Confidence scales: a new approach to derived environment effects

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1. Introduction

This paper introduces representational confidence scales as a new dimension in phonological representations.* In addition to representing individual segments in terms of distinctive features, each individual segment token is, on this proposal, lexically stored with a confidence value reflecting the robustness of its storage in memory. This proposal offers a way of building psycholinguistic and phonetic salience into scalar phonological representations:

(1) Confidence scale: *Weak*--------------------------------*Strong*

Instead of assuming that every token of /a/ in underlying representation is represented identically, confidence scales allow each token of /a/ to be represented with a relative strength value. For purposes of this paper, a binary distinction between "weak" and "strong" will generally be sufficient, but in theory confidence scales are continuously valued between 0 (weakest) and 1 (strongest).

The proposal that individual elements of linguistic representation are stored with differential degrees of robustness is grounded in exemplar models of memory and storage, in which a speaker abstracts classificatory featural information about linguistic structures from fine-grained details about the speaker's own experience with the articulation and acoustics of those structures. A particular segment token which has many tightly

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clustered points in motor-acoustic exemplar space is strong; a segment token with few, or widely scattered, points in exemplar space is weak.

Confidence scales offer an intriguing new perspective on several long-standing problems in phonological theory, including neutral vowels in vowel harmony (e.g., Finnish), abstract contrasts in segment quality (e.g., Kashaya), and nonderived environment blocking, the focus of this paper.

We begin, in section 2, with a proposal to build confidence scales into an Optimality-Theoretic grammar, briefly illustrating in sections 2.1 and 2.2 the potential applicability of confidence scales to the enigmatic behavior of neutral and abstract vowels. Section 3, the core of this paper, applies confidence scales to the problem of morphologically nonderived environment blocking. Section 5 discusses the functional underpinnings of confidence values. Section 6 returns to morphologically derived environment effects and shows that confidence scales correctly predict a range of attested effects beyond the usual canonical examples. Section 7 briefly compares confidence scales to competing analyses of morphologically derived environment effects, which are more limited in their coverage. Section 8 relates confidence scales to other formal scales that have been proposed in phonological theory.

2. Building confidence scales into a model of grammar

It is widely accepted in Optimality Theory that “special” faithfulness constraints can be indexed to segments in phonologically prominent positions — initial, stressed, or geminate, to take three common examples (see e.g. Beckman 1997, Smith 2002). Special faithfulness protects such segments from alternations that unprotected segments undergo:

(2) FAITH-special » PHONO-C » FAITH

Special faithfulness has also been posited for morphologically prominent constituents, i.e. roots (McCarthy & Prince 1995), and even for part of speech; Smith (2011) proposes that noun faithfulness outranks verb faithfulness in many if not all languages.

This paper extends special morphophonological faithfulness down to the level of individual segment tokens: highly confident representations are subject to more stringent faithfulness constraints than weaker representations are. Operating under the useful fiction that segments are stored either as “strong” or “weak”, each constraint in the Faithfulness family can be split into two: one ($\text{F}\textsc{aith}_\text{S}$) specific to "strong" segments, and one which applies to all segments.

(3) Strength-sensitive faithfulness: $\text{F}\textsc{aith}_\text{S}$, $\text{F}\textsc{aith}$

Note that no $\text{F}\textsc{aith}_\text{W}$ is posited, following Kiparsky (1994) and DeLacy (2002), who split Faithfulness in a similar manner to account for asymmetries between marked and unmarked structure. This continues the tradition from underspecification theory of not referring to unmarked structure (see e.g. Kiparsky 1993). Positing $\text{F}\textsc{aith}_\text{W}$ would not change the logic of the arguments presented in this paper, but compels the analyst to account for why the perverse ranking $\text{F}\textsc{aith}_\text{W}$ » $\text{F}\textsc{aith}_\text{S}$ is not observed.

We turn next to two very brief applications of strength sensitivity to problems often classified under "phonological abstractness" because standard phonological representations fail to capture observed phonological distinctions between phonetically identical segments.

2.1 Finnish: neutral vowels are weakly front

Finnish famously exhibits vowels which are front phonetically but which do not act as front phonologically. Finnish progressive palatal harmony requires suffix vowels to agree in backness with the closest stem vowel (4a). The two "neutral" vowels, /i/ and /e/, neither trigger front harmony on following suffixes nor interfere with back harmony triggered by a preceding vowel (4b). Only if all the vowels in root are neutral does the phonetic frontness of /i/, /e/ trigger front harmony on suffixes (4c):

(4)	a.	pöytä-nä	'table-ESS'			
		pouta-na	'fine weather-ESS'			
	b.	säde-ttä	'ray-PART'	c.	sade-tta	'rain-PART'
		täti-llä	'aunt-ADESS'		kati-lla	(woman's name)
		kesy-llä	'tame-ADESS'		vero-lla	'tax-ADESS'

Rhodes (2012:154), on whose analysis this discussion is based, invokes representational strength to explain the otherwise inexplicable failure of /i/ and /e/ to trigger front harmony in suffixes. Using different notation than that used here, Rhodes proposes that /i/ and /e/ are "weak", while all of the other vowels in the Finnish inventory are "strong".

Taking an Agreement by Correspondence approach to Finnish harmony, Rhodes posits a correspondence constraint ($\text{C}\textsc{orr}\text{-}V_SV_S$)

holding over strong vowels. IDENT-VV(bk) enforces harmony on correspondence sets, which do not include the weak /i/ and /e/: [1]

(5) CORR-V_SV_S : Strong vowels correspond to one another
IDENT-VV(bk): Corresponding vowels agreee in backness
CORR-VV : Vowels (of any kind) correspond to one another

These constraints ensure that suffix vowels will agree with the closest strong stem vowel, if there is one. (Not depicted in this tableau, IDENT-IO-root(bk) is ranked very high and IDENT-IO-(bk) is ranked very low; thus suffixes, but not roots, alternate in service of vowel harmony.)

(6)

	/sade-ttA/	CORR-V_SV_S	IDENT-VV(bk)	CORR-VV
☞ a.	sa$_i$de-tta$_i$			
b.	sa$_i$de-ttä$_i$		*!(a ≠ ä)	*(a ≠ ä)
c.	sade$_i$-tta$_i$	*!(a…a)	*(e ≠ a)	*(e ≠ a)
d.	sade$_i$-ttä$_i$	*!(a…ä)		
e.	sade-tta			*!(e…a)
f.	sade-ttä			*!(e…ä)

When only weak vowels are present, the effects of the lower-ranked CORR-VV(bk) constraint emerge:

(7)

	/tie-llA/	CORR-V_SV_S	IDENT-VV(bk)	CORR-VV
a.	tie$_i$-lla$_i$		*!(a ≠ ä)	
☞ b.	tie$_i$-llä$_i$			
c.	tie-lla			*!
d.	tie-llä			*!

