would eliminate the great majority of candidates, the ultimately relevant remaining part of candidate space may well have quite manageable proportions, and perhaps even reduce to a finite set (Hammond 1997).

Whether or not a computational method can be established for the evaluation of an infinite candidate space in OT grammars is still largely an open issue, but encouraging results are available. For example, Karttunen (1998) demonstrates that 'the computation of the most optimal surface realization of any input string can be carried out entirely within a *finite-state calculus*, subject to the limitation (Frank and Satta (1998)) that the maximal number of violations is bounded'. Karttunen adds that '[i]t is not likely that this limitation is a serious obstacle to practical optimality computations with finite-state systems as the number of constraint violations that need to be taken into account is generally small'.

1.5 Interactions of markedness and faithfulness

This section will deal with important types of interactions of markedness and faithfulness constraints, building on key insights of Prince and Smolensky (1993), Kirchner (1995), and Steriade (1995b). In section 1.3.3 we studied final devoicing in Dutch as a case of positional neutralization: the feature [voice] is neutralized in a specific context (the syllable coda), as a result of a markedness constraint dominating a faithfulness constraint. Here we will first extend this simple interaction of markedness and faithfulness to a new phenomenon: allophonic variation. In section 1.6 we will look into the notion of *contrast* as it is defined in OT, and its consequences for *lexical representation*. This will allow us to define more clearly the ranking schemata of faithfulness and markedness constraints that are responsible for the various attested situations ('contrast', 'neutralization', and 'allophonic variation'). In section 1.7 we will summarize these results in the form of a 'factorial typology'. In section 1.8 we will see how *segment inventories* follow from interactions of faithfulness and markedness.

1.5.1 *Allophonic variation*

Consider a language that has no lexical contrast of oral and nasal vowels. In this language oral and nasal vowels are *allophones*, variants of one another which are fully predictable from the phonological contexts. For example, vowels are generally oral except when they directly precede a tautosyllabic nasal stop, in which case they are nasal. This allophonic pattern occurs in many dialects of English; see the examples below:

(40)	a.i	cat	[kæt]	b.i	can't	[kæ̃nt]
	a.ii	sad	[sæd]	b.ii	sand	[sæ̃nd]
	a.iii	met	[mɛt]	b.iii	meant	[mɛ̃nt]
	a.iv	lick	[lɪk]	b.iv	link	[lɪ̃ŋk]

When we say that English lacks a contrast of oral and nasal vowels, we do not imply that English completely lacks either kind of vowels, but only that no word pairs occur that are distinguished by orality/nasality of their vowels. Whatever variation there is between oral and nasal vowels is totally conditioned by the context and does not reflect lexical specification. Vowels are nasal when they precede a tautosyllabic nasal, and are oral in all other contexts. This complementary distribution, and the corresponding lack of word pairs that differ only in the specification of some feature, is what defines an allophonic pattern. How can the allophonic pattern in (40) be stated in terms of violable constraints?

In order to answer this question, we must first identify the set of constraints which are involved. Universally, nasal vowels are 'marked' as compared to oral vowels. Most of the world's languages completely lack nasal vowels, having oral vowels only (Maddieson 1984). Languages may have both oral and nasal vowels, but no languages have only nasal vowels. In sum, when a language has nasal vowels, it must also have oral vowels. The marked status of nasal vowels is expressed by the *context-free* markedness constraint in (41), which militates against nasal vowels:

(41) **$*V_{NASAL}$**
Vowels must not be nasal.

When this constraint is undominated in some language, then all of its vowels will be oral, regardless of their lexical specification, or their position in the syllable (before an oral or nasal).

Moreover, many languages tend to nasalize vowels in precisely the position where they are nasal in English: before a tautosyllabic nasal stop. The vowel thus anticipates the nasality of the following stop, a preferred state of affairs from the viewpoint of perception and articulation (Cohn 1993a).[14] Again, a markedness constraint expresses the universal markedness, ruling out oral vowels that precede a tautosyllabic nasal:

(42) **$*V_{ORAL}N$**
Before a tautosyllabic nasal, vowels must not be oral.

Observe that this constraint is *context-sensitive*, since it states a connection between the nasality of a vowel and a nasal stop in its context. More precisely, it is violated by an oral vowel that stands directly before a tautosyllabic nasal:

[14] Cohn (1993a) argues that nasalization in English vowels is gradient, and has no phonological status, as in French. For the sake of the argument, we will assume here that English nasalization is in fact categorical, although it is crucially non-contrastive.

