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What is Optimality Theory?

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Abstract. Optimality Theory is a general model of how grammars are structured. This article surveys the motivations for OT, its core principles, and the basics of analysis. It also addresses some frequently asked questions about this theory and offers suggestions for further reading.

1. Introduction

In 1991, Alan Prince and Paul Smolensky began presenting their work on a new approach to language. By 1993, this new approach had a name — Optimality Theory — and it became known through their widely-circulated manuscript *Optimality Theory: Constraint Interaction in Generative Grammar* (hereafter, Prince and Smolensky (2004)). The impact of this work on the field of phonology was extensive and immediate; since 1993, it has also stimulated important research in syntax, semantics, sociolinguistics, historical linguistics, and other areas. OT would probably go on anyone's list of the top five developments in the history of generative grammar.

This survey article sketches the motivations for OT, its core principles, and the basics of analysis. It also addresses some frequently asked questions about this theory. Since any survey of such a broad topic is necessarily incomplete, each section concludes with suggestions for further reading.

2. The motivations for OT

Since the early 1970's, it has been clear that phonological and syntactic processes are influenced by constraints on the output of the grammar. Two different kinds of influence can be identified:

i. Processes can be **blocked** by output constraints. In Yawelmani Yokuts, syllables are maximally CVC. A process of final vowel deletion is blocked from applying when it would produce an unsyllabifiable consonant (Kisseberth, 1970): /taxaː-k^{ʔ}**a**/ → [taxak^{ʔ}] 'bring!' vs. /xat-k^{ʔ}**a**/ → [xatk^{ʔ}**a**], *[xat**k^{ʔ}**] 'eat!'. In English, *wh* movement is blocked when it would create a *that*-trace sequence (Chomsky and Lasnik, 1977): *Who did you say* **t** *left?* vs. **Who did you say* ***that*** **t** *left?*
ii. Processes can be **triggered** by output constraints. In Yawelmani, unsyllabifiable consonants in the input are fixed by epenthesizing a vowel: /ʔil**k**-hin/ → [ʔil**i**khin] 'sings'. In Spanish, clitics are moved to satisfy an output constraint requiring that second person precede first person (Perlmutter, 1971): ***Te me*** *presento/****Te me*** *presentas* 'I introduce myself to you'/'You introduce yourself to me'.

Although the blocking and triggering relationships between the processes and the output constraints are easy to grasp at an intuitive level, it is not obvious how to

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express these relationships formally in linguistic theory. In fact, phonological and syntactic theory, which developed along parallel lines until the 1970's, diverged on exactly this point.

The mainstream syntactic approach to blocking and triggering is represented by works like Chomsky and Lasnik (1977). All transformations are optional. An input to the grammar — that is, a deep structure — freely undergoes any, all, or none of the transformations, and the result is submitted to the surface-structure constraints, called filters. Any candidate surface structure that satisfies all of the filters is a well-formed sentence of the language. A transformation T is in effect blocked whenever a surface filter rules out the result of applying T. Similarly, T is in effect triggered whenever a filter rules out the result of not applying T. The net result is that much of the burden of explaining syntactic patterns is shifted from the theory of transformations to the theory of filters, which is arguably better equipped to produce such explanations. Ultimately, the theory of transformations withered away in Government-Binding Theory to just Move α (Chomsky, 1981).

The Chomsky-Lasnik model (hereafter CLM) was extremely influential in syntax, but not in phonology. The main reason, in my view, is that it could not be made to work on typical phonological data if output constraints are inviolable.

Yawelmani illustrates. In CLM, obligatory application of a process is obtained by positing an output constraint against structures where that process has not applied. In Yawelmani, epenthesis is obligatory after unsyllabifiable consonants: /ʔilk-hin/ → [ʔil**i**khin]. In CLM, this means that the epenthesis transformation is optional, but failure to epenthesize is marked as ungrammatical by a constraint against unsyllabified consonants in the output: *[ʔil**k**hin]. Final vowel deletion is obligatory as well in /taxaː-kˀ**a**/ → [taxakˀ], so some constraint must be ruling out *[taxaː-kˀ**a**]. An obvious candidate for this constraint is a general prohibition on final vowels, *V#. But this cannot be correct because it also marks as ungrammatical those well-formed surface structures where deletion has correctly failed to apply, such as /xat-kˀ**a**/ → [xatkˀ**a**]. So the constraint responsible for the obligatoriness of deletion in /taxaː-kˀ**a**/ → [taxakˀ] has to be something more specific: a prohibition on final vowels that are preceded by a single consonant, *VCV#.