The advantage of using a strength diacritic to distinguish /i/ and /e/ from the other front vowels is that it is not necessary to deny that they are phonologically front. Studies have shown that they are indeed articulated like front vowels and that they exert and undergo comparable coarticulatory effects in the environment of other vowels (Gordon 1999).

[1] On Agreement by Correspondence theory, see e.g. Hansson 2001, Rose and Walker 2004, Hansson 2007. Following Rhodes 2012, I assume that correspondence is local and pairwise. Other approaches to vowel harmony could also be modified to take the weak/strong distinction into account.

Other approaches to Finnish-style vowel harmony have used temporary underspecification for [back] (see Ringen and Vago 1998 on Hungarian), have distinguished between “core” and “autosegmental” [back] specifications (Poser 1982) or have proposed that Finnish /i/ and /e/ temporarily harmonize to [ɯ] and [ɤ] and are subsequently restored (Clements 1976). This last approach, especially, is abstract in relying on representations which cannot surface. By contrast, confidence-based representational differences are not ephemeral; they persist to the surface.

2.2 The two i’s of Kashaya

Buckley (1994) presents a classic puzzle of linguistic abstractness in Kashaya, which has a typical five-vowel surface inventory: [i, e, a, o, u]. However, among the vowels that surface as [i] there is a two-way underlying distinction, which Buckley annotates as /i/ and /î/. These vowels pattern differently in a number of ways.

First, underlying /i/ is subject to two unusual phonological alternations (see Buckley 2000) which /î/ resists. Following /d/, /i/ becomes [u] (8a); following /m/ and /q/, it becomes [a] (8b,c):

(8)	a.	cad-ins’	→ cadúns’	‘I wonder if he saw it’
		cahno-ad-iyic’-ʔ	→ cahnodu·yíʔ	‘talk to oneself’
	b.	p^{h}a-nem-i	→ p^{h}anemá	‘punch him!’
		kel-m-w	→ kélmaw	‘peer directly down at’
	c.	sima·q-i	→ sima·qá	‘sleep!’
		ʔusaq-iyic’-i	→ ʔusá·qayi·c’i	‘wash yourself!’

In three of the 21 [i]-initial suffixes in Kashaya, however, [i] surfaces intact, resisting the alternations above. (9a) illustrates resistance to /di/ → [du]; (9b) illustrates resistance to /mi/ → [ma]. (9c) shows that, following a uvular, /î/ surfaces intact as [i] but causes the uvular to front to velar [k]:

(9)	a.	cahno-ad-îc’-ʔ	→ cahno·díʔ	‘talk to oneself’
		cahno-ad-îyic’-ʔ	→ cahnodi·yíʔ	‘talk to oneself’
	b.	caq^{h}am-îbic-ʔ	→ caq^{h}amí·biʔ	‘start to cut with a knife’
		q^{h}os’am-îbic-ʔ	→ q^{h}os’amí·biʔ	‘winter to begin’
	c.	ʔusaq-îbic-ʔ	→ ʔusá·kibiʔ	‘start to wash the face’
		p^{h}i-ʔya·q-îc’-ʔ	→ p^{h}iʔya·kíʔ	‘notice (about) oneself’

Buckley attributes the different behavior of /i/ and /î/ to their underlying representations: /i/ is unspecified, while /î/ is [+high]. Giving

/î/ a feature that /i/ lacks, Buckley argues, explains the uvular assimilation to /î/ in (9c): [+high] spreads to the uvular, converting it to /k/. Underspecifying /i/ accounts for the fact that [i] is the epenthetic vowel in Kashaya, as well as for its suceptibility to assimilation.

Buckley's insights can be modelled equally well by assigning /i/ and /î/ the same phonological features but treating /i/ as "weak" and /î/ as "strong". Strong /î/ is protected by faithfulness; weak /i/ is not protected and therefore undergoes alternations. As a strong vowel, /î/ is a better assimilation trigger than /i/ is. Clearly, underspecification and specification with a weak feature are similar concepts. But the weak feature option avoids what Steriade (1995) calls "temporary underspecification" in order to represent a vowel contrast. Since strength values can persist on the surface, they obviate the need for two stages of derivation, one (for lexical phonology) in which underspecification exists and one (for phonetic interpretation) in which it does not.

The preceding two examples were suggestive of the work that strength values can do. In Finnish, weakness was a property of vowel type, in that all neutral vowels were weak and all other vowels were strong. In Kashaya, strength was a property of indvidual tokens of phonetic [i]. The case study that we will focus on in this paper is closer to the latter, relying on strength differences among tokens of the same type of segment to model derived environment effects. In this case study, strength is not arbitrary, nor is it determined by vowel type; it is determined by context. A segment occurring in an alternation environment is weaker, all else equal, than a segment occurring in a nonalternating environment.

We begin with a brief introduction to derived environment effects. Morphologically derived environment effects, also known as nonderived environment blocking (NDEB), have proved tricky to capture over 40 years of trying. The proposal in this paper is that the behavioral asymmetries can be attributed to strength differences.

3. Canonical morphologically derived environments

Morphologically derived environment effects (MDEEs) have been a focus of phonological theory since a series of influential papers by Kiparsky in the late 1960's and early 1970's. A recent statement of the phenomenon is offered by McCarthy (2003), who characterizes an MDEE as "a process that takes place only when its conditions are crucially met by virtue of material from two different morphemes" (p. 21).

