatural classes of segments **simultaneously**.

This has the consequence of allowing SCT to model unnatural classes of harmonic vowels, providing a solution to the problem in (4), while adhering to the basic assumptions outlined in section 1. Further computational and typological consequences are also considered.

4.1 Union operators

One way of achieving (27) is by allowing rules to target the conjunctions of natural classes. This can be done through introducing AND/OR operators in the phonology, as Sayeed (2018) proposes.[48] For example, the Finnish [±back] harmony rule can be characterised as a Search for segments that belong to the set {[+round] ∪ [+low]}:

(28) Finnish [±back] harmony

a. Search($\Sigma, \zeta, \gamma, \delta, \beta$):
   i. Σ: word
   ii. ζ: [+vocalic]
   iii. γ: [+round] ∪ [+low]
   iv. δ: L
   v. β: %

b. Copy [αback] from γ_i to ζ_i.

Consider again the partitive forms [tyrɑnːiɑ] and [ɑnɑlyːsiæ] as seen in Table 10. The union-operator analysis predicts that harmony looks for the closest harmonic (i.e. [+round] OR [+low]) vowel, and straightforwardly derives the correct pattern.

[48] There are some precedents for this idea, for example, Zwicky's (1970) proposal, and there is some similarity with the brace notation of that era (Odden 2011). Furthermore, Nevins (2010) proposes set union of CONTRASTIVE and MARKED [F] to model Oroch [±ATR] harmony. Note that the Oroch pattern is not a problem for our SCT, since the set of transparent vowels is [-back] /i æ/; Search simply looks for [+back] vowels in that case.

UR	/tyrɑnːi-A/	/ɑnɑlyːsi-A/
ζ_i	/A/	/A/
γ_i	ɑ	y
Copied [F]	[+back]	[-back]
SR	[tyrɑnːiɑ]	[ɑnɑlyːsiæ]

Table 10 Finnish derivation using set union to target [+round] ∪ [+low].

4.1.1 'Crazy' classes

The addition of union operators provides a substantial increase in the computational power of phonology. In principle, any arbitrary set of segments can now be the focus or the environment of a phonological rule, as Sayeed (2018) proposes for the analysis of 'crazy-class' processes which involve featurally-unnatural classes, like River West Tarangan (RWT; Austronesian) nasal assimilation:

(29) /m/ → [place] / __ /t̪ g s j/

The RWT consonant inventory is given in Table 11. Under any standard feature-based account, it is impossible to characterise the environment of rule (29) while also excluding /k d r l/ (Samuels et al. 2022).

	Labial	Dental	Alveolar	Palatal	Velar
Stop [-voi]		**t̪**			k
Stop [+voi]	b		d		**g**
Fricative	ɸ		**s**		
Nasal	m		n		ŋ
Liquid			r l		
Glide				**j**	

Table 11 River West Tarangan consonant inventory; **bolded** segments trigger nasal assimilation.

Note that it *is* possible to provide a traditional rule-based account of many such processes, e.g. by simply postulating a conspiracy of rules, one rule targeting each segment:

(30) Conspiracy analysis of RWT[49]

a. /m/ → n̪ / __ /t̪/: [+coronal, +distributed]

b. /m/ → n / __ /s/: [+coronal, -distributed, +continuant]

c. /m/ → ɲ / __ /j/: [+coronal, +dorsal]

d. /m/ → ŋ / __ /g/: [-coronal, +dorsal, +voice, -nasal]

Of course, vowel harmony cannot be analysed in this way, as argued at length in section 2.

4.1.2 Typological consequences

Furthermore, the observation that rules tend to be defined over natural classes must be treated as a typological generalisation, rather than a defining feature of phonological rules (contra Bale & Reiss 2018, etc.). This raises two important questions:

(31) a. Why don't we find crazy classes more often?

b. A duplication problem arises in cases like RWT nasal assimilation (but not VH): given the two possible analyses - conspiracies and union-operators - how does the language-learner choose?