(43) a. $*V_{ORAL}N$ satisfied b. $*V_{ORAL}N$ violated
i. æ̃n]$_\sigma$ æn]$_\sigma$
ii. æd]$_\sigma$

If this constraint is undominated, underlying contrasts between oral and nasal vowels (if any) will be neutralized in positions before a tautosyllabic nasal.

1.5.2 *Neutralization and contrast as constraint rankings*

Now consider the consequences of the OT assumption of the *Richness of the Base*, which was stated in section 1.4.1. This says that no constraints restrict the input, or to put it differently, that lexical representations in any language are free to contain any kind of phonological contrast. Whether some surface phonetic contrast (such as that between oral and nasal vowels) is allophonic or lexically distinctive in a language depends on interactions of two basic kinds of constraints: markedness constraints, which express markedness statements, and faithfulness constraints, which penalize deviations of the surface form (output) from its lexical form (input). When markedness dominates faithfulness, the language achieves outputs that are minimally marked, at the expense of a neutralization of lexical contrasts. But when faithfulness dominates markedness, the language makes the reverse choice, realizing its input contrasts at the expense of output markedness:

(44) a. Markedness ≫ Faithfulness lexical contrasts are neutralized
b. Faithfulness ≫ Markedness lexical contrasts are expressed

Richness of the Base implies that English (as any other language) is allowed the option of setting up a contrast of oral and nasal vowels in its underlying representations. However, this hypothetical contrast is never realized at the surface, because with respect to nasality/orality in vowels, English happens to be a language of the type (44a), which gives priority to markedness over faithfulness. Whatever lexical contrast of nasality there might be in vowels will be *obscured* by effects of markedness. The input faithfulness constraint that is crucially dominated in English requires that surface values of nasality in vowels are identical to their underlying values:

(45) **IDENT-IO**(nasal)
Correspondent segments in input and output have identical values for [nasal].

In a language in which IDENT-IO(nasal) is undominated, any lexical contrast of nasality in vowels will be allowed to surface, uninhibited by the markedness constraints (41–2). Such a language is free to set up and preserve any lexical contrast between oral and nasal vowels *anywhere*, that is, without any neutralization. This situation corresponds to the interaction (44b). But in a language in which IDENT-IO(nasal) is dominated by both of the markedness constraints (41) and (42), any (potential) contrast of orality/nasality in vowels will be fully neutralized, as is the case in allophonic variation. This is the situation (44a), found in English.

Let us now return to the allophonic pattern (40) and find out how this results from the interaction of the three constraints that were introduced earlier. In terms of constraint interaction, faithfulness to the lexical specification of a vowel is completely dominated by markedness constraints reflecting markedness of orality/nasality in vowels. In terms of ranking, IDENT-IO(nasal) is dominated by both markedness constraints:

(46) Neutralization of lexical contrast
Markedness ≫ Faithfulness
$*V_{NASAL}$, $*V_{ORAL}N$ ≫ IDENT-IO(nasal)

This is an instantiation of the schema in (44a), where markedness constraints completely dominate faithfulness.

The question which arises next is how both markedness constraints, $*V_{ORAL}N$ and $*V_{NASAL}$, are ranked with respect to each other. As we observed earlier in connection with the context-free constraint $*V_{NASAL}$, any language in which this is undominated will totally lack nasal vowels in its surface patterns. This is not the case in English, however, where nasal vowels do occur (as allophones of oral vowels) in specific positions, that is, before tautosyllabic nasal stops. We must therefore refine the ranking in (46) to that in (47):

(47) Allophonic variation
Contextual markedness ≫ Context-free markedness ≫ Faithfulness
$*V_{ORAL}N$ ≫ $*V_{NASAL}$ ≫ IDENT-IO(nasal)

This ranking states that nasal realization of vowels before tautosyllabic nasal consonants takes priority over a total lack of nasality in vowels. In sum, both nasal and oral vowels occur at the surface, but their distribution is fixed, rather than free.

This ranking is illustrated in the tableaux (48–51). First consider the case of an oral vowel in the actual output, for example *sad* [sæd]. When we assume that this has an oral vowel in its lexical representation, e.g. /sæd/, matching its surface status, we arrive at the first tableau (48). Candidate (48a) is optimal as it violates none of the constraints in the tableau, regardless of ranking. It satisfies $*V_{ORAL}N$ since this constraint has nothing to say about vowels that stand before oral stops. It also satisfies $*V_{NASAL}$ since it has no nasal vowel. Finally it satisfies IDENT-IO(nasal) because the input and output agree in nasality.