When MDEEs are mentioned in introductory textbooks (e.g. Haspelmath 2002:186, Spencer 1991:108), the canonical illustrative examples tend to be very similar. The classic MDEE is Finnish Assibilation, in which stem-final /t/ assibilates to [s] preceding suffix-initial /i/ (10a,c). /ti/ sequences within roots do not undergo the alternation (10b,c) (Kiparsky 1973:58, Keyser and Kiparsky 1984; Kiparsky 1993):

(10)

a.	halut-i	→ halusi	'want-3P.SG.PRET'	
	halut-a	→ haluta	'want-INF'	
b.	æiti	→ æiti	'mother'	(*æisi)
c.	tilat-i	→ tilasi	'order-3P.SG.PRET'	(*silasi)
	tilat-a	→ tilata	'order-INF'	(*silata)

Structurally completely parallel examples occur in many languages. Two commonly cited examples, both involving palatalization, occur in Polish (Łubowicz 2002) and Korean (T. Cho 1998, Y. Cho 2009):

(11) Polish Palatalization: *k, x, g → č, š, ž* before *i, e.*

a. 'to step' kro[k]-i-ć → kro[č]ɨć
'to frighten' stra[x]-i-ć → stra[š]ɨć
'to weigh' va[g]-i-ć → va[ž]ɨć

b. 'kefir' [k]ef'ir *[č]ef'ir
'agent' a[g]ent *a[ž]ent

c. 'chemist-DIM' [x]em'i[k]-ek → [x]emi'[č]ek (*[š]emi'[č]ek)

(12) Korean Palatalization: *t, tʰ → c, cʰ* before *i, y*

a. 'eldest-NML = eldest son' mat-i → maci
'field-COP = to be the field' patʰ-ita → pacʰita

b. 'joint' mati *maci
'to tread' titi-ta *cicita

Deviating from this theme only in the nature of the alternation, Turkish Velar Deletion deletes *k, g* when intervocalic and stem-final, but not when stem-medial (Lewis 1967, Zimmer and Abbott 1978, Sezer 1981):

(13)	a. bebek-e	→ bebe-e	'baby-DAT'	bebek
	katalog-u	→ katalo.u	'catalog-3SG.POSS'	katalog
	b. avukat	→ avukat	'lawyer'	avukat
	sigorta	→ sigorta	'insurance'	sigorta
	c. sokak-a	→ soka.a	'street-DAT'	sokak
	ʧøkek-in	→ ʧøke.in	'hollow-GEN'	ʧøkek

Section 6 will introduce a broader variety of morphologically derived environments. However, the pattern of stem-final consonant alternation demonstrated here is the canonical MDEE that every theory of MDEE's aspires to capture. One interpretation of these facts is the following:

(14) **Contextual Stability generalization**: Segments occurring in variable contexts are more likely to alternate than segments occurring in invariant contexts.

Early theoretical approaches, like the Alternation Condition (Kiparsky 1968) and the Revised Alternation Condition, have captured the Contextual Stability Generalization with a meta-condition that directly inhibits alternations, exemplified below by Kiparsky's (1982:148, 152) Revised Alternation Condition:

(15) **The Revised Alternation Condition (RAC)**: Obligatory neutralization rules apply only in derived environments

The RAC works straightforwardly for Finnish Assibilation and Polish and Korean palatalization. It is less clearly applicable to Turkish velar deletion, which does not technically neutralize a phonemic contrast.

There have been tweaks to the RAC since 1982; in particular, Kiparsky (1993) questions the "obligatory neutralization" component on the basis of allophonic alternations showing derived environment effects. It is still the received view, however, that across languages, many or most morphophonological alternations are restricted to applying in derived environments. The RAC stipulates this. But ideally we would like a basic principle of this kind to follow from our theory, without stipulation.

The proposal advanced in this article derives the Contextual Stability Generalization from the interaction of grammar with confidence-based representations. In this respect the proposal builds on Kiparsky (1993), who uses underspecification to distinguish alternating from nonalternating segments, as Buckley used underspecification to distinguish the alternating and nonalternating [i]s of Kashaya. However, the representations in question are quite different. Kiparsky's proposal, along with other alternative methods of generating MDEEs, is discussed in section 7.

4. Confidence and morphologically derived environments

Confidence scales allow specific units of phonological representation to be lexically stored with varying degrees of confidence. The confidence model draws on exemplar theories of memory to propose that the frequency and regularity with which a given piece of phonological structure is produced or perceived will contribute to its representational entrenchment, or strength (see Johnson 1997, Bybee 2000, Pierrehumbert 2002, among many others). Applying this concept to morphophonology leads to the following hypothesis in (16a), and its corrollary in (16b):

(16) a. Segments occurring in invariant contexts have more consistent representations than those in variable contexts.
b. **Confidence Corollary**: segments occurring in invariant contexts are stronger, on the confidence scale, than those occurring in variable contexts, all else equal

Let us illustrate the Confidence Corollary with a Finnish stem like /tilat/. The initial /t/ occurs in an invariant environment, while the final /t/ occurs before a variety of segments, including /i/, /a/, and consonants. By the Confidence Corollary, the initial /t/ should have consistent phonetic realizations and be stored with a very high degree of confidence, while the /t/ at the end of *tilat* occurs in a variable environment and is stored with a lower degree of confidence. On a scale from 0 to 1, initial /t/ has the features of [t] with a probability of 1, while final /t/ is represented as having those features with a probability of, say, .5, reflecting the fact that /t/ surfaces variably as an onset, as a coda, as [t], as [s], and preceding a variety of vowels. These probabilies can be crudely quantized into the binary values "strong" and "weak", as discussed above. Section 5 explores more deeply the underpinnings of confidence strength values. For now, let us simply assume that stem-final segments are represented more weakly than stem-initial and stem-medial ones, whose confidence strength benefits from more robust contextual cues.

MDEEs can be captured by Faithfulness constraints which refer to representational strength:

(17) $\text{F}_{\text{AITH}_\text{S}}$ » MARKEDNESS » FAITH

In (21), faithfulness to confident representations generates MDEEs of the type seen in section 1. In Finnish, the constraint *TI penalizes /t/ before /i/. FAITH$_S$ protects strong nonfinal /t/ from *TI, but weak, stem-final /t/ is at its mercy:

(18)

/ $t_s i_s l_s a_s t_w$ –i/	FAITH$_S$	*TI	FAITH
tilati		**!	
tilasi		*	*
silasi	*!		**

Attributing MDEEs to ranked and violable constraints makes nonderived environment blocking is a "soft," defeasible condition, vs. the deterministic outcome of the Revised Alternation Condition. The factorial typology below describes the three logically possible outcomes for a phonological pattern deriving from markedness constraint(s) "M":

(19)

FAITH$_S$ » M » FAITH	Pattern imposed in derived environments
FAITH$_S$, FAITH » M	Pattern not imposed at all
M » FAITH$_S$, FAITH	Pattern imposed everywhere

These three possibilities are all attested, a point made in Kiparsky 1993. Some phonological patterns, like syllabification and stress assignment, apply in derived and nonderived environments alike. Some patterns are never imposed at all (in a given language). While it is *possible*, on this account, for an alternation to be restricted to derived environments, there is no guarantee that every alternation will be.

