PROSODIC INHERITANCE AND MORPHOLOGICAL GENERALISATIONS

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ABSTRACT

Prosodic Inheritance (PI) morphology provides uniform treatment of both concatenative and non-concatenative morphological and phonological generalisations using default inheritance. Models of an extensive range of German *Umlaut* and Arabic intercalation facts, implemented in DATR, show that the PI approach also covers 'hard cases' more homogeneously and more extensively than previous computational treatments.

1. INTRODUCTION

Computational models of sentence syntax are increasingly based on well-defined linguistic theories and implemented using general formalisms; by contrast, morphology and phonology in the lexicon tend to be handled with tailor-made hybrid formalisms selected for properties such as finite state compilability, object orientation, default inheritance, or procedural efficiency. The linguistically motivated Prosodic Inheritance (PI) model with defaults captures morphotactic and morphophonological generalisations in a unified declarative formalism, and has broad linguistic coverage of both concatenative morphology and the notorious 'hard cases' of non-concatenative morphology. This paper integrates the PI concepts underlying previous descriptions of German *Umlaut* (Reinhard 1990a, 1990b), Bantu tone morphology and Arabic C-V intercalation (Gibbon 1990); *Umlaut* and intercalation are treated here. PI descriptions are currently implemented in a DATR dialect (Gibbon 1989; for DATR cf. Evans & Gazdar 1989, 1990, 1989a, 1989b); DATR was chosen for its syntactic simplicity and its explicit formal semantics.

2. INHERITANCE AND NON-CONCATENATIVE MORPHOLOGY

Morphological generalisations are of three basic kinds: *morphotactic*, the combinatorial principles of word composition in terms of immediate dominance (ID) relations, *morphosemantic*, interpretation functions from morphotactic structures to semantic representations, and *morphophonological* (or '*morphographic*'), interpretation functions from morphotactic structures to surface phonological or orthographic representations. This paper is mainly concerned with modelling morphotactic and morphophonological generalisations.

Simple abstract morphotactic combinations (denoted by the operator '*') may be represented as follows:

Ger.: [*Rad* * singular], [*Rad* * plural]
Eng.: [*cat* * plural], [*dog* * plural], [*horse* * plural]

Morpheme ID combinations receive a compositional morphophonological interpretation based on the forms of the component morphemes and the kind of construction involved. Phonological interpretations are composed primarily by means of concatenation, with phonological feature variation at morpheme boundaries:

Ger.: Rad-Rades, /ra:t/-/ra:des/
(Voicing specification of stem final C)
Eng.: cats-dogs-horses, /kæts/-/dogz/-/ho:siz/
(Voicing specification of C and epenthetic V in suffix)

Non-concatenative morphophonological composition (which we will here refer to as *morphoprosody*) deals specifically with temporal feature overlap phenomena such as infixing, vowel gradation, consonant mutation, morphological tone and stress patterning, involving the structural 'association' of temporally coextensive categories such as features and autosegmental tiers:

Eng.: $\underline{\text{te}}$lephone, te$\underline{\text{le}}$phony, tele$\underline{\text{pho}}$nic
(stress, vowel quality)
Ger.: Fuchs, Füchse, fuchsig
(*Umlaut*)
Arab.: ktb, kutib, aktabib
(intercalation)
Kikuyu: ${}^{h}ma{}^{h}mo{}^{l}ror{}^{l}i{}^{h}re$, ${}^{h}ma{}^{h}mo{}^{l}tom{}^{h}i{}^{h}re$
(tone)

Morphoprosodic operations generally occur in combination with concatenation. Concatenation and association operators ('quasi-linear precedence, QLP, operators') are represented here by '^' and '°' respectively. QLP representations are intermediate specifications of morphotactic detail between abstract ID and concrete phonological representations.

Morphophonological generalisations thus require three levels of abstraction:

L_1, Morphotactic ID:	[*telephone* * ADJ-*ic*]
L_2, Morphotactic QLP:	[[*telephone* ° final-stress] ^ *ic*]
L_3, Phonological:	/t E l @ 'f O n I k/ (SAMPA computer phonetic notation)
Orthographic:	"*telephonic*"

Details of phonological feature structure will not be dealt with here.

The only explicit computational treatment of association operations is by Kay (1987; but cf. also the formal account by Bird & Klein, 1990), who models autosegmental phonological association with a multi-tape finite state transducer. Like autosegmental descriptions, Kay's finite state tranducers explicitly operate with directional (left-to-right or right-to-left) algorithms. Other approaches rely on lists of stem variants, string permutations, or string position indices (Cahill 1990).