As for (31a), we could plausibly state learning or economy biases (e.g. as part of an evaluation metric) that penalise the use of union operators in the phonology, such that most rules continue to operate on natural classes. As a result, unnatural-class rules, like the River West Tarangan nasalisation rule, may be on the outer edge of the 'learnable' circle in Hale & Reiss's (2008) hierarchy of grammars (but still very much 'computable', as are even crazier rules).

Answering (31b) seems more problematic, since we do not know which analysis the learner chooses in the first place. In classical generative phonology, the evaluation metric would assign a higher score to rules that could be abbreviated using the brace notation (Odden 2011), itself somewhat similar to the union operator. We might thus assume that the learner prefers to abbreviate rules rather than allow conspiracies, though this does not seem compatible with the suggestion above that the use of union operators be penalised by the evaluation metric. However, Bridget Samuels (p.c.) notes that crazy classes do not seem to be all that rare; in Mielke's (2008) crosslinguistic survey of phonological patterns, 1498 out of 6077 classes (24.7%) are featurally unnatural in a number of feature theories.[50] One might thus suppose that learners are perfectly willing to construct rules involving union operators, instead of them being a 'marked' choice in grammar-construction.

[49] The features used to characterise the environment are not exhaustive for notational convenience.

[50] Note that some of Mielke's putative cases are spurious; see, for example, Hall (2010) for discussion.

4.2 Competing Search

An alternative proposal relies on the idea that rules can apply simultaneously and in competition. Under any rule-based theory, rules can be ordered with respect to one another: given Rules A, B, we can say that A {FOLLOWS, PRECEDES} B. Suppose it is also possible to say that Rules A and B apply SIMULTANEOUSLY. Consider again the two Search rules that must be posited for Finnish, repeated from (20):

(32) Finnish vowel harmony rules

a. Harmony with low vowels (LVH):
Search for a [+low] V and Copy [±back]

b. Harmony with round vowels (RVH):
Search for a [+round] V and Copy [±back]

Assume that LVH and RVH apply concurrently: both Searches apply at the same time, and scan the phonological string at the same rate (i.e. segment by segment). In the form /ɑnɑlyːsi-A/, /A/ (partitive suffix) **simultaneously** initiates SEARCH-LVH (S1) and SEARCH-RVH (S2):

i. S2 identifies its target /y/ and terminates.

ii. Copy applies, so /A/ copies [-back] from /y/, giving [æ] as desired.[51]

When (i) happens, S1 will also be 'on' /y/; unlike S2, it does not terminate, since /y/ is not [+low]. But what happens to S1 afterwards? Since Copy is constrained by the requirement that segments be CONSISTENT (see section 1.3.1), nothing else needs to be said:

i. S1 terminates on /ɑ/, which is the closest [+low] vowel.

ii. Copy applies; the suffix vowel [æ] (no longer /A/ at this point) attempts to copy /ɑ/'s [+back] value. Since the output is not consistent for [±back], Copy fails to apply (or applies vacuously).

Disjunctive application does not have to be stipulated; we get this result due to independently needed properties of our rule architecture.

4.2.1 Distance-sensitivity

This analysis assumes Search to be distance-sensitive. Irrelevant segments (consonants and neutral vowels) are not completely invisible to Search; Search scans the string segment by segment, but only terminates on relevant segments. In the Finnish example, irrelevant interveners are consonants [-vocalic], and the neutral vowels /i e/ [-round, -low]; Search must traverse these segments. For example, in a word like /ɑnɑlyːsi/:

[51] The converse applies for forms like /tyrɑnːi-A/, where LVH finds its target /ɑ/ before RVH /y/.

(33) Distance traversed by Search to find γ_i

a. LVH = 5 intervening segments, l $\rightarrow$ y $\rightarrow$ y $\rightarrow$ s $\rightarrow$ i

b. RVH = 2 intervening segments, s $\rightarrow$ i

If Search is sensitive to distance, then RVH finds its target before LVH does, simply because LVH has to traverse a longer distance, thus 'taking longer' to find its target. It should be noted that this conception of Search does not seem to be compatible with Tier-Based Strictly Local (TSL) implementations of SCT (Andersson, Dolatian & Hao 2019), where irrelevant interveners are not projected onto the Search tier, and are thus truly invisible. This could be seen as a point against the competing-Search approach, especially since the union-operator analysis seems to be compatible with TSLs.