5. What motivates confidence strength?

It is convenient to assume that in a stems like *tilat* or *sokak*, the final consonants are weak and the nonfinal consonants are strong. Indeed, Kiparsky (1993) makes a similar assumption in devising intermediate representations for stems like the Finnish *tilat* in which the the final /t/ is unspecified for continuancy. The underspecified /t/ is filled in as [+continuant] before an /i/-initial suffix but as [-continuant] otherwise.

But what motivates the strong/weak differential? If it is a substance-free ad hoc diacritic used just for the purpose of deriving MDEEs, then it does not advance our understanding. In the next section, we discuss substantive factors that can contribute, additively, to positional asymmetries in representational strength, concluding that stem-final position represents a conspiracy of demonstrable weakness.

5.1 Phonetic cue strength

Speech segments occurring in acoustically optimal environments are likelier to be perceived correctly than those in environments with impoverished phonetic cues, all else being equal. Steriade (2001) proposes a ranking of faithfulness constraints in specific contexts, based on a scale of perceptibility for major place consonantal contrasts in those contexts:

(20) ID[place]/V_V » ID[place]/C_V » ID[place]/V_C » ID [place]/C_C

For many contrasts, including voicing as well as major place, an intervocalic environment is the phonetically richest context in which to identify the consonant; being sandwiched between other consonants is the most impoverished (Steriade 2001); similarly, word-initial position is generally better than word-final position. If there is any kind of connection between phonetic cue strength and representational strength, via more reliable perception and categorization, the scale in (20) is consistent with the proposal that stem-final consonants are weaker than other consonants.

5.2 Variability of phonetic context

Contextual variation, with its concomitant variability in phonetic cues, has been shown to affect performance. In a perception study comparing English and Dutch speakers, Johnson and Babel (2010) tested the perception of [s] vs. [ʃ], which alternate in English but not in Dutch. English speakers had more difficulty distinguishing [s] and [ʃ] in perception tests. Järvikivi and Bertram (2005) found that affixes with invariant surface forms are more easily parsed by subjects than affixes exhibiting allomorphic variation (see also Wedel 2002, 2009). Derwing, Yoon, and Cho (1993) found that Korean speakers blend two CVC words by combining CV from Word #1 with C of Word #2, while English speakers do the opposite. Beckman (2003) attributes this result to the fact that root-final consonants alternate, in Korean, creating more instability or, in terms of this paper, less confidence in their representations.

Simplifying a very large and complex literature, there appears to be experimental support for the Confidence Corollary: segment (types) occurring in a variety of phonological contexts are "weaker" than those occurring in invariant contexts.

Alternation itself can also contribute to relative representational weakness of a given underlying segment, in a self-perpetuating feedback loop. The medial *k* of *sokak* is always heard as *k*, and thus has greater representational strength than final *k,* which is deleted before vowels. This alternation of course is what the model is trying to predict, and so using alternation as a criterion for drawing the strong/weak distinction would be circular. However, once established, the strength differential produced by the alternation/nonalternation contrast can predict other effects.

5.3 Lexical strength

Lexical properties affect representational strength. McCarthy & Prince (1995) proposing that phonological faithfulness to root segments is universally ranked higher than faithfulness to affix segments. This proposal has been widely adopted (see e.g. Alderete 1999). The empirical motivation for the claim is the cross-linguistic observation that roots are more phonologically complex than affixes and draw on larger structural inventories (see Urbanczyk 2011 for an overview). Along related line, Smith 2002, 2011 observes that across languages, nouns tend to exhibit a greater variety of structures than verbs do. Pycha (2008) drills down even further to individual morphemes, proposing that individual roots and affixes in a language can have their own characteristic weights, such that a given affix might outweigh a given root.

Ussishkin and Wedel (2002) and Wedel (2002) suggests that the root-affix asymmetry, at least, may emerge from the relative importance of contrast. The larger quantity of roots, vs. affixes, in any given language makes it more important to maintain segmental contrasts in roots, inhibiting the normal evolutionary progress of lenition and other markedness-reducing processes. The same logic would apply to noun roots, which usually outnumber verb roots in the lexicon.

If it is true that contrast leads to finer-grained representations, a positive correlation between contrast and confidence strength is expected. Roots should be stored with more confidence, and thus be less prone to phonological alternation, than affixes; ditto for nouns vs. verbs. Wedel even hypothesizes that neighborhood density in the lexicon affects propensity of a morpheme to alternate: the denser the neighborhood, the greater the need to maintain contrast, and the less likely alternations are to apply. Wedel hypothesizes that the dense neighborhoods of CVC roots in Turkish accounts for their otherwise unexpected failure to participate in derived-environment velar deletion. An alternative hypothesis is that the segments of CVC roots, occurring in dense neighborhoods, are represented more strongly than those of longer roots.[2]

5.4 Frequency and strength

Relating exemplar models of memory to the current proposal, the representational confidence of a specific segment in a specific lexical item should be affected by the frequency with which that segment has been produced or perceived in a fixed phonological context in that lexical item. A segment which always occupies the same phonological environment should be stronger than one which occurs in a variety of phonological contexts, all else being equal.

In a root like *sokak*, the medial *k* always occurs flanked by /a/ vowels, whereas the final *k* can be word-final or, if the root is suffixed, can precede a wide variety of vowels and consonants (e.g. *sokak-tan* 'street-ABL', *sokak-lɯ* 'street-ASSOC', *sokak-mɯ* 'street-INTERR', *sokak-sɯz* 'street-WITHOUT', *sokağ-a* 'street-DAT', etc. This variety means that the frequency of each individual phonological context in which final *k* can appear is necessarily less frequent that the freqency of stable medial *oka*.

Segments occurring in a variety of contexts — e.g. stem-final segments, followed by a variety of suffixes — will occur in each type of phonological context with only a fraction of the overall frequency with which the morpheme containing the stem is used. By contrast, a segment internal to that morpheme will occur in the same phonological context every time; context frequency is identical to morpheme frequency.[3] Numerous studies have correlated frequency with representational robustness. Studies of child-directed speech, for example, have shown that children's production accuracy correlates with the frequency of particular phones in the input (e.g. Beckman, Yoneyama, and Edwards 2003, Edwards, Beckman, and Munson 2004, Munson, Edwards, and Beckman 2011). Frequency effects have been the focus of exemplar theories of memory (see e.g. Johnson 1997, Pierrehumbert 2002; Hay, Pierrehumbert, and Beckman 2003, among many others). Speech segments that are perceived frequently will have more representations in memory; segment

[2] On the size condition on Turkish velar deletion, see Inkelas and Orgun 1995; Pycha, Inkelas, and Sprouse 2007; Becker, Michael, Ketrez, and Nevins 2011.