(48)

Input: /sæd/	$*V_{ORAL}N$	$*V_{NASAL}$	IDENT-IO(nasal)
a. ☞ [sæd]			
b. [sæ̃d]		*!	*

The losing candidate [sæ̃d] (48b) is less harmonic than (48a) in two respects. It contains a nasal vowel, fatally violating the markedness constraint $*V_{NASAL}$. It violates IDENT-IO(nasal) as well, as the nasal vowel in the output fails to match its oral correspondent in the input.

Because of Richness of the Base, we must guarantee that this correct result is not negatively affected when we make different assumptions about the nasality of vowels in the input. Indeed, the same candidate [sæd] is selected when the input would contain a nasal vowel, e.g. /sæ̃d/, here in defiance of its surface form. This is shown in tableau (49). Again markedness uniquely determines the outcome, without interference on the part of the faithfulness constraint IDENT-IO(nasal).

(49)

Input: /sæ̃d/	$*V_{ORAL}N$	$*V_{NASAL}$	IDENT-IO(nasal)
a. ☞ [sæd]			*
b. [sæ̃d]		*!	

Note that in this case IDENT-IO(nasal) is violated in the optimal candidate. This motivates the ranking $*V_{NASAL} \gg$ IDENT-IO(nasal), a markedness constraint dominating faithfulness. That is, even if the input of *sad* were to contain a nasal vowel, its nasality would be wiped out in the surface form by markedness constraints. This is of course the central result that we need to account for allophonic variation, in a theory which assumes Richness of the Base.

We can only rightfully claim to have captured the ‘complementary distribution’ of oral and nasal vowels if we can prove the total ‘irrelevance of the input’ for words which surface with nasal vowels, for example *sand* [sæ̃nd]. Again we consider two underlying forms, one with an oral vowel and the other with a nasal vowel. Tableau (50) shows that an underlying form with an oral vowel /sænd/ results in an optimal output with a nasal vowel, [sæ̃nd]. This is due to the undominated context-sensitive markedness constraint $*V_{ORAL}N$, which requires that vowels are nasal before a tautosyllabic nasal stop:

(50)

Input: /sænd/	$*V_{ORAL}N$	$*V_{NASAL}$	IDENT-IO(nasal)
a. [sænd]	*!		
b. ☞ [sæ̃nd]		*	*

Observe that two markedness constraints, $*V_{ORAL}N$ and $*V_{NASAL}$, are in conflict here. The former requires a nasal vowel in the output whereas the latter militates against it. The fact that the actual output [sæ̃nd] has a nasal vowel shows that $*V_{ORAL}N$ dominates $*V_{NASAL}$. (If the ranking had been reverse, the result would have been in favour of candidate 50a, which has an oral vowel.) Observe also that the underlying orality of the vowel in *sand* does not affect the outcome. IDENT-IO(nasal) is violated in the optimal output, since it contains a nasal vowel whereas the input contains an oral vowel. This conclusion is essential to the argument that faithfulness is dominated by *both* markedness constraints. We have already reached this conclusion for $*V_{NASAL}$ in tableau (49), and now we confirm it for $*V_{ORAL}N$.

The argument for the irrelevance of inputs in allophonic patterns is completed by an inspection of tableau (51), which has an underlying form with a nasal vowel, /sæ̃nd/. In this tableau, the same optimal candidate is selected as in the previous one, simply because markedness uniquely determines the outcome.

(51)

Input: /sæ̃nd/	$*V_{ORAL}N$	$*V_{NASAL}$	IDENT-IO(nasal)
a. [sænd]	*!		*
b. ☞ [sæ̃nd]		*	

A comparison of tableaux (50) and (51) reveals the complete inactivity of the faithfulness constraint IDENT-IO(nasal). We conclude that the orality/nasality of the underlying vowel is completely irrelevant to the surface distribution of oral and nasal vowels.

1.6 Lexicon Optimization

The main result of the preceding section is that lexical specifications for [nasal] in vowels in English are totally irrelevant to their surface realization. Should we then conclude that the English lexicon is completely unstructured for nasality in vowels, in the sense that the vowels in lexical items *sad* and *sand* are randomly specified for this feature? Or should we still insist that the lexicon be kept 'clean' from featural noise, and contain only feature values that are actually related to output values? An answer to this question is potentially relevant to language acquisition. In order to build a lexicon, the learner must somehow be able to determine *underlying* forms, for example to infer the underlying form of *sad* on the basis of its surface form [sæd]. When we concentrate on possible values for nasality in the vowel, there is a choice of two lexical representations, /sæd/ and /sæ̃d/. We have seen that, given the ranking of $*V_{NASAL}$ over IDENT-IO(nasal), both lexical representations result in identical outputs. This ranking completely *masks* the input, obscuring empirical evidence that the learner might use to base his/her choice of an underlying form on.