However, Nevins (2010) discusses evidence from various languages suggesting that Search can be subject to domain limitations; Search may 'give up' if unable to find a relevant target after a certain amount of time (i.e. distance traversed). For example, Nevins argues that for some Hungarian speakers, Search halts (and default [-back] insertion occurs) after traversing two or more syllables without finding a target. As a result, [BNN] stems (section 2.1) surface with [-back] suffixes, e.g. [ɔnɔliziʃ-nɛk] 'analysis-DAT'.[52] There also seem to be a few other languages that show such domain-bounding effects, e.g. Yucatec Maya, where a process of total harmony can apply if there are 0-1 (but not two or more) intervening consonants, here demonstrated with the imperfective suffix /-Vl/:

(34) a. Total harmony with one intervening C:

ʔok-ol	'enter-IMPF'
lu-ɓul	'fall-IMPF'
kiːm-il	'die-IMPF'

b. Default [a]-insertion with two Cs:

t'otʃ-ɓ-al	'harden-PASS-IMPF'
*t'otʃ-ɓ-ol	(id.)

While the crosslinguistic data is somewhat sparse, it seems to suggest that Search *is* sensitive to irrelevant material. Intervening consonants are not the targets of Search in Yucatec Maya, but Search must still traverse these segments while finding a target; additional domain-bounding constraints prevent Search from traversing more than one consonant. If Search is distance-sensitive, then the minor modification proposed here, that Searches can be stipulated to apply simultaneously, predicts that two Search operations can compete with one another.[53]

[52] Speakers also seem to 'vacillate': they entertain a rule that is not domain-bounded, hence [ɔnɔliziʃ-nɔk] with [+back] harmony. Some similarity may be drawn with 'agreement attraction' in morphosyntax (Bock & Miller 1991). Attraction is usually treated as a performance/real-time processing effect; it is possible (though I do not explore this any further) that 'vacillation' arises from similar processing constraints, in which case it is not really part of phonological competence proper.

[53] As with the union-operator analysis, the question arises as to when the learner would postulate ordered vs. simultaneous application of rules. It seems to me that *only* harmony processes like those in Hungarian and Finnish can provide the necessary evidence to disambiguate, so it is unclear which choice the learner would take by default.

4.2.2 Bidirectional processes

The competing-Search proposal also makes an interesting prediction with respect to bidirectional processes. In some harmony systems, a vowel Searches in both directions for a target, e.g. in Woleaian (Nevins 2010) and in 'dominant-recessive' harmony processes (van der Hulst 2016). We also find patterns of epenthetic vowel harmony where epenthetic vowels harmonise in either direction, e.g. in Goris Armenian (Vaux & Addy Suhairi 2021). Consider a hypothetical language L with epenthetic vowel harmony for [αF]; this language allows stems containing both values of [F].

(35) Hypothetical epenthesis patterns in L (V_1 is [+F], V_2 is [-F], and E is the epenthetic vowel)

a. V_1 C C E C V_2

b. V_1 C E C C V_2

c. V_2 C C E C V_1

d. V_2 C E C C V_1

Which target would the epenthetic vowel harmonise with? There seem to be three logical possibilities as shown in Table 12.

Type of preference	Predictions
Directional	E prefers to harmonise with a vowel in a specific direction. If it prefers the vowel to its right, then it will pick V_2 in (35a, b) and V_1 in (35c, d).
Featural	E prefers to harmonise with just one of the [F] values. For example, if it prefers [+F], then it harmonises with V_1 in all cases.
Distance	E prefers to harmonise with the *segmentally closest* V, so we should expect (35a): V_2, (35b): V_1, (35c): V_1, (35d): V_2

Table 12 Possible outcomes from bidirectional epenthetic VH.

Karchevan Armenian epenthetic harmony instantiates DIRECTIONAL PREFERENCE (Vaux 1995), while dominant-recessive patterns show FEATURAL PREFERENCE. The competing-Search account predicts that DISTANCE PREFERENCE should be possible; such a pattern would involve two simultaneously-applying Search operations with different directions. This pattern does not seem to be attested; one might thus argue that the competing-Search analysis overgenerates. Further investigation, possibly using artificial-grammar paradigms, is required to determine its (un)learnability.