[3] This is an oversimplification, omitting stem-internal effects like stress shift, syncope, affix-triggered harmony, etc. Of course, these same effects also multiply the variety of phonological contexts at the stem-affix boundary.

types with less phonetic variability will constitute a tighter cloud within phonetic space than segment types whose realization is highly variable (e.g. schwa vowels in English).

5.5 Summary

A table summarizing the various factors discussed so far that can additively contribute to the confidence strength of a given segment, measured paradigmatically or syntagmatically:

(21)

Weaker…	**…Stronger**
Variable context	Invariant context
weak phonetic perceptual cues	strong phonetic perceptual cues
is in affix	is in root
morph is infrequent	morph is frequent
Alternates	Invariant

The contention of this paper is that the last of these is, if not completely predictable, then heavily influenced by the previous factors.[4]

Determining a confidence quotient which appropriately weights the first four factors in (21) is an empirical challenge beyond the scope of this paper, as is the question of whether the confidence scale should be quantized into more than two values, or be continuously valued. Going forward, we will use confidence scales with the impressionistic conviction that they are functionally motivated by factors which can in principle be quantified, and we will stick to two values ("weak" and "strong") despite the other imaginable possibilities.

6. Broadening the phonological variety of MDEEs

The representational confidence approach extends to a broader variety of MDEE's than do competing approaches. We will see in this section that not all MDEEs are like the canonical example in Section 1, in which a

[4] An additional factor in representational strength which has not been discussed is neighborhood density, or the number of phonologically similar morphemes in the lexicon (e.g. Storkel 2002, 2004; Storkel and Hoover 2011, Storkel and Lee 2011). Sparse lexical neighborhoods have been argued to enable coarse-grained, or "weak', segmental representations, while dense ones force speakers into finer-grained or "stronger' representations.

stem-final consonant is subject to an alternation triggered by a following suffix-initial vowel. The examples surveyed in this section depart from the canon in several ways. In one (Samala), a stem-initial consonant triggers alternations in a prefix. In another (Finnish Vowel Coalescence), a stem-final vowel triggers an alternation in a suffix. In a third (Norwegian), a prefix-final and stem-initial consonant fuse, such that both are simultaneously trigger and target. We will see that confidence-based strength scales account for all of these cases. Whether competing approaches can account for them as well is the topic of Section 7.

Samala. The extinct isolate Samala (Ineseño Chumash; Applegate 1972) exhibits a phenomenon Poser (1982, 1993) names “Pre-Coronal Laminalization” (PCL). This process converts /s/ to /š/ preceding a coronal consonant (22b). /s/ and /š/ contrast in Samala, though the contrast is neutralized by the well-known sibilant harmony system. As seen in (22c), PCL does not apply to root-internal sequences.

(22)

a.	/s-kaw̓ɨy/	[skaw̓ɨy]	‘he cuts a notch in it’
b.	/s-niʔ/	[šnʔ]	‘his neck’
	/s-lok̓in/	[šlok̓in]	‘he cuts it’
	/s-is-tɨʔ/	[šištɨʔ]	‘he finds it’
	/ma-l-is-tɨk-Vn/	[malištɨk^{h}ɨn]	‘the first one’
c.		[wastu]	‘pleat’
		[astɨmɨn]	‘to buzz, hum’

The alternating consonants belong to a prefix and are morpheme-final; the nonalternating consonants belong to a root and are morpheme-medial. The Contextual Stability Generalization predicts the possibility of a case like this. Prefix-final consonants occur in a variety of contexts; their confidence rating should therefore be lower than that of a root-medial consonant, whose local context is less variable. Morpheme strength also points in this direction. Recall McCarthy & Prince’s (1995) claim that root faithfulness outranks affix faithfulness; translated into confidence terms, any root should be stored with greater confidence than any affix, all else being equal. On either criterion, Samala prefix-final consonants should be represented with less confidence than root-internal consonants.

In the tableau below, “PCL” represents the constraint banning s-coronal clusters; the s→š repair violates IDENT. The ranking IDENT$_S$ » PCL » IDENT ensures that only weak consonants are affected by PCL. Ignoring any strength differences among root segments, the “s” and “w” annotations indicate that root segments are stronger than affix segments:

(23)

/$w_s a_s s_s t_s u_s$ʔ$_s$ /	ID$_S$	PCL	ID
☞ wastuʔ		*	
waštuʔ	*!		*
/s_w-$t_w i_w$-$y_s e_s p_s$-$u_w s_w$/	ID$_S$	PCL	ID
stiyepus		*!	
☞ štiyepus			*

Finnish. An optional process of Vowel Coalescence in Finnish fuses adjacent heterosyllabic vowels into a tautosyllabic long vowel (Anttila 2009; Kiparsky 1993). The process applies only across the stem-suffix boundary; it does not affect stem-internal VV sequences:

(24)

a.	mini-ä	~ mini-i	‘mini-PAR’
	lasi-a	~ lasi-i	‘glass-PAR’
	hattu-a	~ hattu-u	‘hat-PAR’
b.	miniä	*minii	‘daughter-in-law’
	rasia	*rasii	‘box’
	saippua	*saippuu	‘soap’

In this case, stem vowels resist alternation, even in final position. Morpheme position is not a clear contributor to segmental strength differentials, since both stem-final and suffix-final vowels occupy the same morpheme position. However, the root-affix strength distinction invoked above for Samala is consistent with the observed asymmetry in Finnish Vowel Coalescence. If we assume underlying representations in which root segments are all stronger than affix segments, then a ranking of IDENT$_S$ » VC » IDENT accounts for the data, as shown in the following tableau. “VC” stands for the constraints mandating vowel coalescence:

(25)

/$m_s i_s n_s i_s$ä$_s$/	ID$_S$	VC	ID
☞ miniä		*	
minii	*!		*

/$m_s i_s n_s i_s$-ä$_w$/	ID$_S$	VC	ID
miniä		*!	
☞ minii			*

Anttila (2009) proposes essentially this same analysis of Finnish VC, though indexes faithfulness to roots instead of to strong segments.

