APPLYING OPTIMALITY THEORY TO GERMAN PHONOLOGY: [x]/[ç] DISTRIBUTION AND FINAL DEVOICING

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This paper explores two specific phonological alternations of German, final devoicing and ach-Laut/ich-Laut ([x]/[ç] distribution) within Optimality Theory (Prince & Smolensky 1993). The issues for the two alternations are reviewed, based on work by Hall (1989a, 1989b), and the components of Optimality Theory (OT) are discussed, including how candidates are represented and generated, especially with respect to the problem at hand. Next, OT constraints are formulated, and candidate output sets generated from sets of words that exemplify the alternations are tested with the constraints. It is shown that by analyzing all candidates in parallel, the constraints formulated and the relative rankings for them succeed in choosing the correct optimal output predicted by more traditional phonological theories, without the requirement of multiple levels, serial analysis and level-specific rules as in those theories. Moreover, compared to the older serial rules, the constraints found are more general and closely related to the phonological principles involved, and thus the explanation within OT for these two alternations is a more satisfactory one.*

1. INTRODUCTION. Optimality Theory (OT, Prince & Smolensky 1993) is a theory of constraint satisfaction in generative grammar. In this approach, a huge number of possible outputs are generated from a single input, and a set of well-formedness constraints choose from among them. The claim is that the constraints can be ranked in such a way, specific to the language at hand, as to ensure that the optimal output will be chosen, without recourse to the rules and exceptions and multiple cycles put forth by many of the more traditional analyses. Or, as summarized by McCarthy & Prince (1993:4),

> 'Within OT, the role of grammar is to select the output form from among a very wide range of candidates, including at least all of the outputs that would be possible in any language whatsoever. Thus, language-specific rules or procedures for creating representations have no role at all in the theory, and the entire burden of accounting for the specific patterns of individual languages falls on the well-formedness constraints. These constraints are ranked in a language-particular hierarchy; any constraint is violated, minimally, if such violation leads to the satisfaction of a higher-ranking constraint.'

The claim has been made that any result of the various syntactic, morphological, and phonological processes of a given language ought to be expressible within OT. In this paper I will explore two phonological alternations of German, to try to fit them into the OT framework. The alternations are those of final obstruent devoicing and the distribution of the palatal and velar voiceless fricatives. Modern Standard German is the version of German assumed for this discussion, as described in Hall 1989a, 1989b.

2. BACKGROUND

2.1. FINAL DEVOICING OF OBSTRUENTS. In German, syllable-final obstruents are devoiced. Hall 1989a, among others, claims that the devoicing rule is post-cyclical, and at the word level (if not post-lexical). On the other hand, Hall holds that syllabification occurs cyclically, starting in the first cycle of level 1, and that in addition, there is a language-specific rule of resyllabification applying at all three lexical levels, which is sensitive to grammatical information. I will assume his model of syllabification as outlined in Hall 1989a in that the optimal forms chosen will match the results predicted by his model.[1] The correct operation of the devoicing rule depends crucially on correct syllabification. Syllable-final obstruent devoicing may or may not be fully neutralizing (see Port & O'Dell 1985, and Fourakis & Iverson 1984 for opposing views; see also Dinnsen 1985); also, it may or may not span units bigger than the word (see, e.g., Charles-Luce 1985, and Port & Crawford 1989). However, it IS true that it operates word-internally, even though in much of the literature it is referred to as 'word-final' devoicing. Final devoicing is also an interesting place in which to examine the phonology-morphology interface, due to the interactions of the syllabification and morphological structure of a word.

Table 1 gives a representative sample of the different types of forms we'd like any theory to be able to handle.Included are minimal pairs where the target phoneme is in syllable-initial and syllable-final position, and sets

* This paper began as a squib for the *Phonology-Morphology Interface* course at the 1993 Linguistic Institute. I would like to express my appreciation to: Sharon Inkelas for many useful comments in getting me started in this project, and for introducing me to the work of Tracy Hall in German syllabification (Hall 1989a, 1989b); Paul Smolensky for helping me understand to a much deeper level the intricacies and subtleties of Optimality Theory, especially as it pertains to the matters at hand; and Tilo Weber, Ken Zook, and Bill Raymond for their comments and corrections. All remaining errors are my own.

1 Hall's algorithm even correctly predicts the pronunciation of a word such as *Magdalena* — the /g/ does indeed devoice in that position.

WORD	WITH MORPHEME BOUNDARIES	SURFACE FORM OF THE OBSTRUENT(S) OF INTEREST	GLOSS
Bund		t	union, federation
Bunt		t	colored, colorful
dick		d	thick
Tick		t	crotchet, kink
dir		d	to you
Tier		t	animal
Hand		t	hand
Hän . de	Hand+PL	d	hands
hand . lich	hand+lich	t	handy, manageable
Han . dlung,	Handl+ung,	d	action, deed
Or . dnung	Ordn+ung[3]		order, arrangement
Mäd . chen	Mäd+chen	t	girl
Kö . nig		k (or ç; see Hall 1989b)	king
Kö . ni . ge	König+PL	g	kings
las	les+PAST.SG	s	read (past)
le . sen	les+INF (or 3PL, etc.)	z	to read (etc.)

TABLE 1. Words exemplifying the behavior of final devoicing rule.

of related words showing the effect of morphology on syllabification, and thus voicing of the phoneme.[2] In the first column, syllable boundaries are indicated with a period. Put another way, /t/ and /d/ (as representatives of all voiceless/voiced obstruent pairs) contrast syllable-initially but not syllable-finally. Thus a way of specifying voiced and voiceless phonemes differently (in a non-parallel fashion) will be needed. This will be taken up in §3.1.

2.2. FRICATIVE SELECTION. In German, the velar and palatal voiceless fricatives, [x] and [ç], are in almost complete complementary distribution. They may be fully distinguished from the remainder of the German consonant inventory by the description [-voice, +high] fricative, if one takes /j/ in German to be a fricative rather than an approximant. If /j/ is an approximant, [+high] fricative will suffice. If a single phoneme, unspecified for backness, is posited, the surface form can be found by the following rule: The segment takes the value of backness from an immediately preceding vowel, unless the segment is word-initial or follows another consonant, in which case it is [-back]. Thus, if it is directly after a back vowel, it surfaces as the [+back] velar fricative [x], otherwise it surfaces as the [-back] palatal fricative [ç]. Following Hall 1989b, I therefore take [-back] to be the default; contrary to him I will represent this segment as /Ç/ rather than /X/.