5 Conclusion

I have sought to propose a substance-free account of the problem (4) identified in section 1: how do we formulate phonological rules (Search/Copy operations) to target unnatural classes of segments? The most unambiguous conclusion is that the standard SFP account of this problem, which relies on multiple ordered rules (Mailhot & Reiss 2007, Leduc et al. 2020), is empirically insufficient; it runs into ordering paradoxes in languages with a variety of disharmonic stems, like Hungarian and Finnish, and its ability to weakly generate the correct surface pattern is contingent on possibly-accidental gaps in the lexicon. Approaches based on underspecification and visibility were also rejected. As a result, I suggested in section 4 that phonological computation should be allowed to target unnatural classes simultaneously. One way of doing this is by introducing a union operator into the rule system, and allowing rules to target the set union of natural classes. The alternative is to allow simultaneous application of rules; given the assumption that Search is sensitive to (irrelevant) segmental distance, the analysis predicts that Search operations can be in competition with one another. While both analyses seem capable of deriving the various harmony patterns discussed here, several problems arise. The clearest issue is the 'duplication problem' in our analysis of processes like RWT nasalisation:

(36) a. How do we decide between a conspiracy (i.e. multiple ordered rules) and a single rule that uses set union?

b. A similar problem arises for competing-Search proposals: are the multiple rules ordered or simultaneous in application?

In the VH cases discussed here, however, there is no choice to be made, since the conspiracy analysis fails, as argued in section 2; but this is unclear in other processes. Further investigation is thus required to determine the conditions under which learners choose between analyses. The competing-Search proposal also rests on the idea that phonology is sensitive to segmental distance, even if the segments traversed are non-targets. Further research into putative distance effects in phonology is needed, e.g. in the form of experimental investigation of the hypothetical 'distance preference' pattern in bidirectional epenthetic harmony.

References

Andersson, S., H. Dolatian & Y. Hao. 2019. Computing Vowel Harmony: The Generative Capacity of Search and Copy. In H. Baek, C. Takahashi & A. H.-L. Yeung (eds.), *Proceedings of the 2019 Annual Meeting on Phonology*, Linguistic Society of America.

Bale, A., M. Papillon & C. Reiss. 2014. Targeting underspecified segments: A formal analysis of feature-changing and feature-filling rules. *Lingua* 148. 240–253. doi:10.1016/j.lingua.2014.05.015.

Bale, A. & C. Reiss. 2018. *Phonology: A Formal Introduction.* Cambridge, MA: MIT Press.

Blumenfeld, L. & I. Toivonen. 2016. A featural paradox in Votic harmony. *Natural Language & Linguistic Theory* 34(4). 1167–1180. doi:10.1007/s11049-016-9329-9.

Bock, K. & C. A. Miller. 1991. Broken agreement. *Cognitive Psychology* 23(1). 45–93. doi:10.1016/0010-0285(91)90003-7.

Bowman, S. R. 2013. Two arguments for vowel harmony by trigger competition. In *Proceedings of the 49th Annual Meeting of the Chicago Linguistic Society*, Chicago Linguistic Society.

Burness, P., K. McMullin & A. Nevins. 2020. Restrictive Models and Relativized Locality in Harmony. In H. van der Hulst & N. Ritter (eds.), *The Oxford Handbook of Vowel Harmony*, Oxford: Oxford University Press. Preprint article.

Calabrese, A. 1995. A Constraint-Based Theory of Phonological Markedness and Simplification Procedures. *Linguistic Inquiry* 26(3). 373–463.

Calabrese, A. 2005. *Markedness and Economy in a Derivational Model of Phonology* Studies in Generative Grammar. Berlin; New York: Mouton de Gruyter.

Chomsky, N. & M. Halle. 1968. *The Sound Pattern of English*. New York: Harper & Row.

Clements, G. N. 1987. Toward a Substantive Theory of Feature Specification. In *Proceedings of NELS 18*, North East Linguistics Society.