This seemingly innocent analytic move disguises a fundamental failure of explanation. The constraint *VCV# stipulates something that should be accounted for independently: final vowel deletion is blocked in a VCCV# context because then it would produce an unsyllabifiable consonant: /xat-kˀ**a**/ → *[xat**kˀ**] With inviolable constraints there is no way of saying that *V# is enforced unless enforcing it would produced an unsyllabifiable consonant. There is no way of establishing such priority relationships between two inviolable constraints; at least one of the constraints (the lower priority one) has to be violable for priority relationships to make any sense.

Another reason for CLM's lack of influence in phonology is the continuing force of the phonological research program defined by *The Sound Pattern of English* (*SPE*) (Chomsky and Halle, 1968). This program strongly influenced the kinds of explanations that could be entertained. *SPE*'s central hypothesis, embodied in the Evaluation Metric, is that rules statable with a few features have greater explanatory value than rules requiring more features, *ceteris paribus*. The *SPE* theory supplies abbreviatory conventions that capture generalizations by allowing certain rules to be stated in a more compact form. Although Kisseberth (1970) proposed a theory of blocking effects along these lines, using output constraints to abbreviate rules, the idea did not extend to triggering effects, as Kiparsky (1973) showed.

Novel theories of phonological representation, which rose to prominence beginning in the mid 1970's, led to progress of a different sort on the blocking and triggering problems. As phonological representations became increasingly complex, it became possible to imagine an almost rule-less phonology in which automatic satisfaction of universal constraints on representations was all that mattered. Goldsmith (1976a; 1976b) and Prince (1983) developed proposals along these lines for autosegmental and metrical phonology, respectively. This work ran headlong into another problem, however: the proposed universal constraints did not hold in every language all of the time. That is why the subsequent literature on autosegmental and metrical phonology, such as Pulleyblank (1986) and Hayes (1995), places considerable reliance on language-particular rules.

This last point brings us to another of the primary motivations for OT: the problem of constraint universality or the lack of it. In both phonology and syntax, initially plausible candidates for universal constraints often become increasingly dubious as they are surrounded with an apparatus of hedges and parameters to deal with empirical challenges.

The constraint requiring all syllables to have initial consonants (Ito's (1989:222) Onset Principle), supplies a nice example of how a good constraint can go bad if parametrization is taken seriously. In Arabic or German, every syllable must have an onset, *tout court*, and [ʔ] is epenthesized whenever it is needed to ensure that outcome. In Timugon Murut (Prentice, 1971), on the other hand, onsetless syllables are tolerated, so the Onset Principle needs to be parametrized: [onsets required: yes/no]. In Axininca Campa (Payne, 1981), onsetless syllables are tolerated word-intially, but not word-medially, so a further parameter is required: [onsets required medially: yes/no]. Dutch is similar to German, except that it allows syllables to be onsetless if they are unstressed (Booij, 1995:65), so yet another parameter will be necessary. Of course, no analyst has seriously proposed such nuanced parametrization of this constraint, but the facts would seem to demand it of anyone with a serious commitment to a parametric theory of phonological typology.

Even such complex parametrization is doomed to fail, however, because constraints can still be active in languages that seem to violate them freely. Timugon Murut, as was just mentioned, allows onsetless anywhere in the word: [am.bi.lu.o] 'soul'. (The periods stand for syllable boundaries.) Onsetless syllables are nevertheless avoided in two circumstances. A single intervocalic consonant is syllabified as an onset, such as the [l] of [am.bi.lu.o]. And reduplicated syllables must have onsets, even at the expense of infixing the reduplicative morpheme: [a.ba.lan] 'bathes' reduplicates as [a.ba.ba.lan], not *[a.a.ba.lan], whereas [bu.lud] 'hill' reduplicates as [bu.bu.lud]. Examples like these show that a constraint can remain "on" in the phonology of a language even when it would seem to have been turned off parametrically.

By the end of the 1980's, there was certainly a consensus about the importance of output constraints, but there were also major unresolved questions about the nature and activity of these constraints. That "conceptual crisis at the center of phonological thought", as Prince and Smolensky (2004:2) refer to it, was not very widely acknowledged at the time, but in hindsight it is hard to miss. It is a major feature of the intellectual context in which OT was developed.