It has been proposed that in the absence of empirical evidence for one input form over another, the input should be selected that is closest to the output, in this case /sæd/. That is, wherever the learner has no evidence (from surface forms) to postulate a specific diverging lexical form, (s)he will assume that the input is identical to the surface form. In terms of constraint violations, this strategy has the advantage of minimizing the violation of faithfulness, *as compared to any other hypothetical inputs producing the same output*. This strategy is called *Lexicon Optimization* in Prince and Smolensky (1993: 192):

(52) **Lexicon Optimization**: suppose that several different inputs I_1, $I_2 \ldots, I_n$ when parsed by a grammar G lead to corresponding outputs O_1, $O_2 \ldots, O_n$, all of which are realized as the same phonetic form Φ – these inputs are *phonetically equivalent* with respect to G. Now one of these outputs must be the most harmonic, by virtue of incurring the least significant violation marks: suppose this optimal one is labelled O_k. Then the learner should choose, as the underlying form for Φ, the input I_k.

This principle is, in its turn, an elaboration of an idea of Stampe (1972), who suggested that underlying forms should always match surface forms in the absence of evidence to the contrary. (The 'masking' effect of one underlying form, /sæ̃d/, by another, /sæd/, is called 'Stampean occultation' in Prince and Smolensky 1993.)

An alternative to Lexicon Optimization is to assume that certain inputs contain no specification with respect to a feature (Kiparsky 1985, Steriade 1987, Archangeli 1988). This *underspecification* analysis of nasality in vowels is based on the idea that the burden of explanation for contrastive versus allophonic patterns is in the underlying form, rather than in the relationship between underlying form and surface form, as is the case in OT.[15]

[15] See Smolensky (1993), Inkelas (1995) and Itô, Mester, and Padgett (1995) for comments on underspecification in OT.

Importantly, Lexicon Optimization does not contradict the assumption of Richness of the Base, even though it may give rise to lexicons that are 'impoverished' in terms of featural 'noise'. The burden of explanation still remains on the interaction of markedness and faithfulness. More specifically, the ranking markedness $\gg$ faithfulness implies that it is not an accidental observation that nasality is never distinctive in vowels in English – on the contrary, this is a solid effect of constraint interactions in the English grammar.

1.7 **A factorial typology of markedness and faithfulness**

In the remainder of this chapter we will consider the consequences of reranking the three constraint types which we have assumed in the analysis of allophonic variation, that is: context-*free* markedness, context-*sensitive* markedness, and faithfulness. We will see that by reranking these three constraint types into different hierarchies, a 'factorial typology' arises which exactly matches the attested cross-linguistic variation in terms of allophonic variation, positional neutralization, and free contrast. This will provide further support for the 'markedness' approach of allophonic variation which we have used so far, as well as for the assumption of Richness of the Base.

1.7.1 ***Typological goals of OT***

The important notion of *factorial typology* requires some explanation, before we actually construct one. The key assumption of OT is that grammars are means to resolve conflicts between universal constraints. More specifically, the grammar of an individual language is a specific way, out of many possible, to rank a set of universal and violable constraints. Differences between languages must therefore be due to different rankings of a single set of universal constraints. To state it differently, we can build one grammar out of another by a rearrangement of its basic universal material, that is, by 'reranking' the constraints.

The relative success of any theory of grammar should be measured by its ability to characterize the notion of 'possible grammar' (see again the remarks in the introduction of this chapter). Constructing grammars ('constraint hierarchies') of individual languages may tell us much about the ways in which linguistic properties are interconnected within a single linguistic system. But what we are eventually interested in are *typological* results of the theory, that is, the predictions it makes about clusterings of linguistic properties, on a broad cross-linguistic basis. For example, the theory should explain why no languages occur that have a contrast of oral and nasal vowels, but contextually restrict this contrast to vowels immediately preceding nasal stops (neutralizing it everywhere else). Languages of this kind are logically possible, yet unattested. Can this situation be described by a reranking of the constraints governing nasality in vowels? Conversely, we should ask what language types would arise by reranking a number of constraints that are motivated in the analysis of an individual language. Does reranking of these constraints produce attested languages as well?