Clements, G. N. & E. Sezer. 1982. Vowel and Consonant Disharmony in Turkish. In H. van der Hulst & N. Smith (eds.), *The Structure of Phonological Representations (part II)*, Dordrecht: Foris Publications.

Dresher, B. E. 2009. *The Contrastive Hierarchy in phonology*. Cambridge: Cambridge University Press.

Dresher, B. E. 2018. Contrastive Hierarchy Theory and the Nature of Features. In *Proceedings of the 35th West Coast Conference on Formal Linguistics*, Calgary: Cascadilla Proceedings Project.

Finley, S. 2008. *Formal and cognitive restrictions on vowel harmony*: John Hopkins University dissertation.

Hahn, R. F. 1991. *Spoken Uyghur*. Seattle: University of Washington Press.

Hale, M. & C. Reiss. 2008. *The Phonological Enterprise*. Oxford: Oxford University Press.

Hall, D. C. 2007. *The Role and Representation of Contrast in Phonological Theory*. Toronto, Canada: University of Toronto dissertation.

Hall, D. C. 2010. Probing the unnatural. *Linguistics in the Netherlands* 27(1). 73–85. doi:10.1075/avt.27.07hal.

Hall, D. C. 2017. Locality, neutrality, and contrast: A new resolution to the Votic paradox. Paper presented at NELS 48.

Henry, C. 2018. An Optimality Theoretic analysis of vowel harmony in Kazan Tatar. *Proceedings of the Linguistic Society of America* 3(1). doi:10.3765/plsa.v3i1.4278.

Howe, D. 2004. Vocalic Dorsality in Revised Articulator Theory. Unpublished ms., University of Calgary.

van der Hulst, H. 2016. Vowel Harmony. In *The Oxford Research Encyclopedia of Linguistics*, Oxford: Oxford University Press. doi:10.1093/acrefore/9780199384655.013.38.

van der Hulst, H. 2018. *Asymmetries in Vowel Harmony: a Representational Account*. Oxford: Oxford University Press.

Inkelas, S. 1995. The consequences of Optimization for Underspecification. In *Proceedings of NELS 25*, Massachusetts.

Kenstowicz, M. 1994. *Phonology in Generative Grammar*. Oxford: Blackwell.

Kiparsky, P. 1973. How Abstract is Phonology? In *Explanation in Phonology*, Dordrecht: Foris Publications.

Kiparsky, P. & K. Pajusalu. 2001. Seto vowel harmony and the typology of disharmony. Unpublished ms., Stanford University.

Kiparsky, P. & K. Pajusalu. 2003. Towards a typology of disharmony. *The Linguistic Review* 20(2-4). 217–241. doi:10.1515/tlir.2003.009.

Leduc, M., C. Reiss & V. Volenec. 2020. Votic vowel harmony in Substance Free Logical Phonology. In H. van der Hulst & N. Ritter (eds.), *The Oxford Handbook of Vowel Harmony*, Oxford: Oxford University Press. Preprint article.

Lindblad, V. M. 1990. *Neutralization in Uyghur*. University of Washington MA thesis.

Mailhot, F. & C. Reiss. 2007. Computing Long-Distance Dependencies in Vowel Harmony. *BIOLINGUISTICS* 1. 028–048.

Mayer, C. & T. Major. 2018. A Challenge for Tier-Based Strict Locality from Uyghur Backness Harmony. In A. Foret, G. Kobele & S. Pogodalla (eds.), *Formal Grammar 2018*, 62–83. Berlin: Springer.

McCollum, A. 2016. Mayak and the Typology of Labial Harmony. In K. Jesney, C. O'Hara, C. Smith & R. Walker (eds.), *Proceedings of AMP 2016*, Linguistic Society of America.

Mielke, J. 2008. *The Emergence of Distinctive Features* Oxford Studies in Typology and Linguistic Theory. Oxford: Oxford University Press.

Nevins, A. 2010. *Locality in Vowel Harmony*. Cambridge, MA: MIT Press.