If no reference to morpheme boundary is made, problems arise due to the minimal pairs found in 1, which exemplify that in just the case of a stem followed by the diminutive morpheme *-chen*, the surface form is always [ç], no matter what the preceding vowel.

(1)	*Kuchen*	[ku:.xən]	'cake'	vs.	*Kuh+chen*	[ku:.çən]	'little cow'
	tauch+en	[tau.xən]	'to dive'	vs.	*Tau+chen*	[tau.çən]	'little rope'
	pfauch+en	[p^{f}au.xən]	'to hiss'	vs.	*Pfau+chen*	[p^{f}au.çən]	'little peacock'

However, as pointed out in Hall 1989b, if the stipulation that the vowel and /Ç/ must be tautomorphemic for /Ç/ to get its value for [back] from the vowel, then the right choices are made in 1, and also are still made in all cases not affected by the tautomorphemic requirement. Notice too that this phonemic alternation does NOT refer to the syllabification in the way devoicing does, because the syllabification is the same in both sets of these minimal pairs. (The only exceptions to this revised rule are in a few loan words, esp. of Slavic origin, with syllable-/word-initial [x]: e.g. *Cheb* [xep], the name of a city). A summary statement of this alternation is given in 2; 3 lists further examples of the alternation in action.

(2) a. /Ç/ → [+back] / { V[+back]___ }MORPH
b. /Ç/ → [-back] / elsewhere

[2] Most of my examples will use the alveolar stop pair {d,t}, but the explanations and constraints put forth here are intended to work equally well with the other obstruents. The one exception is in handling the velar obstruent as outlined in Hall 1989b. I have not tried to implement the intricacies of G-spirantization and G-devoicing.

[3] Note that the root does include the /l/ or /n/; see Hall 1989a.

(3)

RESULTING IN /x/		RESULTING IN /ç/	
rauchen	'to smoke'	*Chemie* (followed by [-back] V)	'chemistry'
Sprache	'language'	*Charisma* (followed by [+back] V)	'charisma'
auch	'also'	*Foto#chemie* (compound)	'Photochemistry'
		solch, manch (follow a [–back] V but a sonorant intervenes)	'such', 'many a'
		ich ([–back]V precedes)	'I'
		Küche ([–back]V precedes)	'kitchen'

Of course, OT should be able to handle all of these, and anything like them. In short, it must be able to handle all of the cases of [x]/[ç] alternation brought up in Hall 1989b, Macfarland & Pierrehumbert 1991, or Iverson & Salmons 1992.

3. OPTIMALITY THEORY. The basic tenets of OT as given in Prince & Smolensky 1993, and in McCarthy & Prince 1993, are the following. There is a function *Gen* which produces many output candidates from the input, from which the optimal candidate (the candidate chosen by a native speaker as the correct form) is selected by using a set of minimally violable constraints which are ranked in a language specific way. All morphology is done before the forms are submitted to the constraints, rather than cyclically producing forms and having the constraints pick one form to be input to the next level of *Gen*. The task at hand then is (a) to briefly describe *Gen*, (b) to determine what constraints are needed, and in what form and ranking to accomplish the goal of picking the optimal output, and (c) to give examples in which the rankings and constraints are shown to choose the correct output.

3.1. INPUTS TO *GEN*. As noted above, the segments in the inputs (from the lexicon) must be specified in such a way that the results of parsing them by *Gen* will give output candidates that include the desired optimal candidate, but which do not produce so many that the constraints cannot choose between two valid candidates which are valid minimal pairs different only on the feature we care about (e.g. words like *dir* and *Tier*). The segments that always surface as [t], and those which surface as [d] syllable-initially, but [t] syllable-finally, will be specified differently in the lexicon. Voicelessness will be taken as the unmarked case, such that if a segment is parsed with the root not being connected to any feature of voicing, it will be voiceless by default. Thus the segments that always surface as [t] will be stored in the lexicon with a feature set which is unspecified for voicing, as shown in Figure 1A. Voicing, as the marked case, must then be specified for the segments which surface syllable-initially as voiced, as shown in Figure 1B. The segment /Ç/ will be unmarked for [back], with [–back] as the default case. Figure 1C shows how (the relevant parts of) its feature set might be stored in the lexicon.

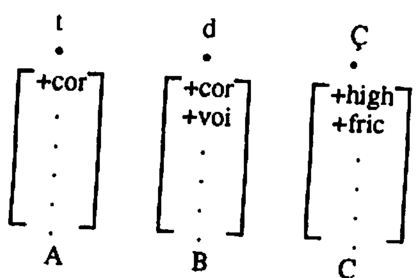

FIGURE 1.

Parsing (which is done by *Gen*) will generate many outputs, with various combinations of connections of the root to the features. This will be further explained in §3.2. The same type of segment feature representation will be true of all other voiced/voiceless pairs; and indeed, to make the system much more general, it will be assumed for all consonants: Traditionally voiceless phonemes will be unmarked for voicing, and traditionally voiced phonemes will be marked for [+voi] in the feature set.

3.2. *GEN*. *Gen* is a function that takes an input and produces a set of candidate outputs, all but one of which are incorrect (unless free variation is allowed). The input to *Gen* presumably comes from the lexicon, and consists of the root and all the affixes. *Gen* only runs once, rather than after each level or the adding of each morpheme.

Gen is wildly over-generating, outputting all the possible syllabifications, including phonotactically illegal ones. *Gen* also, for EACH segment, produces all of the possible combinations of connections of root to feature, so we can see that there is a combinatorial explosion of possible candidates. Furthermore, associations can even be made to features of adjacent segments, although there will be a penalty for this in the constraints. An example of this can be seen in Figure 2: For only the features shown in Figure 1A and 1B, each of these segments would contribute all of the following possibilities, which must then combine with all of the other segmental, syllabificational, etc. possibilities. Phonetic realization is shown below each feature matrix.

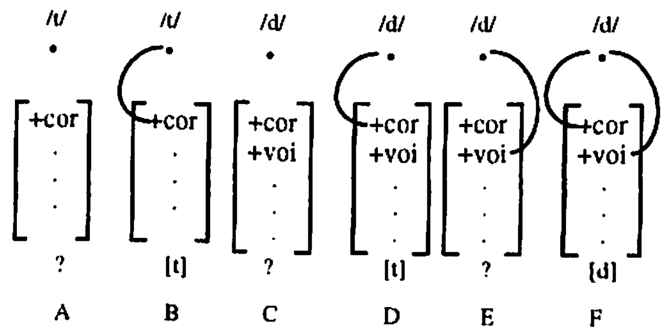

FIGURE 2.