Norwegian. Norwegian illustrates yet another kind of departure from the MDEE canon. The trigger is in a prefix and the target is in a stem. As discussed by Kristofferson (2000) and Bradley (2002), certain Norwegian dialects exhibit the patterns illustrated in (26). Prefix-final /r/ fuses with following coronal (/t,n,s/) whether heteromorphemic (26a) or tautomorphemic (26d)). Before /d/ and noncoronal consonants, /r/ shows derived environment effects. /r/ fuses with /d/ in derived environments (26b) but not root-internally (26e); before noncoronals, /r/ optionally deletes in derived environments (26c) but not root-internally (26f):

(26)

	Derived environments			Nonderived environments	
a.	*vår-tegn*	[ʋoːʈæjn]	d.	*svart*	[sʋɑʈ]
	‘spring sign’			‘black’	
	for noen	[fɔɳuː.un]		*barn*	[bɑːɳ]
	‘for some’			‘child’	
	vår-sol	[ʋoːʂuːɭ]		*vers*	[ʋæʂ]
	‘spring sun’			‘verse’	
b.	*vår-dag*	[voːɖɑːg]	e.	*sve*[ɾd]	
	‘spring day’			‘sword’	
c.	*er-klære*	[æ(ɾ)klærə]	f.	*merke*	[mæɾ.kə]
	‘to declare’			‘mark’	
	vær-melding	[ʋæː(ɾ)mɛlliŋ]		*larm*	[lɑɾm]
	‘weather forecast’			‘noise’	
	for-banne	[fɔ(ɾ)bɑnnə]		*skarp*	[skɑɾp]
	‘to curse’			‘sharp’	

Confidence scales can account for this pattern on the assumption that prefix-final consonants are “weak” while stem-initial consonants are “strong”. *RD, compelling /rd/ fusion, and *RK, compelling deletion, rank below FAITH$_S$ but above general FAITH, as shown in (27a,b).[5] *RT, the ban on /r/ before a coronal other than /d/, is ranked above even FAITH$_S$, so that RT clusters are simplified even in nonderived environments (27c).

(27) a. /rd/: Fusion in derived environments only

/sve[ɾ$_s$d$_s$]/	FAITH$_S$	*RD	FAITH
☞ sve[ɾd]		*	
sve[ɖ]	*!		
/vå[ɾ-d]ag/	FAITH$_S$	*RD	FAITH
☞ vå[ɾd]ag		*!	
vå[ɖ]ag			*

[5] The faithfulness constraints violated by Fusion — MAX, IDENT, UNIFORMITY (Kager 1999) — are abbreviated as FAITH. Since /r/-deletion applies optionally, *RD and FAITH are freely ranked.

b. /rk/: (optional) Deletion in derived environments only

/me[ɾ$_s$k$_s$]e/	FAITH$_S$	*RK	FAITH
☞ me[ɾk]e		*	
me[k]e	*!		
/fo[ɾ$_W$-k$_s$]lare/	FAITH$_S$	*RK	FAITH
☞ fo[ɾk]are		*	
☞ fo[k]are			*

c. /rt/: Fusion in all environments

/sva[ɾt]/	*RT	FAITH$_S$	FAITH
sva[ɾt]	*!		
☞ sve[ʈ]		*	*
/vå[ɾ-t]egn/	*RT	FAITH$_S$	FAITH
vå[ɾt]egn	*!		
☞ vå[ʈ]ag		*	*

Although this survey of MDEEs is by no means exhaustive, these examples show that confidence-based strength scales extend easily to MDEEs beyond the most basic cases.

7. Some past formal approaches to MDEEs

One reason for the broad coverage achieved by confidence-based strength scales is that the scales build on various past approaches to MDEEs, to be surveyed in this section. Each approach contributes an important insight. However, none has coverage as broad as the more versatile confidence-based strength scales.

7.1 Root faithfulness

Anttila (2009) proposes special root faithfulness to handle Finnish Vowel Coalescence (27). Root faithfulness protects tautomorphemic vowel sequences (e.g. /miniä/) from undergoing $V_iV_j \rightarrow V_iV_i$ coalescence, but leaves heteromorphemic ones unprotected: (e.g. /mini-ä/ → *minii*.

As Anttila points out, however, this account works only for a subset of MDEEs; it cannot extend even to canonical examples of stem-final consonant alternations triggered by a suffix. The root-affix asymmetry does play a role in establishing the confidence rating of individual segments, but the confidence-based strength approach is a more broadly applicable way of modeling the generalization.

7.2 Sequential faithfulness

Another important insight into MDEEs, which feeds directly into the confidence proposal, is found in the sequential faithfulness proposals of Itô and Mester (1996, 1998), Burzio (1997) and Cho (1998) (see also Bradley 2002). These researchers propose special faithfulness to input strings. Optimality Theory standardly assumes that stems and affixes are not linearized in the input (McCarthy and Prince 1994). This creates a difference between heteromorphemic and tautomorphemic strings. A tautomorphemic string has a corresponding input string to which it can be compelled to be faithful; a heteromorphemic string does not. Burzio (1997) exploits this difference by proposing special faithfulness to phonologically defined substrings, e.g. FAITH-ti for Finnish. Itô & Mester (1996, 1998) propose a NEIGHBORHOOD constraint which is violated if either member of an input bigram is altered. Self-conjoining NEIGHBORHOOD, around a shared "pivot" segment, enforces trigram faithfulness. The latter could successfully handle Turkish Velar Deletion:

(28)

	/sokak-a/	NEIGHBORHOOD[2]	*VGV	MAX-IO
a.	sokaka		**!	
☞ b.	soka.a		*	*
c.	so.a.a	*! (oka → oa)		**

Cho (1998) proposes a variant of sequential faithfulness, attributing MDEEs to fact that "the timing between two gestures created by morpheme concatenation is not lexically specified and is therefore potentially subject to any phonological change which can be produced by varying gestural overlap" (p. 5). Cho's case study is Korean palatalization, a classic stem-final MDEE seen earlier in (12). Bradley (2002) applies Cho's model to Norwegian fusion and /r/-deletion. Bradley attributes fusion to an OVERLAP constraint requiring consonantal gestures which are close in time to overlap completely, producing a single consonant. Overlap is inhibited by faithfulness to gestural timing (IDENT(timing)). If an input contains a consonant sequence whose timing specifies nonoverlap, IDENT(timing) prevents the OVERLAP constraint from being satisifed ((29b) vs. (29a)). When, however, the morphology would sequence two consonants in output which are not sequenced in input, OVERLAP prevails ((29c) vs. (29d)). The following tableau is adapted from Bradley (2002):

(29)

	/…Vɾ/ + /d…/	IDENT(timing)	OVERLAP
a.	Vɾᵊd		*!
☞ b.	Vɖ		
	/…Vɾᵊd/		
☞ c.	Vɾᵊd		*
d.	Vɖ	*!	