Taken quite literally, the reranking approach would predict that any new grammar that arises from a reranking of any pair of constraints will precisely correlate with one of the world's languages. This prediction is based on the deeply naive assumption that every possible ranking should be instantiated by some attested language. This is naive, just as it is deeply naive to expect that all logically possible permutations of genetic material in the human genome are actually attested in individual humans. Therefore, in order to test the typological predictions of the theory of contrast and contextual neutralization presented in this section, we will rerank *types* of constraints (rather than individual constraints) of the general types 'faithfulness', 'contextual markedness', and 'context-free markedness'. The resulting factorial typology will be matched with broad *typological* diversity between languages, along the dimensions that these constraint types represent. (Of course, this is not to deny that cases can occur in which it is more useful to compute factorial typologies of individual constraints.)

1.7.2 *Constructing a factorial typology*

To construct a factorial typology of a set of constraints, we sum up all logically possible rankings of this set of constraints, and compute the different outcomes. With large sets of constraints the number of possible rankings rises steeply, as with a constraint set of size n, we must consider all $n!$ rankings. (This equals 2 rankings for 2 constraints, 6 rankings for 3, 24 for 4, 120 for 5, 720 for 6, etc.) Fortunately, many of the individual rankings in a factorial typology produce identical surface patterns. Therefore the number of predicted patterns is much smaller than the total number of logically possible rankings. Keeping these remarks in mind, we now turn to a real case.

Our goal is to construct a factorial typology of the constraint types introduced so far (faithfulness constraints, context-free and context-sensitive markedness constraints). One proviso has to be made: actual grammars rank individual constraints, not 'constraint types'. (For example, no grammar ranks all faithfulness constraints above all markedness constraints, for reasons discussed in section 1.2.2.) Nevertheless, we will *generalize* the factorial typology by a reranking of constraint types. Accordingly, the emerging factorial typology should be taken as a catalogue of general effects, which may be instantiated in an individual grammar with respect to specific features.

A factorial typology of markedness and faithfulness is presented below, resulting from a reranking of both markedness constraint types with faithfulness. We will abbreviate these types of markedness constraints as *MC-free* (for context-free markedness constraint) and *MC-sensitive* (for context-sensitive markedness constraint).

(53) A factorial typology of markedness and faithfulness

a.	MC-free ≫ MC-sensitive, Faithfulness	Lack of variation (unmarked)
b.	MC-sensitive ≫ MC-free ≫ Faithfulness	Allophonic variation
c.	MC-sensitive ≫ Faithfulness ≫ MC-free	Positional neutralization
d.	Faithfulness ≫ MC-sensitive, MC-free	Full contrast

The attentive reader may have noted that we have only four rankings here, rather than the predicted six (or 3!). This reduction is due to the fact that in rankings (53a) and (53d), the mutual ranking of the bottom two constraints is of no importance to the outcome.

The following subsections discuss how these situations arise from these rankings, and also illustrate each ranking by tableaux for contrastive nasality in vowels.

1.7.3 *Neutralization: lack of variation versus allophonic variation*

Both (53a) and (53b) are situations of complete neutralization, since in both cases there is a total lack of activity of the faithfulness constraint, which is at the very bottom of the hierarchy. The difference between the rankings resides in whether or not the neutralized feature is 'contextually coloured', that is, subject to allophonic variation.

First consider the situation of total lack of variation, which is produced by ranking (53a), due to an undominated context-free markedness constraint for some feature [αF]. Accordingly the unmarked value of this feature (for segments of a given type), [*u*F], will always appear at the surface, regardless of its underlying specification, and regardless of the context. This results in the complete neutralization of this feature in the direction of the unmarked value. Such total *lack of variation* for a given feature (in all segments of some type) is widely attested for different features among the world's languages.

For example, if the constraint $*V_{NASAL}$ is undominated, then all surface vowels are oral, even those vowels which are underlyingly nasal, and even those vowels which are adjacent to a nasal consonant. This is illustrated in the set of four tableaux below. Each of these tableaux takes as its input one of the four possible combinations of input nasality in vowels (nasal versus oral) and output context of the vowel (preceding a nasal [n] or an oral [l]). All four possible inputs {/pan/ ~ /pãn/ ~ /pal/ ~ /pãl/} map onto oral output vowels:

(54) Lack of variation of nasality in vowels (total orality)
$*V_{NASAL} \gg *V_{ORAL}N$, IDENT-IO(nasal)

(i) Input: /pan/	$*V_{NASAL}$	$*V_{ORAL}N$	IDENT-IO(nasal)
a. pãn	*!		
b. ☞ pan		*	