Suggestions for further reading: McCarthy (2002:48-65) is a short overview of the intellectual context of OT. Some of the main issues that arose in the field of phonology in the years after the publication of *SPE* are given a historical perspective in Anderson (1985:328-350). Prince and Smolensky (2004:238-257) contrast OT with phonological systems that attempt to combine rules and constraints. Harmonic Grammar, another important predecessor of OT, has not been touched on here; see Prince and Smolensky (2004:234-238) for brief discussion and Legendre, Sorace, and Smolensky (2006) for a much more detailed treatment.

3. The fundamentals of OT

How does OT respond to the issues raised in the previous section? That is, how does OT address the following two questions?

i. How are constraints on the output of the grammar satisfied? What is the relationship between constraints on output structures and the operations that transform inputs into outputs? How are triggering and blocking effects accounted for?
ii. What is the relationship between the universal and the language-particular? How can constraints differ in their activity from language to language?

The answers to these questions follow directly from the fundamental properties of OT.

OT sets up a basic dichotomy between the operational component of the grammar and the constraint component. The operational component, called GEN, constructs a set of candidate output forms that deviate from the input in various ways. The constraint component, called EVAL, selects a member of this set to be the actual output of the grammar.

GEN functions something like the optional transformations in the Chomsky and Lasnik model or GB's Move α. GEN applies all linguistic operations freely, optionally, and sometimes repeatedly. This property of GEN, which is known as **freedom of analysis**, is assumed for two reasons. First, it is simpler to define GEN with freedom of analysis than without it. For example, the phonological GEN can repeatedly epenthesize — GEN(/pa/) ⊃ {pa, paə, paəə, paəəə, …} — because complicating GEN with limits on epenthesis is unnecessary, since EVAL puts limits on epenthesis anyway. Second, GEN's freedom of analysis is necessary because of the related assumption that GEN is universal. Because GEN is the same in every language, it must in effect anticipate all of the ways that any language could transform a given input, so as to be certain that all of these options are represented in the candidate set. The simplest way to do this is to supply GEN with certain operations and allow them to apply freely, thereby over- rather than undergenerating the necessary range of candidates. Again, overgeneration by GEN does not mean overgeneration by the grammar, since the output of GEN is filtered by EVAL.

EVAL receives the candidate set from GEN, evaluates it using some constraint hierarchy, and selects its **most harmonic** or **optimal** member as the output of the grammar. Assume that the hierarchy consists of the constraints C1, C2, and C3, in that order, and that the candidate set is {*cand1, cand2, cand3*}. If *cand2* violates top-ranked C1 less than both *cand1* and *cand3* violate it, then *cand2* is optimal. If, on the other hand, *cand1* and *cand2* both violate C1 equally, and if they violate C1 less than *cand3* does, then *cand3* is out of the running and the choice between *cand1* and *cand2* goes to C2, so on from there.

As this example illustrates, with the constraint hierarchy [C1 >> C2 >> C3] (for >> read "dominates"), satisfaction of C1 is categorically more important than satisfaction of C2, and satisfaction of C2 is categorically more important than satisfaction of C3. The preferences expressed by C2 are significant only insofar as they decide among candidates that tie for best performance on C1. In other words, OT constraints are arranged in strict-domination hierarchies, in which superior performance on lower-ranking constraints can never overcome inferior performance on higher-ranking constraints. OT constraints are violable, unlike Chomsky and Lasnik's inviolable filters or the various pre-OT phonological constraints.

Each language has its own constraint ranking. The strongest hypothesis is that constraint ranking is the only thing in the grammar that is language-particular: GEN, EVAL, and even the constraints themselves are universal. The universal constraint component is called CON. If the ranking of universal CON is the only difference between grammars, then all of the constraints in CON are present in the grammars of all languages. Only the ranking is different.

CON itself consists of two types of constraints. **Markedness** constraints are similar to the surface-structure constraints or filters of the 1970's. The inventory of markedness constraints in CON is a substantive theory of linguistic well-formedness — e.g., complex consonant clusters or *that*-trace sequences are bad. A significant innovation in OT is the notion of a **faithfulness** constraint. Faithfulness constraints are inherently conservative, requiring the output of the grammar to resemble its input. Because markedness constraints favor some linguistic structures over others, they are often in tension with faithfulness constraints, which resist changes to input structures. This tension is called **constraint conflict**, and it is resolved in OT by ranking. Conflict between two markedness constraints or between two faithfulness constraints is also possible, of course.

This brief summary of the most important properties of OT is sufficient to support some preliminary answers to the questions raised at the outset of this section.