Figure 3 shows how associations between /Ç/ and adjacent segments might be made, giving /Ç/ a value for [back] from those segments. (3A shows no spread of association, 3B shows association to the right from the preceding segment, 3C shows association to the left from the following segment, and 3D shows association from both left and right, on the feature of interest, backness. Phonetic realizations are shown in the accompanying notes.) Thus, the featural representation of [ç] is [+high, –back, +fric], and for [x] it is [+high, +back, +fric].

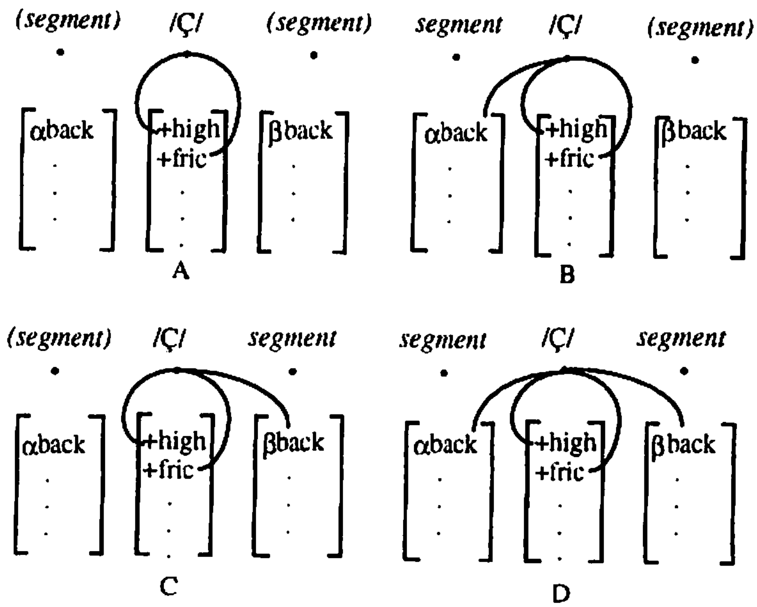

FIGURE 3. Observe the following notation:

SHOWN IN	DESCRIPTION	VALUE FOR [back]	PHONETIC REALIZATION
Fig. 3A	/Ç/ segment does not associate to the [back] value of either neighbor	default value [–back]	ç
Fig. 3B	/Ç/ gets its value for [back] from the preceding segment	whatever value is for previous segment	→x or →ç
Fig. 3C	/Ç/ gets its value for [back] from the next segment	whatever value is for next segment	x← or ç←
Fig. 3D	/Ç/ gets values from both preceding and following segments	(a) the two values for [back] are the same	(a) x↔ or ç↔
		(b) the values are different	(b) (*Gen* will not produce this value)

Thus, candidates will include those with voiced obstruents in syllable codas, voiceless sonorants, and illegal onset and coda clusters such as *nt-*, *ndl-*, and *-dç*. A set of constraints ranked highly is assumed, which will quickly eliminate incorrect syllabifications and segments which are never found in German (see also fns. 4 and 5, and §3.3). This will mean that the devoicing and other constraints will only consider output candidates that are correctly syllabified. A few operations of *Gen* are shown in 4, with respect to items interesting for final devoicing. It should be noted that not every output as exemplified in Fig. 2 is shown here. In representations of candidates from here on, *t* represents a t-node with the root attached to [+cor] OR a d-node with the root attached to [+cor] but not to [+voi], and *d* represents a d-node with the root attached to both [+cor] and [+voi]. The remaining segment possibilities in Fig. 2 (A, C, E) will not be represented in the partial lists of outputs here or throughout the paper, because, as described in §3.3, they will wind up with even more violations (due to not parsing [+cor]) than the corresponding B, D, and F, and will never be chosen as the optimal output, so they can safely be ignored.

(4)	WORD	*GEN* INPUT	PARTIAL CANDIDATE SET
	Hand	/hand/	{hant, hand}
	Hünde	/hand+PL+umlaut/	{hɛn.də, hɛnd.ə, hɛn.tə, hɛnt.ə, hɛ.ndə, hɛ.ntə}[4]
	handlich	/hand+liÇ/	{hand.liç, hant.liç, han.dliç, han.tliç}[5]
	Handlung	/handl+uŋ/[6]	{han.dluŋ, hand.luŋ, han.tluŋ, hant.luŋ}
	durch	/durÇ/	{durç, turç}
vs.	*hart*	/hart/	{hart}
	entspannen	/ent+ʃpanen/	{ɛnt.ʃpanən, ɛntʃ.panən} but not *endspanen

The range of outputs with respect to the phoneme /Ç/ are:

(5)	WORD	*GEN* INPUT	PARTIAL CANDIDATE SET
	durch	/durÇ/	{durç, turç,dur→ç, tur→ç}
	handlich	/hand+liÇ/	{hand.liç, hant.liç, han.dliç, han.tliç, hand.li→ç, hant.li→ç, han.dli→ç, han.tli→ç}
	rauchen	/rauÇən/	{rau.çən, rau.→xən, rau.x←ən, rau.x↔ən, rauç.ən, raux←.ən, rau→x.ən, raux↔.ən}
	Kuhchen	/ku.+Çən/	{ku.]çən, ku.]x←ən, ku.]→xən, ku.]x↔ən, ku]ç.ən, ku]←x.ən, ku]→x.ən, ku]↔x.ən}
	kuchen	/ku.Çən/	{ku.çən, ku.x←ən, ku.→xən, ku.x↔ən, kuç.ən, kux←.ən, ku→x.ən, kux↔.ən}
	Chemie	/Çɛmi/	{çɛmi, ç←ɛmi}
	Charisma	/Çarısma/	{çarısma, x←arısma}

Further assumptions about *Gen*: In the output *Gen* includes whatever stem, prosodic word, etc. boundary information as is necessary. Original stem boundaries, as well as other morpheme boundaries, will be marked with square brackets. Syllable boundaries are marked with a period, as has already been seen in previous examples.

Umlauting is caused by some morphemes on the stem vowel. This is interesting here because umlauting affects the backness of the vowel, and thus is reflected in the fricative choice. For the purposes of this discussion, the input is assumed to already have umlauting performed on it if the particular stem+morpheme demands it.