(ii) Input: /pãn/	$*V_{NASAL}$	$*V_{ORAL}N$	IDENT-IO(nasal)
a. pãn	*!		
b. ☞ pan		*	*

(iii) Input: /pal/	$*V_{NASAL}$	$*V_{ORAL}N$	IDENT-IO(nasal)
a. pãl	*!		
b. ☞ pal			

(iv) Input: /pãl/	$*V_{NASAL}$	$*V_{ORAL}N$	IDENT-IO(nasal)
a. pãl	*!		
b. ☞ pal			*

Observe that the ranking of $*V_{ORAL}N$ and IDENT-IO(nasal) with respect to one another is totally irrelevant to the outcome, since the orality of the vowel is uniquely determined by $*V_{NASAL}$.

Ranking (53b) produces the typologically common case of *allophonic variation*, of which we have already encountered an example in the form of vowel nasalization before tautosyllabic nasals in English. As compared to the previous ranking, (53a), this ranking maintains complete neutralization, yet it allows for some variation in output values for the relevant feature. For example, both values of nasality in vowels do occur in surface forms, although their distribution is totally determined by the context. Vowels are nasal before nasal consonants (regardless of their input specification), and they are oral in all other contexts (regardless of their input specification). Although tableaux of English examples have already been presented in section 1.5.2, we include new tableaux here for maximal clarity:

(55) Allophonic variation of nasality in vowels
$*V_{ORAL}N \gg *V_{NASAL} \gg$ IDENT-IO(nasal)

(i) Input: /pan/	$*V_{ORAL}N$	$*V_{NASAL}$	IDENT-IO(nasal)
a. ☞ pãn		*	*
b. pan	*!		

(ii) Input: /pãn/	$*V_{ORAL}N$	$*V_{NASAL}$	IDENT-IO(nasal)
a. ☞ pãn		*	
b. pan	*!		*

(iii) Input: /pal/	$*V_{ORAL}N$	$*V_{NASAL}$	IDENT-IO(nasal)
a. pãl		*!	*
b. ☞ pal			

(iv) Input: /pãl/	$*V_{ORAL}N$	$*V_{NASAL}$	IDENT-IO(nasal)
a. pãl		*!	
b. ☞ pal			*

The two remaining rankings in the factorial typology, (53c) and (53d), produce varying degrees of contrastiveness, as we will see below.

1.7.4 *Contrast: positional neutralization versus full contrast*

Ranking (53c) produces a *positional neutralization* of underlying feature values. This is a situation in which an underlying contrast is freely realized in most contexts, but where it is neutralized in a specific context. For example, nasality is contrastive in vowels, except in the context before a nasal consonant, where all vowels are nasal:

(56) Positional neutralization of nasality in vowels before nasal consonants
$*V_{ORAL}N \gg$ IDENT-IO(nasal) $\gg *V_{NASAL}$

(i) Input: /pan/	$*V_{ORAL}N$	IDENT-IO(nasal)	$*V_{NASAL}$
a. ☞ pãn		*	*
b. pan	*!		

(ii) Input: /pãn/	$*V_{ORAL}N$	IDENT-IO(nasal)	$*V_{NASAL}$
a. ☞ pãn			*
b. pan	*!	*	

(iii) Input: /pal/	$*V_{ORAL}N$	IDENT-IO(nasal)	$*V_{NASAL}$
a. pãl		*!	*
b. ☞ pal			

(iv) Input: /pãl/	$*V_{ORAL}N$	IDENT-IO(nasal)	$*V_{NASAL}$
a. ☞ pãl			*
b. pal		*!	

Finally, the logically opposite situation of (53a) is that produced by ranking (53d), where a faithfulness constraint governing a feature dominates all markedness constraints (governing this feature). This produces a pattern in which input feature specifications are freely realized, that is, a situation of *full contrast* for the relevant feature.

For nasality, this ranking produces a situation in which underlying specifications in vowels are realized at the surface, regardless of their adjacency to nasal consonants:

(57) Full contrast of nasality in vowels
IDENT-IO(nasal) ≫ $*V_{NASAL}$, $*V_{ORAL}N$

(i) Input: /pan/	IDENT-IO(nasal)	$*V_{NASAL}$	$*V_{ORAL}N$
a. pãn	*!	*	
b. ☞ pan			*

(ii) Input: /pãn/	IDENT-IO(nasal)	$*V_{NASAL}$	$*V_{ORAL}N$
a. ☞ pãn		*	
b. pan	*!		*

(iii) Input: /pal/	IDENT-IO(nasal)	$*V_{NASAL}$	$*V_{ORAL}N$
a. pãl	*!	*	
b. ☞ pal			

(iv) Input: /pãl/	IDENT-IO(nasal)	*V_{NASAL}	*$V_{ORAL}N$
a. ☞ pãl		*	
b. pal	*!		