By contrast, the PI approach to morphoprosody does not rely on algorithmic conditions such as left-right rule application, but on a general default principle:

> Assign a default value everywhere in a given context unless a) a designated value, and b) a designated position are otherwise specified in an explicit constraint.
>
> E.g. Ger.: Assign non-umlaut everywhere in a stem unless
> a) an umlauting stem, and
> b) an umlaut-triggering affix cooccur.
>
> Arab.: Assign the default vowel of a vocalism (default consonant of a radical) everywhere in a word unless
> a) a designated vowel (designated consonant), and
> b) a designated position in stem syllable structure are explicitly specified.

In the PI approach, lexemes are treated as individual (or 'most specific') nodes in an inheritance net. They are underspecified and inherit their full representations from semantic, syntactic, and phonological default inheritance hierarchies. Each node in these hierarchies represents a morphophonological generalisation and is associated with a set of special cases (relative exceptions) over which a default priority ordering in terms of relative specificity is defined. Fully specified phonological and orthographic lexeme representations are inherited from a hierarchy of general templates representing word, syllable and segment structures, and marked with QLP operators. The template slots are instantiated with properties inherited from specific lexemes. In the DATR implementation, inheritance of representations is implemented by local inheritance, and inheritance of specific exceptions and template instantiations is implemented by global inheritance.

3. MORPHOLOGICAL GENERALISATIONS: UMLAUT AND INTERCALATION

Two superficially related cases of non-concatenative morphology are *Umlaut* in German and vowel-consonant-intercalation in Arabic. They are similar in respect of the QLP operation of stem vowel variation in different morphological contexts, though the Arabic case is more complex, with additional variation of syllable structure and consonant position; in German, *Umlaut* primarily affects the vowel fronting feature.

3.1. GERMAN UMLAUT

Current computational descriptions of German vowel fronting (*Umlaut*) are linguistically inadequate, in that they do not take into account the complexity of mutual conditioning between stem classes and inflectional and derivational affixes: either they ignore the complexities of derivational morphology (Schiller & Steffens 1990), or overgeneralise, with lists of absolute exceptions (Trost 1990).

In the PI model of German *Umlaut*, a wide range of 'exceptions' turn out to be important subregularities. The inflectional properties of stems are taken as defaults for both inflection and derivation, and captured in an inheritance hierarchy. Lexemes inherit fully specified stem forms, inflectional and derivational affixes, and *Umlaut* specification, via this hierarchy. The hierarchy for nouns specifies that *Umlaut* with zero-suffix plurals depends on gender, is arbitrarily specified for each lexeme with e-suffix plurals (*Umlaut* being the default case), always occurs with er-suffix plurals, never with en-, s-, and exotic plurals. Derivational suffixes are also specified for their *Umlaut*-triggering properties, but different subregularities hold for different derivational suffixes in non-default cases.

stem	plur. infl.	-isch deriv.	-ig deriv.
Fuchs	Füchs-e	füchs-isch	fuchs-ig
Hund	Hund-e	hünd-isch	hund-ig

Consequently, *Umlaut* conditions must be inherited from several sources.

The three levels of morphophonological generalisation for an umlauted plural form like Füchse have the following representations:

L_1, Morphotactic ID:	[*Fuchs* * Plural]
L_2, Morphotactic QLP:	[[*Fuchs* ° Umlaut] ^ *e*]
L_3, Phonological:	/f Y k s @/
Orthographic:	"*füchse*"

The DATR implementation fragment shown below can be interpreted fairly straightforwardly as a representation of a semantic inheritance net, in which the 'most specific' node is *Fuchs*, which has some typed properties of its own and inherits others via *Noun_E*. Queries specify a starting node and an attribute path. The left hand side of an equation is required to match a prefix of the query path; if there is more than one match for a node, the longest matching path overrides any others. Inheritance from more general nodes on the right hand side of an equation is explicitly constrained by associating them with a path. This path replaces the matching prefix of the query path in any further inheritance. If node or path are not specified, the node or path from the current local (or global) query environment is transferred.