Gestural timing faithfulness is pertinent only when the same gestures occur in input and output; it is a constraint on their relative timing, not their presence or absence. Thus gestural timing faithfulness is more limited descriptively than the broader NEIGHBORHOOD constraint.

Like confidence-based strength scales, sequential faithfulness gets at the insight that segments in medial position are more protected than peripheral segments. However, it does so indirectly. Nothing in the statement of NEIGHBORHOOD, or IDENT(timing), predicts that stem edges are vulnerable. This leads to difficulties in covering some of the most canonical MDEEs. For example, neither NEIGHBORHOOD$_2$ nor a simple bigram NEIGHBORHOOD constraint can account for /tilat-i/ → [tilasi]:

(30)

	/tilat-i/	NHOOD^2	NHOOD	*TI	IDENT-IO
💣 a.	tilati			**	
b.	tilasi		*	*	*
💣 c.	silasi		**		**

NEIGHBORHOOD^2 protects trigrams. This is useful in accounting for alternations with two-sided environments like Turkish Velar Deletion, in which the protected target segment is always flanked by tautomorphemic vowels). But this same property renders NEIGHBORHOOD^2 inapplicable to Finnish Assibilation, in which the trigger and target are both monosegmental. NEIGHBORHOOD protects bigrams, like the initial *ti* of *tilat-*. NEIGHBORHOOD does not, by itself, distinguish between stem-initial and stem-final bigrams. That is what dooms candidate (30b).

A solution to this problem would be to index IDENT(timing) or NEIGHBORHOOD to specific segmental strings. This is essentially Burzio's (1997) proposal. Burzio's FAITH-ti constraint correctly penalizes candidate (30c), but not candidates (30a,b). Candidate (30a) violates *TI, leaving (30b) as the winner. While this account succeeds, it does so at a price.

FAITH-ti replicates the markedness constraint (*TI) exactly. The approach stipulates but does not capture the generalization that nonderived environments are protected.

7.3 Parasitic alternations: tying markedness to ANCHOR-R

Łubowicz's (2002) constraint conjunction approach targets canonical MDEEs by focusing on the syllabification of stem-final segments. Łubowicz's generalization is that stem-final consonants alternate precisely when they resyllabify as the onset of the syllable headed by a following suffix-initial vowel. Łubowicz uses constraint conjuntion to model this dependency. Applied to a case like Finnish Assibilation, an account like Łubowicz's would conjoin the Assibilation constraint (*TI) with R-ANCHOR(Stem, σ), which requires stem-final consonants to surface in syllable-final position.[6] If both parts of the conjoined constraint are violated, then the conjoined constraint itself is violated. The final *t-i* in the faithful candidate *tilat-i* (31a) fatally violates *TI & R-ANCHOR; the *t* fails to assibilate *and* occupies onset, rather than coda, position. Stem-internal *ti* sequences, however, including the one in winning candidate (31b), violate ASSIB but not R-ANCHOR, thus satisfying the conjoined constraint.

(31)

/tilat-i/	*TI & R-ANCHOR	IDENT	ASSIB
a. tilati	*! (t-i)		**
☞ b. tilasi		*	*
c. silasi		**!	

This approach is ideally suited to canonical MDEEs like those in Setion 1. It connects with the confidence-based analysis in that stem-medial consonants behave differently from stem-final ones. The former occur in invariant contexts; the latter potentially resyllabify upon suffixation. However, the conjoined constraint approach does not extend naturally to the broader range of MDEEs illustrated in Section 6. For example, the vowels undergoing Coalescence in Finnish do not alternate in their syllable position any more than the vowels that do not coalesce. However the R-ANCHOR constraint is stated, candidates (32b) and (32d) violate or obey it to the same degree, as their syllable structure is identical.

[6] Łubowicz's analysis is formulated with respect to the Polish data in (12), rather than Finnish, but the cases are structurally parallel.

(32)

/mini-ä/	$*V_1V_2$ & R-ANCHOR	IDENT	$*V_1V_2$
a. miniä	*!		*
☞ b. minii		*	
/miniä/	$*V_1V_2$& R-ANCHOR	IDENT	$*V_1V_2$
c. miniä	*!		*
💣 d. minii		*	

In sum, Łubowicz's insight about resyllabification potentiating other changes may not generalize well enough within the domain of known MDEEs to be broadly useful. However, it makes a valuable contribution in pointing to contextual variation as a contributing factor in MDEEs.

7.4 Underspecification

Confidence strength has points of contact with featural underspecification, a technique used by Kiparsky (1993) to differentiate stem-final and stem-medial segments in an analysis of NDEB phenomena. (Cho's 1998 gestural timing model also appeals to underspecification, though of timing rather than features.) Kiparsky couples contextually determined underspecification with context-sensitive default feature fill-in rules to model the fact that segments in invariant context behave differently from those occurring in variable contexts. For Finnish, Kiparsky proposes that stem-final /t/ is underlyingly underspecified for [cont]. One rule fills in [+cont] on this segment when /i/ follows; otherwise, default [-cont] is assigned. Stem-internally, the vocalic context of the underspecified segment is fixed, causing default fill-in rules to treat it uniformly. Stem-finally, the environment varies, producing alternation.

The underspecification approach, like the confidence scale approach, draws a representational distinction between alternating and nonalternating segments. The underspecification approach does not limit underspecification to peripheral positions; however, it limits the *effects* of underspecification to those positions, since those are the only positions in which contextual variation can trigger the application of different default rules to the same segment (each in its appropriate context).

One way in which the underspecification approach is descriptively more limited than the confidence scale approach is in accounting for deletion. Consider the case of Turkish intervocalic velar deletion or Norwegian /r/-deletion. Deletion is not accomplished by feature-filling default rules of the type that account for Finnish Assibilation. Therefore, Kiparsky's account for Finnish cannot transfer straightforwardly to the

Turkish or Norwegian cases. Fusion poses a similarly difficult challenge, since it is not an inherently additive, feature-filling process.

By contrast, the confidence scale approach provides a consistent account of all of these cases which directly ties representation to behavior. Strong segments are more likely to surface faithfully than weak segments, whatever the alternation.