Again, this *free contrast* is a cross-linguistically common type of situation.

1.7.5 *Positional neutralization of voice in Dutch*

It will now be clear that Dutch final devoicing is an example of positional neutralization: it produces a neutralization of the feature [voice] in obstruents in the specific context of a syllable coda, while leaving unaffected the lexical distribution of [voice] in obstruents in other contexts. To fit the Dutch case into the ranking schemata of the previous section, we must first determine which context-free markedness constraint is involved in the ranking.

The unmarked value for the feature [voice] in obstruents is [–voice], as stated in VOICED OBSTRUENT PROHIBITION (58c, henceforth VOP, after Itô and Mester 1998), which is accompanied by the other two constraints relevant to the Dutch devoicing pattern:

(58) a. ***VOICED-CODA** (*context-sensitive markedness constraint*)
Coda obstruents are voiceless.
b. **IDENT-IO**(voice) (*faithfulness constraint*)
The value of the feature [voice] of an input segment must be preserved in its output correspondent.
c. **VOP** (*context-free markedness constraint*)
*[+voi, –son]
No obstruent must be voiced.

These three constraints are ranked in the following way in Dutch, instantiating the pattern of positional neutralization (53c) with respect to the feature [voice]:

(59) Ranking producing positional neutralization of voice in Dutch
MC-sensitive ≫ Faithfulness ≫ MC-free
*VOICED-CODA ≫ IDENT-IO(voice) ≫ VOP

This ranking states that a voiceless realization of obstruents in coda position takes priority over preservation of [voice] in coda obstruents. However, preservation of input values of [voice] takes priority over the complete devoicing of obstruents. In sum, the contrast of voiced and voiceless obstruents is positionally neutralized in the syllable coda. Elsewhere, a contrast is possible – input values of [voice] are preserved in the output.

In terms of concrete examples, this ranking correctly predicts that the output of /bɛd/ is [bet], which is unfaithful to input values for [voice] *only in its coda consonant*. But the voiced onset consonant /b/ is protected from the complete devoicing of obstruents required by the context-free markedness constraint VOP (hence, *[pet]). This interaction is shown by tableau (60), containing all four logically possible combinations of [voice] in the onset and coda consonants:

(60)

Input: /bɛd/	*Voiced-Coda	Ident-IO(voice)	VOP
a. ☞ [bɛt]		*	*
b. [pɛt]		**!	
c. [bɛd]	*!		**
d. [pɛd]	*!	*	*

Two candidates (60c–d) are eliminated by undominated *Voiced-Coda, as each contains a voiced obstruent in coda position. Both remaining candidates (60a–b) satisfy *Voiced-Coda, hence both are passed on for evaluation by the next-lower-ranked constraint in the hierarchy, Ident-IO(voice). Although both (60a) and (60b) violate Ident-IO(voice), the former is selected since it violates Ident-IO(voice) *minimally.* It has only one violation, while its contestant (60b) incurs two violations, one more than is strictly necessary. This result reflects an important property of the architecture of OT: a constraint can be 'active' even when it is dominated by one or more other constraints. *Constraints may be violated, but violation must be minimal*. This property of constraint interactions will reoccur many times in this book.

Another major property of constraint interaction is also illustrated by tableau (60). This is that *some candidates can never emerge as optimal, regardless of the ranking of constraints*. To see this, consider output candidate (60d), [pɛd], which preserves the input value for [voice] in its coda consonant, but is unfaithful to [voice] in its onset consonant. This incurs violations for each of the three constraints in the tableau: it violates *Voiced-Coda as it has a voiced coda obstruent [d], it violates Ident-IO(voice) as it is unfaithful to the input value of [voice] in one of its consonants (the onset [p]), and finally it violates VOP because it contains a voiced obstruent [d]. Under what constraint ranking might this candidate be selected as optimal? The surprising answer is: 'under no ranking', since all logically possible rankings of the three constraints evaluate (60d) as *suboptimal to some other candidate*. To prove this point, we need not go through all tableaux of all possible rankings, although this method will certainly lead to the same conclusion. A more general proof is available. To mark a candidate $cand_1$ as 'intrinsically suboptimal', it suffices to identify a rivalling candidate $cand_2$ which shares with $cand_1$ the violation marks for every constraint, except for at least one constraint *C*, on which $cand_2$ is more harmonic. If such a constraint *C* exists, then $cand_2$ must be a better candidate than $cand_1$ regardless of the ranking of *C*, since the minimal difference in violation marks always works in its favour, even if *C* were to dwell at the very bottom of the hierarchy.