In this implementation, the lexeme Fuchs inherits a full morphologically conditioned phonological/orthographic representation. In the lexical representation of Fuchs, the vowel is not specified for orthographic or phonological *Umlaut*. The vowel representation is inherited from a template with a vowel slot which conditionally inherits a [+ umlaut] or [- umlaut] morphological subcategory by multiple inheritance from the stem and affix concerned. The condition is implemented in DATR as nested inheritance:

```
e.g. Vowel:<orth> == <Plur:<stem cond>>
        which conditionally specifies either
     Vowel:<orth> == <[+umlaut]>
        or
     Vowel:<orth> == <[-umlaut]>
        depending on the value of Plur:<stem cond>
        for the lexeme concerned.
```

A fragment of the PI implementation in DATR is stated below.

```
Fuchs:
  <>                    == Noun_E
  <orth onset cons>     == f
  <orth peak vowel>     == u
  <orth coda>           == (c h s)
  <morph gender>        == masc
  <sem cat>             == animate.
Noun_E:
  <>                         == Noun
  <orth flex plur suff op>   == e_suff.
Noun:
  <>            == ()
  <syn cat>     == noun
  <orth>        == (Onset Vowel Coda Suffix).
Vowel:
  <orth>        == <Plur:<stem cond>>
  <[+umlaut]>   == Umlaut:<<>>
  <>            == "<orth peak vowel>".
Plur:
  <stem cond>   == <stem "<orth flex plur suff op>">
  <stem 0_suff> == <stem "<morph gender>">
  <stem e_suff> == <stem "<morph gender>">
  <stem en_suff> == <stem marked>
  <stem masc>   == <stem "<morph umlaut exc>">
  <stem neut>   == <stem marked> % classes 1 & 2
  <stem neut marked> == <stem>  % Kloster
  <stem marked> == [-umlaut]
  <stem>        == [+umlaut]
  <suff>        == <suff "<orth flex plur suff op>">
  <suff 0_suff> == ()
  <suff e_suff> == e
  <suff er_suff> == (e r)
  <suff en_suff> == (e n).
```

Typical PI mappings in DATR notation are:

```
Fuchs:<orth infl plur> = (F ü c h s e).
Fuchs:<orth deriv ig-af> = (f u c h s i g).
```

A detailed account of the linguistic basis for the PI *Umlaut* model and the DATR implementation are given in Reinhard (1990a, 1990b).

3.2. INTERCALATION IN ARABIC VERB MORPHOLOGY

A number of linguistic descriptions and computational implementations have treated various aspects of Arabic verb conjugation (McCarthy 1982, Hudson 1984, Kay 1987, Calder 1989, Cahill 1990, Bird 1990, Gibbon 1990).

The full range of generalisations is dealt with in the PI model in an integrated morphological hierarchy, which is shown in the feature structure in Figure 1. The generalisations cover stem type (CV-skeleton) exceptions and subregularities, interactions between different morphological categories, and the relations between intercalation, prefixation and suffixation.

Arabic morphology has an agglutinative (concatenative) verb inflectional structure (cf. Table 1). It is combined with a radical (consisting only of consonants) and a vocalism (determined by three morphological categories: aspect, voice, and stem type) which are both intercalated in complex consonant-vowel skeletons, which are themselves derivational morphemes (cf. the DATR theorems in Table 2). These different stem types in Arabic verb morphology modify the meaning of the radical in partially predictable ways (e.g. as causative, reflexive). Morphophonological intercalation involves association of marked vowels and consonants to fixed skeleton positions, and "spreading" of the initial vowel and the final consonant, e.g. imperfective active in stem type xi: [*qtl* ° *<a,i>* ° VCCVVCVC] = "*aqtaalil*". Spreading is represented in feature structures by coindexing, and is implemented in DATR by treating the spreading vowel and consonant as defaults.

The categories involved in a word like yanqatilna with radical qtl, as in yanqatilna min halaali al-harbi 'they (fem) are being killed in the war', are:

3-pers, pl-num, fem-gen circumfix (PNG):	*y ... na*
Aspectual prefix:	default V
Stem type prefix:	*n*
Aspect/voice/stem type vocalism (Voc):	*<a,i>*
Reflexive stem type, vii (Skel):	C V C V C
Radical consonantism 'kill' (Cons):	*qtl*

Thus the morphological generalisations are the following:

L_1, Morphotactic ID:

[PNG * Aspect * Voice * Binyan * Radical],

i.e. [3-pl-fem * imperf * active * vii * *qtl*]

L_2, Morphotactic QLP:

[PNG_1 ^ [Voc ° [Aspect prefix ^ Stem type prefix ^ [Skel ° Cons]]] ^ PNG_2],

i.e. [*y* ^ [<*a*, *i*> ° [V ^ *n* ^ [CVCVC ° *qtl*]]] ^ *na*]

L_3, Orthographic (Roman):

"yanqatilna"