7.5 Comparative Markedness

The most versatile of previous approaches to MDEE's, McCarthy's (2003) Comparative Markedness distinguishes "old", inherited input structures from "new" structures that exist only as a result of morphological concatenation or phonological alternation; see Hsiao (this volume) for discussion. The key insight is that MDEE's represent the emergence of unmarkedness. McCarthy's account relies on two new types of constraints. OO-$_{N}$P penalizes "new" marked structures of type P. OO-$_{N}$P is defined only in derived words. Assessing OO-$_{N}$P requires a cross-word comparison to the output of the unaffixed base of the derived word in question. (See Cho 2009 for a similar proposal.) A "new" structure P is one that is present in the output of the derived word but not present in the output of the unaffixed base of that word. IO-$_{O}$P is an "old" markedness constraint. Assessing IO-$_{O}$P requires reference to the fully faithful candidate (FFC) output of the input in question. An output candidate violates IO-$_{O}$P if it possesses a structure P that is also present in the fully faithful output. IO-$_{O}$P permits *new* markedness; it does not permit *inherited* markedness.[7]

Comparative Markedness captures MDEEs by ranking OO-$_{N}$P high and IO-$_{O}$P low. Marked structure P is tolerated if inherited but not tolerated when "new", i.e. arising through morphological combination. This is illustrated in (33) for Korean palatalization, discussed by McCarthy (2003). Consider the suffixed input /mat-i/. Top-ranked OO-$_{N}$PAL bans [ti] if it is "new", i.e. does not surface in the unaffixed base of the word. To assess OO-$_{N}$PAL, it is necessary to examine the output of the unaffixed base, /mat/. Since /mat/ contains no palatalization trigger, its output is [mat], as shown in (33b). Candidate (33ai) contains an unpalatalized [ti] which is *not* present in [mat]; that makes it new, and therefore OO-$_{N}$PAL is violated. As a result, the palatalized candidate, [maci] (33aii), is optimal.

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[7] See also Hall 2006 on marked structures in derived environments.

(33) a. Affixed stem	/mat-i/	OO-$_{N}$PAL	IDENT	IO-$_{O}$PAL
(FFC) i.	mati	*!		
☞ ii.	maci		*	
b. Unaffixed stem	/mat/	OO-$_{N}$PAL	IDENT	IO-$_{O}$PAL
☞ (FFC) i.	mat			
ii.	mac		*!	

Comparative Markedness captures the insight that segments in invariant contexts are more protected than those in variable positions. Segments in invariant contexts may violate “old” markedness, but only segments in variable contexts have the opportunity to violate “new” markedness. This basic insight is congruent with the component of confidence scales that assigns more representational strength to segments in invariant contexts. As a result of this congruency, the two approaches make similar predictions. One difference between them is the reliance of Comparative Markedness on the ability of the base of an affixed word to surface on its own as a word. Candidate (33ai), [mati], would not violate OO-$_{N}$PAL if there were no surface form [mat] (33bi) to compare it to. For Korean nouns, this is no problem; nouns are capable of surfacing unaffixed as words, and the scenario in (33) is broadly plausible. But verb roots in Korean are bound, unable to surface unaffixed as words. For verb root, OO-$_{N}$PAL is undefined. Nonethless, palatalization exhibits MDEEs across the boundary between (bound) verb root and suffix, just as with nouns. The following verbal examples are taken from Cho (2009:466):

(34)	kat^h-i	→	kac^{h}i	‘be_like-NML = together’
	kut-i	→	kuci	‘be_firm-NML = firmly’
	put^h-i	→	puc^{h}i	‘adhere-CAUS = to affix’
	mut-hi	→	muc^{h}i	‘bury-PASS = to be buried’

In sum, confidence scales and Comparative Markedness both achieve the result that the faithful preservation of tautomorphemic structures has priority over the preservation of heteromorphemic structures. Because the confidence scales approach does not require trans-word faithfulness, however, it has greater descriptive adequacy than the Comparative Markedness method of achieving the relevant faithfulness asymmetry.

8. Relation to other kinds of strength scales

If adopted, confidence scales will join other continuously valued representational scales that phonologists make reference to. For example, Flemming (2001) models categorical and gradient effects on vowel height through direct grammatical reference to scalar F2. Kirchner (1998) posits (quasi-)continuously valued scales of articulation difficulty and vowel height in accounting for scalar lenition and reduction/raising patterns.

In practice, reference to scales in phonological has generally involved discrete values. Flemming and Kirchner establish threshold values to chunk the continuous scales and allow phonological constraints to refer to those chunks as discrete values. Others simply define scales as discretely valued to start with. Building on Vennemann 1972, Selkirk (1982) and Gouskova (2004) assign integer values to capture the sonority of segments, using sonority difference as a evaluation metric syllable-internal well-formedness and syllable contact. DeLacy (2002) and Crowhurst and Michael (2005) derive syllable weight scales that determine the location of stress in quantity-sensitive stress systems. Gnanadesikan implements ternary scales in OT to handle scalar effects involving inherent voicing, consonant stricture, and vowel height. Some of the earliest examples of scales are the lenition scales used by Foley (1977), Lass (1971) to accomplish chain-shifting lenition effects.

Mortensen (2006) develops logical scales to account for chain-shifts and ordering effects involving tone and vowel quality in a number of languages. Some of the scales are phonetically motivated ("substantive"); others are phonetically arbitrary ("formal"). Pycha's (2008) Resizing theory rank-orders morphemes in terms of morphological strength; morpheme contact can result in phonological lenition or augmentation to enhance strength asymmetries across morpheme boundaries.

Confidence scales are clearly compatible with existing phonological theory. An open question is whether confidence scales may obviate some of the parochial prominence-based constraints invoked in the literature, including FAITH-root » FAITH-affix, FAITH-noun » FAITH-verb, etc. (McCarthy & Prince 1995, Beckman 1997, Smith 2002). For example, if roots are strong and affixes are weak, then FAITH-strong can replace FAITH-root. But it is unclear whether a single dimension of confidence strength can replace all of the different prominence-based constraint sets simultaneously, especially if some scales are mutually contradictory. Future research is needed to answer this question.

Another open question is the representational locus of strength. As a simplifying assumption, this paper models strength for segments as wholes. Ultimately, though, confidence must be separately assessed for smaller units (features, subsegments) as well as larger units (segment strings, syllables, feet).

9. Conclusions and implications

Confidence-based strength scales are grounded in phonetic and psycholinguistic strength asymmetries. The OT implementation proposed in this paper, in which special faithfulness constraints refer to specific levels of strength, connect formally with existing special faithfulness constraints that index other structural asymmetries, such as roots vs. affixes, stressed vs. unstressed syllables, and so on. Future research is needed to determine the relative importance of the various factors contributing to the strength of particular pieces of phonological structure.

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