There happens to be such a candidate $cand_2$ in tableau (60): candidate (60a), [bɛt], shares with candidate [pɛd] (60d) one violation mark for IDENT-IO(voice), and one for VOP, yet it minimally improves over (60d) with respect to *VOICED-CODA. Hence:

(61) [bɛt] ≻ [pɛd] For input /bɛd/, *irrespective* of ranking.

This does *not* imply that [bɛt] is the optimal candidate under *any ranking*: it clearly is not (only consider rankings in which either *VOICED-CODA or VOP is undominated). It does imply, however, that [pɛd] is 'intrinsically suboptimal' – which means that it will never be selected as optimal under any logically possible ranking of the three constraints under consideration.

This result, although apparently limited to the interaction of the three constraints in tableau (60), in fact has broader typological implications. A prediction follows from it, which is stated in general terms as follows. Assume a context-free markedness constraint banning one value of a feature [αF], and another context-sensitive markedness constraint banning the same value [αF] in a specific context. The prediction is that no language can have a contrast of [±F] *exclusively* in the context where a context-sensitive markedness constraint bans [αF]. This seems to be correct, although further testing may be required.

One particular language type excluded is one that has a lexical contrast of voicing exclusively in syllable codas. See the following hypothetical pattern of contrast:

(62) A hypothetical language that is predicted not to occur
a. a contrast of voice in syllable codas
lap ~ lab, pot ~ pod, muuk ~ muug
b. but no contrast of voice elsewhere
paa (*baa), ma.tol (*ma.dol), tol.ku (*tol.gu)

Such a language would preserve a contrast of voice in the coda, but neutralize it elsewhere. That is, it would map an input /bɛd/ onto an optimal output [pɛd]. But we have just seen that such a mapping is ruled out on principled grounds, since it involves the selection of an intrinsically suboptimal candidate. The asymmetry between onsets and codas is due to a context-sensitive markedness constraint

*VOICED-CODA which rules out [+voice] in the syllable coda, while there is no analogous context-free markedness constraint which rules out any feature of voice *specifically* in the onset.

Alternative theories which do not assume markedness to be the actual substance of the grammar fail to derive this general prediction. For example, a rule-based theory in which the notion of 'markedness' is an external criterion fails to predict that hypothetical languages such as (62) should not exist. This is because phonological rules that neutralize a contrast of voice are 'natural' in *any context*, regardless of whether they apply in onset or in coda position. A rule neutralizing voicing in onsets is 'natural' in this general sense, and no language that has this rule is committed to having a second rule neutralizing voicing in codas as well. Therefore a grammar which neutralizes a voicing contrast in all contexts except in codas should be possible, even though it would be 'complex' (in the sense that different rules would be employed, instead of a single general one).

1.7.6 *Typology: some preliminary conclusions*

To wind up this section let us now summarize the results. At the heart of OT is the notion that grammars of individual languages instantiate general ranking schemata of constraints of different types. The basic method of checking the typological predictions made by the theory is that of constructing a factorial typology by the reranking of constraints of different types. In this section we have constructed a basic factorial typology of faithfulness and markedness, and found that all predicted types of input–output relationships are attested. By varying the ranking of faithfulness with respect to (context-free and context-sensitive) markedness constraints, we found a factorial typology which ranged from a situation of total neutralization on the one hand, to that of total freedom of contrast on the other hand. In between these extremes, we identified two intermediate situations: allophonic variation (a specific kind of neutralization which allows two values of some feature in the output), and positional neutralization (a situation in which a feature is contrastive, except in a specific context, in which it is neutralized). We elaborated on positional neutralization of voice in Dutch to demonstrate two typical properties of constraint interaction in OT. In the first place, we found that dominated constraints may still be active, in the sense that a constraint, even when it is violated, must be minimally violated. Secondly, we found that some output candidates are intrinsically suboptimal to others, regardless of ranking. This captures certain typological observations with respect to positional neutralization.

1.8 On defining segment inventories

This section will show how segment inventories result from interactions of faithfulness constraints and markedness constraints. The discussion is related to the