The fully specified representation for yanqatilna at level 2 is shown in a conventional feature notation in Figure 1. The attribute "surf" (= "surface") subsumes phonology and orthography. The QLP operators of concatenation and association are represented by Prefix and Suffix attributes and by re-entrancy indexing, respectively.

```
[Verb: [Infl: [Morph: [Pers: 3
                       Num:  plur
                       Gen:  fem]
               Surf:  [Pref: [Orth: [Roman: y]]
                       Suff: [Onset: [Orth: [Roman: n]]
                              V:     [Orth: [Roman: a]]]]]]
        Stem: [Asp: [Morph: imperf
                     Surf: [1]  [Pref: [V: [2]]
                                 Voc:  [V:  [2]  [Orth: [Roman: a]]
                                        V*: [2*] [Orth: [Roman: i]]]]]
               Voice: [Morph: active
                       Surf: [1]]
               Stem type: [Morph: reflexive
                           Surf: [Pref: [Orth: [Roman: n]]
                                  Type number: vii
                                  Skeleton: [C1: [3]
                                             V:  [2]
                                             C2: [4]
                                             V*: [2*]
                                             C:  [5]]]]
               Radical: [Sem: 'kill'
                         Cat: verb
                         Surf: [C1: [3] [Orth: [Roman: q]]
                                C2: [4] [Orth: [Roman: t]]
                                C:  [5] [Orth: [Roman: l]]]]]]]
```

Figure 1. PI generalisation hierarchy for Arabic verbs summarised as a re-entrant feature structure.

	1-pers	2-pers-masc	2-pers-fem	3-pers-masc	3-pers-fem
Singular	?-	t-	t- ... -i	y- t-	
Dual	—	t- ... -aa	t- ... -aa	y- ... -aa	t- ... -aa
Plural	n-	t- ... -uu	t- ... -na	y- ... -uu	y- ... -na

Table 1. Imperfective inflection by prefixation and suffixation in Arabic verbs

Qtl: <perf act surf orth roman> =		Qtl: <imperf act surf orth roman> =		Qtl: <part act surf orth roman> =	
i	qatal	i	aqtul-*aqatil	i	qaatil-*muqatil
ii	qattal	ii	uqattil	ii	muqattil
iii	qaatal	iii	uqaatil	iii	muqaatil
iv	?aqtal	iv	u?aqtil	iv	mu?aqtil
v	taqattal	v	ataqattal	v	mutaqattil
vi	taqaatal	vi	ataqaatal	vi	mutaqaatil
vii	nqatal	vii	anqatil	vii	munqatil
viii	qtatal	viii	aqtatil	viii	muqtatil
ix	qtalal	ix	aqtalil	ix	muqtalil
x	staqtal	x	astaqtil	x	mustaqtil
xi	qtaalal	xi	aqtaalil	xi	muqtaalil
xii	qtawtal	xii	aqtawtil	xii	muqtawtil
xiii	qtawwal	xiii	aqtawwil	xiii	muqtawwil
xiv	qtanlal	xiv	aqtanlil	xiv	muqtanlil
xv	qtanlay.	xv	aqtanliy.	xv	muqtanliy.

Qtl: <perf pass surf orth roman> =		Qtl: <imperf pass surf orth roman> =		Qtl: <part pass surf orth roman> =	
i	qutil	i	uqtal-*uqatal	i	maqtuul-*muqatal
ii	quttil	ii	uqattal	ii	muqattal
iii	quutil	iii	uqaatal	iii	muqaatal
iv	?uqtil	iv	u?aqtal	iv	mu?aqtal
v	tuquttil	v	utaqattal	v	mutaqattal
vi	tuquutil	vi	utaqaatal	vi	mutaqaatal
vii	nqutil	vii	unqatal	vii	munqatal
viii	qtutil	viii	uqtatal	viii	muqtatal
ix	*qtulil	ix	*uqtalal	ix	*muqtalal
x	staqtil	x	ustaqtal	x	mustaqtal
xi	*qtuulil	xi	*uqtaalal	xi	*muqtaalal
xii	*qtuwtil	xii	*uqtawtal	xii	*muqtawtal
xiii	*qtuwwil	xiii	*uqtawwal	xiii	*muqtawwal
xiv	*qtunlil	xiv	*uqtanlal	xiv	*muqtanlal
xv	*qtunliy.	xv	*uqtanlay.	xv	*muqtanlay.