True exceptions, such as exceptional pronunciations, will be handled in the lexicon by direct specification; in the case where normally an underspecified phoneme such as /Ç/ is listed, and where the constraints would incorrectly choose as the optimal candidate one with [ç], /x/ will instead be listed (that is, the feature [+back] will be specified for the segment). An extension of this could be that any phoneme that NEVER varies in its surface form could be fully specified in the lexicon, whereas anywhere it could vary — e.g. when its syllable membership could change, for underlyingly voiced obstruents, or when the preceding vowel could be fronted, for the underspecified voiceless fricatives — it would be underspecified in the lexicon. This option would get away from the more elegant specifications used above that are based on current phonological theory, which recognize allophonic relationships for instance between the [x] and [ç] fricative. Thus, for now I will not pursue this possibility.

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[4] {*hɛ.ndə, *hɛ.ntə} are examples of forms to be rendered suboptimal by the very high-level phonotactic constraints — N-<obstruent> is not a valid onset in German.

[5] {han.dliç} is a possible optimal output, because German does allow word-internal onset clusters *dl*- and *dn*-, as can be seen in the real words *Handlung* [han.dluŋ] and *Ordnung* [or.dnuŋ]. {?han.tliç} is questionable (note: '?' stands for a judgment, and should not be confused with '?' glottal stop): Whereas I have seen several analyses prove the existence of *dl*- and *dn*- word-internally, they never mention *tl*- or *tn*-, but on the other hand, it might be possible for the voiceless obstruent if it is possible for the voiced, especially as both other stop locations allow both voiced and voiceless obstruents to precede the /l/ (pl, bl, kl, gl) and both velars and voiceless bilabial can precede /n/ (kn, gn, pn). However, under the assumption that *tl*- and *tn*- are NOT allowed in German, the fact that *Gen* would generate these outputs means that these outputs will have to be eliminated by the phonotactics constraints.

[6] See Hall 1989a for an explanation of the handling of velar nasals.

In summary, *Gen* generates a multitude of forms which must then be passed through the constraints to find the optimal form.

3.3. *EVAL* AND *CON*. *Eval* is a function defined by the system of Constraints *Con* which are ranked in a language specific way. Ideally, all constraints are universal. In reality, sometimes one must temporarily posit constraints that reflect something idiosyncratic to the language at hand; the goal is to eventually reformulate them in such a way as to make them general enough to reflect general phonological principles. Of the constraints posited in this analysis, only one, SAME-BACK, is idiosyncratic to German.

Constraints are ranked, and some are scalar while others are binary. Constraints are also violable. They are evaluated, each in turn, on all (remaining) candidates. The results are shown in a 'constraint tableau': Blank cells indicate constraint satisfaction, an asterisk indicates violation of a binary constraint (multiple asterisks for multiple violations). The place of crucial failure of suboptimal candidates is indicated with '!', and the cells to the right of that point are shaded, for they do not take part in the decision from then on. The winning candidate is signaled with '☞'.

The first constraint needed is ONSET, a universal constraint found in many other OT analyses, including McCarthy and Prince's (1993) analysis of German ʔ-epenthesis.

(6) ONSET
Every syllable has an onset.

Furthermore, as mentioned above, I assume very highly ranked constraints to take care of phonotactic prohibitions against certain cluster combinations at the syllable level. These constraints could be called ONSET-CLUSTER and CODA-CLUSTER, which get rid of truly disallowed clusters. These constraints could actually be a group of constraints; their exact specification will not be set out here because it is not important to the discussion. ONSET-CLUSTER will eliminate *tl-* and *tn-*, but not *dl-* and *dn-* (see fn. 5); it also gets rid of clusters such as 7a while CODA-CLUSTER gets rid of clusters such as 7b. The candidate sets operated on in the examples are those remaining after the operation of these constraints.

(7) a. $\left\{\begin{matrix} n \\ l \end{matrix}\right\}$ [+obstruent] (C)–

b. –(C) [+obstruent] $\left\{\begin{matrix} n \\ l \end{matrix}\right\}$

Furthermore, there are several universal constraints which are highly ranked for German, which get rid of candidates with segments or sequences that are completely impossible in German. They will be discussed briefly here; in remaining analyses the candidates eliminated by these constraints will not be listed.

One of these constraints takes care of the sonorants (e.g. /n/, /l/, /r/) which in half the parses do not have voicing associated with the root node. Voiceless sonorants do not exist (at the phonemic level) in German and many other languages; thus this constraint, *VLS-SON (given in 8), is ranked very high for German. It would be ranked lower in languages that allow voiceless sonorants. Table 2 shows how this constraint will eliminate candidates, leaving only the type of candidates that will be considered in the rest of the paper.

Candidates		*VLS-SON	*OTHER, LOWER RANKED CONSTRAINTS*
a.	hand		
b.	han̥d	*!	
c.	hant		
d.	han̥t	*!	

TABLE 2. Candidates for *Hand*

(8) *VLS-SON
$*\begin{bmatrix} -voi \\ +son \end{bmatrix}$

Another overparsing which results in spurious output occurs when the feature of place is not parsed for a given segment. Take the example of the /t/ parsed with place coronal not attached to its root (represented in Fig. 2A). This results in an extra violation of the constraint PARSE^{FEAT} (given in 9). Since all violations of constraints ranked higher than PARSE^{FEAT} are equal for all candidates remaining at a given point, between two candidates where the only difference is whether place was parsed, the candidate without place being parsed will have more violations of PARSE^{FEAT}, and thus not be as harmonic as its partner which did parse place for that segment. Thus the candidates with unparsed place will never win, and so we can safely ignore them here. Similar arguments can be made for other types of wild overgeneration that result in segments or combinations that do not occur in German.

(9) PARSE^{FEAT}

Features must be parsed.

3.3.1. SYLLABLE-FINAL DEVOICING. What we'd like is some kind of condition on codas that DISPREFERS a voiced obstruent in the coda, while still allowing sonorants. This constraint might look like:

(10) CODA-COND

$$\left.\begin{matrix} *[+\text{voice}] \\ | \\ [\text{obstruent}] \end{matrix}\right)_{\sigma}$$

('A coda consonant or consonant cluster may not contain voiced obstruents.')

However, because candidates with voiceless sonorants are eliminated from consideration by the highly ranked *VLS-SON, we can actually make this constraint much more general:

(10′) CODA-COND

$$\left.\begin{matrix} *[+\text{voice}] \\ | \\ [\text{consonant}] \end{matrix}\right)_{\sigma}$$

('Codas may not contain voiced consonants.')

While candidates with voiced sonorants will incur a violation of this constraint, ALL such candidates will, resulting in an equal number of violations stemming from this constraint for each sonorant, thus the presence of a coda sonorant is not fatal to a candidate.