Nevins, A. 2015. Triumphs and limits of the Contrastivity-Only Hypothesis. *Linguistic Variation* 15. 41–68. doi:10.1075/lv.15.1.02nev.

Odden, D. 2011. Rules v. Constraints. In J. Goldsmith, J. Riggle & A. C. Yu (eds.), *The Handbook of Phonological Theory*, chap. 1, 1–39. Blackwell. doi:10.1002/9781444343069.ch1.

Odden, D. 2019. Radical Substance Free Phonology and Feature Learning. *Phonological Theory Agora* .

Prince, A. & P. Smolensky. 1993. Optimality Theory: Constraint Interaction in Generative Grammar. Manuscript.

Rebrus, P. & M. Törkenczy. 2016. Types and degrees of vowel neutrality. *Linguistica* 56(1). 239–252. doi:10.4312/linguistica.56.1.239-252.

Reiss, C. 2017a. Contrast is irrelevant in phonology: a simple account of Russian /v/ as /V/. In B. Samuels (ed.), *Beyond Markedness in Formal Phonology*, Amsterdam: John Benjamins.

Reiss, C. 2017b. Substance Free phonology. In S. J. Hannahs & A. Bosch (eds.), *The Routledge Handbook of Phonological Theory*, London: Routledge Handbooks Online. doi:10.4324/9781315675428-9.

Ringen, C. O. & O. Heinämäki. 1999. Variation in Finnish Vowel Harmony: An OT Account. *Natural Language & Linguistic Theory* 17(2). 303–337.

doi:10.1023/A:1006158818498.

Ringen, C. O. & M. Kontra. 1989. Hungarian neutral vowels. *Lingua* 78(2). 181–191. doi:10.1016/0024-3841(89)90052-1.

Samuels, B., S. Andersson, O. Sayeed & B. Vaux. 2022. Getting ready for primetime: paths to acquiring substance-free phonology. Forthcoming article in Canadian Journal of Linguistics.

Samuels, B. D. 2009. *The Structure of Phonological Theory*. Cambridge, MA: Harvard University dissertation.

Samuels, B. D. 2011. *Phonological architecture: A biolinguistic approach*. Oxford: Oxford University Press. doi:10.1093/acprof:oso/9780199694358.001.0001.

Sayeed, O. 2018. String phonology. Unpublished ms.

Scheer, T. 2015. How Diachronic is Synchronic Grammar? In *The Oxford Handbook of Historical Phonology*, Oxford: Oxford University Press.

Shen, D. T.-C. 2016. *Precedence and search: Primitive concepts in morpho-phonology*. Taipei: National Taiwan Normal University dissertation.

Törkenczy, M. 2011. Hungarian Vowel Harmony. In M. van Oostendorp, C. J. Ewen, E. Hume & K. Rice (eds.), *The Blackwell Companion to Phonology*, chap. 123, 1–27. Blackwell. doi:10.1002/9781444335262.wbctp0123.

Vaux, B. 1995. Vowel Harmony in the Armenian Dialect of Karchevan. In *Proceedings of the 9th Biennial Non-Slavic Languages Conference*, Chicago: Chicago Linguistic Society.

Vaux, B. 1998. *The Phonology of Armenian* The Phonology of the world's languages. Oxford: Oxford University Press.

Vaux, B. 2000. Disharmony and derived transparency in Uyghur Vowel harmony. In M. Hirotani, A. Coetzee, N. Hall & J.-Y. Kim (eds.), *NELS 30: Proceedings of the North East Linguistic Society*, .

Vaux, B. & A. Addy Suhairi. 2021. Armenian vowel harmony. In H. van der Hulst & N. Ritter (eds.), *The Oxford Handbook of Vowel Harmony*, Oxford: Oxford University Press. Preprint article.

Walker, R. 2011. *Vowel Patterns in Language* Cambridge Studies in Linguistics. Cambridge: Cambridge University Press. doi:10.1017/CBO9780511973710.006.

Zwicky, A. M. 1970. Class Complements in Phonology. *Linguistic Inquiry* 1(2). 262–264.

Ariwan Kai Addy Suhairi
University of Cambridge
aka45@cam.ac.uk