Dhrj: <perf act surf orth roman> =		Dhrj: <imperf act surf orth roman> =		Dhrj: <part act surf orth roman> =	
qi	dahraj	qi	udahrij	qi	mudahrij
qii	tadahraj	qii	atadahraj	qii	mutadahrij
qiii	dhanraj	qiii	adhanrij	qiii	mudhanrij
qiv	dharjaj.	qiv	adharjij.	qiv	mudharjij.

Dhrj: <perf pass surf orth roman> =		Dhrj: <imperf pass surf orth roman> =		Dhrj: <part pass surf orth roman> =	
qi	duhrij	qi	udahraj	qi	mudahraj
qi	tuduhrij	qii	utadahraj	qii	mutadahraj
qiii	dhunrij	qiii	udhanraj	qiii	mudhanraj
qiv	dhurjij.	qiv	udharjaj.	qiv	mudharjaj.

Table 2. PI-mapping in DATR for all Arabic triliteral and quadriliteral verb stem types for radicals qtl ('to kill') and dhrj ('to roll'). (Asterisks denote overgenerated unacceptable forms; unacceptability is due to morphophonological irregularity in stem type i and to semantic subregularities in the other stem types. Idiosyncratic unacceptability is not marked.)

The compact lexeme representation in DATR notation is simply the following:

```
Qtl:  <>       == Morphology
      <gloss>  == kill
      <c 1>    == q
      <c 2>    == t
      <c>      == l.
```

The default root consonant (in this example 'l') spreads over all C positions in skeleton constituents which are unspecified for C_1 or C_2 radical consonants (e.g. in CVCVC, stem type vii, only the last consonant). The main generalisations about the skeleton template hierarchy are shown in the following excerpt from the DATR implementation (note the resemblance to context-free phrase structure rules; the concatenation operation is implicit in DATR list ordering):

```
Stem templates:

Stem:
  <> == (Aspect_prefix        Stem_type).

Stem_type:
  <> == (Stem_type_prefix     Stem_type_body).

Stem_type_body:
  <> == (First_syllable       Second_syllable).

Stem constituents with morphotactic conditions for inflectional class:

Aspect_prefix:
  <>         == ()
  <imperf>   == Mu_affix          % mu imperfective
                                  % affix
  <part>     == Vocalic_affix.    % voc. participle
                                  % prefix
Stem_type_prefix:
  <>      == ()
  <iv>    == Glottal_affix     % glottal prefix stem t. iv
  <v>     == T_affix           % t prefix stem type v
  <vii>   == N_affix           % n prefix stem type vii
  <x>     == St_af.            % st prefix stem type x
```

Syllable templates with morphotactic conditions for derivational class and instantiation from global root node:

```
First_syllable:
 <>       == ("<c 1>"  Vocalism:<>   Geminate)
 <ix>     == ("<c 1>"  "<c 2>"       Vocalism:<>).

Second_syllable:
 <>       == ("<c g>"  Vocalism:<*>  "<c>")
 <ix>     == ("<c>"    Vocalism:<*>  "<c>")
 <xiii>   == (W_affix  Vocalism:<*>  "<c>")
 <xiv>    == ("<c 3>"  Vocalism:<*>  "<c>")
 <xv>     == ("<c>"    Vocalism:<*>  Y_affix).
% '*' denotes a non-default designated terminal.
```

All other information about morphological composition and phonological QLP and feature structure is predictable, and derived from constituent node constraints. Coverage of the verb system is fairly complete, with all 15 triliteral and 4 quadriliteral stem types, including subregularities, stem type and aspect prefixes, and other inflectional prefixes and suffixes for person, number and gender.

4. CONCLUSION

The PI approach to morphologically conditioned phonological and orthographic variation relates linguistically to word grammar (Hudson 1984), word syntax (Selkirk 1982) and to prosodic phonologies, and derives its computational features from DATR (Evans & Gazdar 1989); formally it relates closely to object-oriented morphology (Daelemans 1987), paradigmatic morphology (Calder 1989), and Bird's constraint-based phonology (1990).

PI models use a unified formalism throughout, and thus differ radically from computational morphological systems with hybrid formalisms. These include two-level morphology with continuation lexica and two-level rules (Koskenniemi 1983), its derivates with feature-based lexicon and two-level rules (Karttunen 1987, Bear 1986, Trost 1990), and Cahill's DATR-driven morphology with phonological descriptions in MOLUSC (1990).

Finally, PI models have broad linguistic coverage, capture significant generalisations over a wide range of typologically interesting morphological systems without *ad hoc* diacritics, and have a straightforward and well-defined implementation in DATR.

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