CODA-COND must be ranked fairly high, but it is not clear whether it comes before ONSET or after it.[7] (Now let's look at a couple of examples, first by continuing Table 2 from above. (As ONSET does not differentiate between any of these candidates, it is not included in this example.) The result is in Table 3. Notice that if the constraints were ranked in the opposite way, CODA-COND >> *VLS-SON, the fourth candidate would win, as in Table 4.

	Candidates	*VLS-SON	CODA-COND
a.	hand		**!
b.	han̥d	*!	*
c.	☞ hant		*
d.	han̥t	*!	

TABLE 3. Candidates for *Hand*

	Candidates	CODA-COND	*VLS-SON
a.	hand	**!	
b.	han̥d	*!	*
c.	hant	*!	
d.	**☞ han̥t		*

TABLE 4. Candidates for *Hand*, with incorrect ranking of constraints

To be able to distinguish the correctly generated [d] from the incorrectly generated [t] in *Hände*, another constraint is needed to act as a tie-breaker in the case there are two forms identical except for voicing of obstruents in the onset. Note that this constraint is also needed for underived forms such as *durch*. It turns out PARSE^{FEAT}, already given, will do the trick, as it will cause a violation every time an input *d* is parsed with the root not being attached to [+voi] (thus resulting in a [t] in the output). Of course, when the input started with *t*, there was never a [+voi] to attach to, so there was only one parse created (along this variable), instead of two. Note also that this constraint is ranked below CODA-COND, and therefore does not affect the results of above; see Table 5.

Table 6 demonstrates, however, that this set of constraints is not sufficient. The constraints correctly choose the phonetic output [han.dluŋ] (line a) as the optimal output for *Handlung* /Handl+uŋ/, but for the input *handlich*

[7] ONSET is, however, apparently unviolated in German, as can be seen by ʔ-epenthesis (McCarthy & Prince 1993:47-8). Thus it also is ranked very high. Thanks to Paul Smolensky for reminding me about this consequence of their analysis.

/hand+liÇ/ they incorrectly eliminate [hant.liç] (line h) from consideration, letting the incorrect [han.dliç] (line e) win. Thus we need another constraint, ranked higher than PARSE^{FEAT}, which will eliminate line e before PARSE^{FEAT} would eliminate line h, and yet allow line a to win over the suboptimal parses in lines b, c, and d. (In the examples below, I will assume that the constraints picking the correct fricative among /x/ and /ç/ have already operated (or will operate) correctly; thus only candidates with the correct fricative are listed.)[8]

	Candidates	CODA-COND	ONSET	PARSE^{FEAT}
a.	☞ hɛn.d]ə			
b.	hɛnd.]ə	*!	*	*
c.	hɛn.t]ə			*!
d.	hɛnt.]ə		*!	*
e.	☞ durç			
f.	turç			*!

TABLE 5. Candidates for *Hände* and *durch*[9]

This new constraint is a (non-gradient) alignment constraint (Prince & Smolensky 1993, McCarthy & Prince 1993):

(11) ALIGN(Stem,R,σ,R)
The right edge of all stems are aligned to the right edge of a syllable.

Table 7 shows the revised tableau for these candidates. With this new constraint, and the ranking shown, the correct candidates are chosen.

	Candidates	CODA-COND	PARSE^{FEAT}
a.	☞ han.dl]uŋ		
b.	hand.l]uŋ	*!	
c.	han.tl]uŋ		*!
d.	hant.l]uŋ		*!
e.	*☞ han.d]liç		
f.	hand.]liç	*!	
g.	han.t]liç		*!
h.	hant.]liç		*!

TABLE 6. Candidates for *Handlung* and *handlich* with only CODA-COND and PARSE^{FEAT}

	Candidates	CODA-COND	ALIGN	PARSE^{FEAT}
a.	☞ han.dl]uŋ		*	
b.	hand.l]uŋ	*!	*	
c.	han.tl]uŋ		*	*!
d.	hant.l]uŋ		*	*!
e.	han.d]liç		*!	
f.	hand.]liç	*!		
g.	han.t]liç		*!	*
h.	☞ hant.]liç			*

TABLE 7. Candidates for *Handlung* and *handlich*

3.3.2. FRICATIVE CHOICE. Fricative selection deals with the domain of morphemes, rather than that of syllables, and it also does not deal with edges of constituents. Compare, for example, the following pairs of candidates, where the second column represents the preferred candidate, and the third column gives the candidate we have to find a way to delete.

(12)	a.	*Kuh+chen*	[ku].[çən]	*[ku].[xən]	
	b.	*Kuchen*	[ku:.xən]	*[ku.çən]	V[+back] and /Ç/ are tautomorphemic
	c.	*Tau+chen*	[tau].[çən]	*[tau].[xən]	
	d.	*tauch+en*	[tau.x]ən	*[tau.ç]ən	V[+back] and /Ç/ are tautomorphemic
	e.	*mach+en*	[ma.x]ən	*[ma.ç]ən	V[+back] and /Ç/ are tautomorphemic
	f.	*Koch*	[kox]	*[koç]	
	g.	*Köch+in*	[kö.ç]in	*[kö.x]in	*Köchin=Koch*+FEM; *-in* is umlauting, fronting the V
	h.	*ich*	[iç]		
	i.	*Milch*	[milç]		

We might assume a set of phonological rules stating something like 13 (repeated from 4 above) or 14:

8 Lines c and g in Tables 6 and 7 should actually already be removed by the phonotactic constraint ONSET-CLUSTER but are left here to show that they are also removed by PARSE^{FEAT}.

9 In this section I am only interested in showing the issues around voicing, therefore only the optimal value of /Ç/ is shown in the output candidate set. Section 3.3.2 will deal with choice between /ç/ and /x/.
Also, from this point on, marks for CODA-COND violations due to sonorants will not be shown.

(13) a. /Ç/ → [+back] / { V[+back]___ }MORPH
b. /Ç/ → [–back] / elsewhere

(14) a. /Ç/ → [αback] / { V[αback]___ }MORPH
b. /Ç/ → [–back] / elsewhere

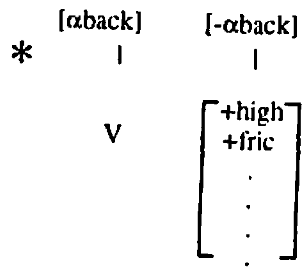
Then we would need a way to eliminate candidates with [ç] in the environment in 13a (or to eliminate all mismatched candidates in the environment in 14a), but to choose candidates with [ç] when that environment is not present (from candidates where both [x] and [ç] remain). The candidates in 12 meeting the environment in 13a are *Kuchen*, *tauch+en*, *mach+en*, and *Koch* (using 14 adds in *Köch+in* and *Milch*). The cases that are most problematic are the multi-syllabic stems like *Kuchen* where the /Ç/ is not at the edge of the stem.

A pair of constraints are proposed that will select outputs based on the domain of the morpheme. I'm using 'morpheme' as the domain here because that is how Hall 1989b discusses the issue, but it is possible that this could be subsumed under the concept of prosodic word as in the McCarthy & Prince example (1993:47-8), and by certain proposals in the literature that suggest that *-chen* (and possibly other derivational morphemes) forms its own prosodic word; I will not pursue that here. The constraints are:

(15) *CROSS

Association lines do not cross morpheme boundaries.

(16) SAME-BACK



or, more informally,

(16′) '[+high] fricatives have the same value of backness as the previous adjacent vowel.'

SAME-BACK will be ranked lower than *CROSS. Moreover, as noted above, there is a penalty to be paid for associating to other segments. *CROSS is one such penalty, and the universal constraint against spreading (*SPREAD) is another. This latter constraint is actually a family of constraints, *SPREAD-RIGHT and *SPREAD-LEFT (17 and 18), reflecting that some languages are perseverative, and others are anticipatory; recall that constraints are violable and also ranked in a language specific order, such that languages that make heavy use of spreading in one direction or the other can still be realized with these constraints when they are properly ranked. In the case of German, obviously spreading to the right is required to get the backness feature for /Ç/ in some environments, so *SPREAD-RIGHT can be ranked very low or even last. Thus its main effect is to fail candidates with spreading that are otherwise equal in all other ways to candidates identical EXCEPT for spreading. As we shall see, however, *SPREAD-LEFT is needed, and must be ranked higher than, at a minimum, SAME-BACK.

(17) *SPREAD-RIGHT

Associations cannot go to the previous segment.

(18) *SPREAD-LEFT

Associations cannot go to the next segment.

Let's see how these fare in examples.[10] To prove that *SPREAD must actually be realized as *SPREAD-RIGHT and *SPREAD-LEFT, at first I will only use *SPREAD, which invokes a penalty for spreading regardless of the direction. This constraint is sufficient for most words, but is not enough in the case of the *-chen* suffix (assuming the pronunciation of *-chen* is [çən], with a back vowel). First, simple, monomorphemic words. *Ich*, and any similar word with a [–back] vowel followed by a word-final /Ç/ merely shows that *SPREAD is required; it takes a word with a [+back] vowel directly preceding the /Ç/ (such as *auch*) to show both the need for SAME-BACK, and its ranking

[10] CODA-COND, ONSET, and ALIGN, and PARSE[FEAT] are not used to differentiate the two fricatives, so they are not shown here. CODA-COND and ONSET have already operated in getting rid of incorrect syllabified candidates.

with respect to *SPREAD (SAME-BACK >> *SPREAD). See Table 8. Note that if we rank these two in the opposite way (*SPREAD >> SAME-BACK) it will not make a difference for *ich, solch, Milch,* or *durch,* but it will choose the wrong optimal output for *auch*; see Table 9.

	Candidates	SAME-BACK	*SPREAD
a.	☞ iç		
b.	i→ç		*!
c.	☞ solç	does not apply	
d.	sol→ç	does not apply	*!
e.	☞ milç	does not apply	
f.	mil→ç	does not apply	*!
g.	?☞ durç[11]	does not apply	
h.	dur→ç	does not apply	*!
i.	?☞ turç	does not apply	
j.	tur→ç	does not apply	*!
k.	auç	*!	
l.	☞ au→x		*

TABLE 8. Candidates *ich, solch, Milch, durch,* and *auch.*

	Candidates	*SPREAD	SAME-BACK
a.	☞ iç		
b.	i→ç	*!	
c.	☞ solç		does not apply
d.	sol→ç	*!	does not apply
e.	☞ milç		does not apply
f.	mil→ç	*!	does not apply
g.	?☞ durç		does not apply
h.	dur→ç	*!	does not apply
i.	?☞ turç		does not apply
j.	tur→ç	*!	does not apply
k.	**☞ auç		*
l.	au→x	*!	

TABLE 9. Candidates *ich, solch, Milch, durch,* and *auch*; incorrect ordering of constraints.

As it stands, *SPREAD will also ensure that no matter what the following vowel, a word initial /Ç/ takes the value [–back], as in Table 10.

	Candidates	SAME-BACK	*SPREAD
a.	☞ çεmi	does not apply	
b.	ç←εmi	does not apply	*!
c.	☞ çarısma	does not apply	
d.	x←arısma	does not apply	*!

TABLE 10. Candidates *Chemie* and *Charisma.*

However, these constraints alone are not enough to handle the multi-morphemic examples, at least where the /Ç/ is at the beginning of a morpheme; they are also not enough to get *tauchen* (Table 11, lines d-g) down to a single candidate, although the two remaining candidates are equivalent.

Thus, we now need *CROSS. Furthermore, it must be ranked higher than SAME-BACK, or else it will not eliminate lines c, i, and j in Table 11, to allow lines a (or b) and h to win; see Table 12.

	Candidates	SAME-BACK	*SPREAD
a.	foto].[çεmi	*!	
b.	foto].[ç←εmi	*!	*
c.	**☞ foto].[→xεmi		*
d.	tau.ç]ən	*!	
e.	?☞ tau.x←]ən		*
f.	?☞ tau.→x]ən		*
g.	tau.x↔]ən		**!
h.	tau.]çən	*!	
i.	**☞ tau.]x←ən		*
j.	**☞ tau.]→xən		*
k.	tau.]x↔ən		**!

TABLE 11. Candidates *Fotochemie, tauchen,* and *Tau+chen.*

	Candidates	*CROSS	SAME-BACK	*SPREAD
a.	☞ foto].[çεmi		*	
b.	foto].[ç←εmi		*	*!
c.	foto].[→xεmi	*!		*
d.	tau.ç]ən		*!	
e.	tau.x←]ən	*!		*
f.	☞ tau.→x]ən			*
g.	tau.x↔]ən	*!		**
h.	tau.]çən		*!	
i.	**☞ tau.]x←ən			*
j.	tau.]→xən	*!		*
k.	tau.]x↔ən	*!		**

TABLE 12. Candidates *Fotochemie, tauchen,* and *Tau+chen.*

Table 12 still shows a problem, in lines h-k, with *Tau+chen*. This is exactly the case where the morpheme boundary affected the rules proposed by Hall 1989b. Notice that, in Table 8, all the cases of spreading are spreading to the right, so *SPREAD-RIGHT would have sufficed, and indeed, the ranking SAME-BACK >> *SPREAD-RIGHT must therefore hold. In Table 10, the spreading is to the left, but the ranking there is inconsequential; *SPREAD-LEFT COULD be ranked higher than SAME-BACK, but does not need to be. In Table 12, lines a-c, the winner, line a, does not violate *SPREAD (so it violates neither *SPREAD-RIGHT nor *SPREAD-LEFT). In lines d-g, the winner, line f, violates only *SPREAD-RIGHT, whereas the only loser we want for sure to eliminate, line d,

[11] The remaining choice between [durç] and [turç] will be made by PARSEFEAT, as shown in Table 5.

violates neither *SPREAD, but does violate SAME-BACK; but as already noted, with the ranking given, the correct choice is made among those two. However, in lines h-k, the correct choice, line h, fails SAME-BACK, whereas the incorrect winner, line i, has association to the left, and so would fail *SPREAD-LEFT. Thus it can be concluded that *SPREAD-RIGHT is not the same as *SPREAD-LEFT, and that *SPREAD-LEFT must be ranked higher than SAME-BACK. However, with these examples, nothing can be said about the relative ranking of *CROSS and *SPREAD-LEFT. As can be seen in Table 13, with the overall ranking of *CROSS, *SPREAD-LEFT >> SAME-BACK >> *SPREAD-RIGHT, the correct optimal output can now be found for *tau+chen*, without affecting the correct outputs for the other words.

	Candidates	*CROSS	*SPREAD-LEFT	SAME-BACK	*SPREAD-RIGHT
a.	☞ foto].[çεmi			*	
b.	foto].[ç←εmi		*!	*	
c.	foto].[→xεmi	*!			*
d.	tau.ç]ən			*!	
e.	tau.x←]ən	*!	*		
f.	☞ tau.→x]ən				*
g.	tau.x↔]ən	*!	*		*
h.	☞ tau.]çən			*	
i.	tau.]x←ən		*!		
j.	tau.]→xən	*!			*
k.	tau.]x↔ən	*!	*		*

TABLE 13. Candidates *Fotochemie*, *tauchen*, and *Tau+chen*.

4. CONCLUSION. The work that remains for the future is to determine an overall ranking of the constraints posited so far for German, and expand the constraints to handle some of the side problems in Hall 1989a and 1989b that are not handled here.

To summarize, the following constraints with the following rankings have been proposed:

(19) a. ONSET-CLUSTER, CODA-CLUSTER, VLS-SON >> all the rest of the constraints,
b. CODA-COND, ONSET >> ALIGN >> PARSE^{FEAT} ,
c. *CROSS , *SPREAD-LEFT >> SAME-BACK >> *SPREAD-RIGHT.

(Constraints separated by commas are not ranked with respect to each other by the examples we have looked at here.) Up until now, I have not specified the rankings of the constraints for each sub-problem (devoicing and fricative choice) relative to each other. It could be that neither subset of constraints interacts with each other, in which case, ranking all of 19b higher than all of 19c will give the same results as ranking all of 19c ahead of 19b. This turns out to be the case, as is shown in tables 14 through 17 in the Appendix. Thus no inter-subset rankings of the constraints can be specified based on the data sets examined here.

A few problems still remain — one is in determining exactly what edges need to be marked in the candidates to be able to simulate multi-level systems wherein different phonology takes place at each level. Moreover, maintaining edges goes against the concept of Bracket erasure which many current theories espouse. Another problem lies in finding situations from which it might be possible to ascertain the relative ranking of the above constraints. Nevertheless, for final devoicing and the fricative alternation, it does appear possible to provide OT solutions that work to pick out the right candidates. Other problems, at least of similar types to those discussed above, seem likely to be tractable in this framework as well.

REFERENCES

CHARLES-LUCE, JAN. 1985. Word-final devoicing in German: Effects of phonetic and sentential contexts. Journal of Phonetics 13.309-24.

DINNSEN, DANIEL A. 1985. A re-examination of phonological neutralization. Journal of Linguistics 21.265-79.

FOURAKIS, MARIOS, and GREGORY K. IVERSON. 1984. On the 'Incomplete Neutralization' of German final obstruents. Phonetica 41.140-9.

HALL, TRACY ALAN. 1989a. German syllabification, the velar nasal, and the representation of schwa. Linguistics 27.807-42.

———. 1989b. Lexical phonology and the distribution of German [ç] and [x]. Phonology 6.1-17.

IVERSON, GREGORY K., and JOE SALMONS. 1992. The place of Structure Preservation in German diminutive formation. Phonology 9.137-43.

MACFARLAND, TALKE, and JANET PIERREHUMBERT. 1991. On ich-Laut, ach-Laut and Structure Preservation. Phonology 8.171-80.

McCARTHY, JOHN J., and ALAN PRINCE. 1993. Generalized Alignment. Paper presented at the Phonology Workshop, Linguistic Institute, Columbus, OH.

PRINCE, ALAN, and PAUL SMOLENSKY. 1993. Optimality Theory: Constraint interaction in generative grammar. Technical Report CU-CS-696-93, Department of Comuter Science, University of Colorado at Boulder, and Technical Report TR-2, Rutgers Center for Cognitive Science, Rutgers University, New Brunswick, NJ. March. To appear in the Linguistic Inquiry Monograph Series; Cambridge, MA: MIT Press.

PORT, ROBERT, and PENNY CRAWFORD. 1989. Incomplete neutralization and pragmatics in German. Journal of Phonetics 17.257-82.

PORT, ROBERT, and MICHAEL L. O'DELL. 1985. Neutralization of syllable-final voicing in German. Journal of Phonetics 13.455-71.

APPENDIX

Candidates that violate the constraints in 19a are omitted, as they have no chance of being the most optimal candidate. The first part of each table (part A) shows that ranking the constraints of 19b ahead of the constraints of 19c produces the correct optimal output, thus that is a possible valid ranking. In the second part of each table (part B), the relative rankings of the constraints of 19b and 19c are reversed. The resulting optimal outputs are the same. (Tables 14 through 17 will be presented in parallel over the next few pages to facilitate comparing the outputs for the two different rankings. Constraints *SPREAD-RIGHT and *SPREAD-LEFT have been abbreviated to *SPR-R and *SPR-L.)

Candidates	CODA-COND	ONSET	ALIGN	PARSEFEAT	*CROSS	*SPR-L	SAME-BACK	*SPR-R
hand	*!							
☞ hant				*				
☞ hɛn.d]ə								
hɛnd.]ə	*!	*						
hɛn.t]ə				*!				
hɛnt.]ə		*!		*				
☞ durç							dna	
dur→ç							dna	*!
turç				*!			dna	
tur→ç				*!			dna	*
☞ han.dl]uŋ			*					
hand.l]uŋ	*!		*					
han.tl]uŋ			*	*!				
hant.l]uŋ			*	*!				

TABLE 14A. First constraint ordering: *Hand, Hände, durch, Handlung*

Candidates	*CROSS	*SPR-L	SAME-BACK	*SPR-R	CODA-COND	ONSET	ALIGN	PARSEFEAT
hand					*!			
☞ hant								*
☞ hɛn.d]ə								
hɛnd.]ə					*!	*		
hɛn.t]ə								*!
hɛnt.]ə						*!		*
☞ durç			dna					
dur→ç			dna	*!				
turç			dna					*!
tur→ç			dna	*				*!
☞ han.dl]uŋ							*	
hand.l]uŋ					*!		*	
han.tl]uŋ							*	*!
hant.l]uŋ							*	*!

TABLE 14B. Second constraint ordering: *Hand, Hände, durch, Handlung*

Candidates	CODA-COND	ONSET	ALIGN	PARSE$^{\text{FEAT}}$	*CROSS	*SPR-L	SAME-BACK	*SPR-R
han.d]liç			*!					
hand.]liç	*!							
han.t]liç			*!	*				
☞ hant.]liç				*				
han.d]li→ç			*!					*
hand.]li→ç	*!							*
han.t]li→ç			*!	*				*
hant.]li→ç				*				*!
tau.ç]ən			*				*!	
☞ tau.→x]ən			*					*
tau.x←]ən			*		*!	*		
tau.x↔]ən			*		*!	*		*
tauç.]ən		*!					*	
tau→x.]ən		*!						*
taux←·]ən		*!			*	*		
taux↔·]ən		*!			*	*		*
☞ tau.]çən							*	
tau.]→xən					*!			*
tau.]x←ən						*!		
tau.]x↔ən					*!	*		*
tau]ç.ən		*!	*				*	
tau]→x.ən		*!	*		*			*
tau]x←.ən		*!	*			*		
tau]x↔.ən		*!	*		*	*		*

TABLE 15A. First constraint ordering: *handlich, tauchen, Tau+chen*

Candidates	*CROSS	*SPR-L	SAME-BACK	*SPR-R	CODA-COND	ONSET	ALIGN	PARSE$^{\text{FEAT}}$
han.d]liç							*!	
hand.]liç					*!			
han.t]liç							*!	*
☞ hant.]liç								*
han.d]li→ç				*!			*!	
hand.]li→ç				*!	*			
han.t]li→ç				*!			*!	*
hant.]li→ç				*!				*
tau.ç]ən			*!				*	
☞ tau.→x]ən				*			*	
tau.x←]ən	*!	*					*	
tau.x↔]ən	*!	*		*			*	
tauç.]ən			*!			*!		
tau→x.]ən				*		*!		
taux←·]ən	*!	*				*		
taux↔·]ən	*!	*		*		*		
☞ tau.]çən			*					
tau.]→xən	*!			*				
tau.]x←ən		*!						
tau.]x↔ən	*!	*		*				
tau]ç.ən			*			*!	*	
tau]→x.ən	*!			*		*!	*	
tau]x←.ən		*!				*!	*	
tau]x↔.ən	*!	*		*		*!	*	

TABLE 15B. Second constraint ordering: *handlich, tauchen, Tau+chen*

Candidates	CODA-COND	ONSET	ALIGN	PARSE^FEAT	*CROSS	*SPR-L	SAME-BACK	*SPR-R
☞ iç		*						
i→ç		*						*!
☞ milç							dna	
mil→ç							dna	*!
auç		*					*!	
☞ au→x		*						*
☞ çεmi							dna	
ç←εmi						*!	dna	
☞ çarısma							dna	
x←arısma						*!	dna	
☞ foto].[çεmi							*	
foto].[ç←εmi						*!	*	
foto].[→xεmi					*!			*
foto][ç.εmi		*!	*				*	
foto][ç←.εmi		*!	*			*	*	
foto][→x.εmi		*!	*		*			*

TABLE 16A. First constraint ordering: *ich, Milch, auch, Chemie, Charisma, Fotochemie*

Candidates	*CROSS	*SPR-L	SAME-BACK	*SPR-R	CODA-COND	ONSET	ALIGN	PARSE^FEAT
☞ iç						*		
i→ç				*!		*		
☞ milç			dna					
mil→ç			dna	*!				
auç			*!			*		
☞ au→x				*		*		
☞ çεmi			dna					
ç←εmi		*!	dna					
☞ çarısma			dna					
x←arısma		*!	dna					
☞ foto].[çεmi			*					
foto].[ç←εmi		*!	*					
foto].[→xεmi	*!			*				
foto][ç.εmi			*			*!	*	
foto][ç←.εmi		*!	*			*	*	
foto][→x.εmi	*!			*		*	*	

TABLE 16B. Second constraint ordering: *ich, Milch, auch, Chemie, Charisma, Fotochemie*

Candidates	CODA-COND	ONSET	ALIGN	PARSE^{FEAT}	*CROSS	*SPR-L	SAME-BACK	*SPR-R
koç							*!	
☞ ko→x								
☞ kö.ç]in			*					
kö.→ç]in			*					*!
kö.ç←]in			*		*!	*		
kö.ç↔]in			*		*!	*		*
köç.]in		*!						
kö→ç.]in		*!						*
köç←.]in		*!			*	*		
köç↔.]in		*!			*	*		*

TABLE 17A. First constraint ordering: *Koch, Köchin*

Candidates	*CROSS	*SPR-L	SAME-BACK	*SPR-R	CODA-COND	ONSET	ALIGN	PARSE^{FEAT}
koç			*!					
☞ ko→x								
☞ kö.ç]in							*	
kö.→ç]in				*!			*	
kö.ç←]in	*!	*					*	
kö.ç↔]in	*!	*		*			*	
köç.]in						*!		
kö→ç.]in				*!		*		
köç←.]in	*!	*				*		
köç↔.]in	*!	*		*		*		

TABLE 17B. Second constraint ordering: *Koch, Köchin*