The first question concerns the interaction between linguistic processes and the output constraints that seem to trigger or block them. OT's answer is that there is no real interaction, since processes and constraints are in separate grammatical components, GEN and EVAL, and information flows in only one direction, from GEN to EVAL. Formally, processes are neither triggered nor blocked; instead, the process component GEN supplies a broad array of possible outputs that reflect the results of applying various operations. In Yawelmani, for example, unsyllabifiable consonants are resolved by epenthesis because candidates with epenthesis are among those supplied by GEN, and because EVAL favors less-marked [ʔil**i**khin] over more faithful *[ʔilkhin] and differently-unfaithful *[ʔilhin]. EVAL is responsible for *choosing* the winning candidate, not for *generating* it.

The second question asks how output constraints can differ in activity from language to language. OT attributes differences in constraint activity to differences in ranking. The ranking of a markedness constraint relative to faithfulness constraints and other markedness constraints determines whether and when it is active. We can illustrate this with some of the examples mentioned near the end of section 2. CON includes a markedness constraint, called ONSET, that requires syllables to have onsets. If ONSET dominates the anti-epenthesis faithfulness constraint (and certain other ranking requirements are met), then candidates that resolve onsetless syllables by epenthesis will be preferred to candidates that preserve them: Arabic /al-walad/ → [**ʔ**al-walad], *[al-walad]. If in addition ONSET is dominated by a faithfulness constraint specific to word-initial syllables, then epenthesis will occur medially but not initially, as in Axininca Campa: /i-N-koma-i/ → [iŋkoma**t**i] 'he will paddle'. On the other hand, if ONSET is dominated by the anti-epenthesis and anti-deletion faithfulness constraints, then we get a language like Timugon Murut that permits onsetless syllables initially and medially: /ambiluo/ → [am.bi.lu.o]. (On Timugon Murut's requirement that a reduplicated syllable have an onset, see McCarthy and Prince (1994).)

Even in Timugon Murut, though, ONSET is not necessarily inactive: it cannot compel deletion or epenthesis, but it may have other effects. One such effect is syllabification of intervocalic consonants, since /VCV/ sequences are syllabified in an ONSET-obeying fashion as [V.CV]: [am.bi.**l**u.o], *[am.bi**l**.u.o]. This is an effect of ONSET in a situation where ONSET can be active without triggering epenthesis or deletion. Situations like this, where even a low-ranking markedness constraint can be decisive in situations where faithfulness is not at issue, are known as **emergence of the unmarked** (McCarthy and Prince, 1994).

As these few examples make clear, constraint ranking gives much more subtle control over constraint activity than parameters do. These examples also remind us, as we saw in section 2, that more subtle control is exactly what is needed.

Suggestions for further reading: The fundamentals of Optimality Theory are laid out primarily in chapter 5 of Prince and Smolensky (2004). Other overviews of this topic, in approximate order of increasing length and depth of coverage, include Archangeli (1997), Tesar, Grimshaw, and Prince (1999), Kager (1999:1-51), Prince and Smolensky (1997; 2003), McCarthy (2002:3-47; 2003a), and Smolensky, Legendre, and Tesar (2006). Legendre (2001) is an introduction to OT syntax.

4. Doing linguistic analysis in Optimality Theory

Since constraint ranking is hypothesized to be the only way in which grammars may differ, the core of any OT analysis is a collection of constraint rankings and the justification for them. In general, a ranking is justified by comparing two output candidates from the same input. One of these candidates, called the winner, is the actually observed output for that input in the language under analysis. The other candidate is a loser: it is derived by GEN from that same input, but it is not the most harmonic candidate according to EVAL. For EVAL to select the correct candidate as winner, *some* constraint that favors the winner over the loser must dominate *every* constraint that favors the loser over the winner. The logic of this statement follows from the properties of EVAL (see section 3). Constraint **ranking arguments** depend on this logic.

There are three essential elements to a valid ranking argument:

First, the constraints to be ranked must conflict; that is, they must disagree in their assessment of a pair of competing output candidates derived from the same input. For instance, Yawelmani /ʔilk-hin/ has competing candidate output forms [ʔili**k**hin] and *[ʔilkhin]. The markedness constraint against unsyllabified consonants (call it $*C_u$) and the anti-epenthesis faithfulness constraint (known as Dep) disagree in their assessment of these forms.

Second, one member of this pair of competing candidates must be the actual output form for the given input — the winner, in short. The constraint that favors the winner, $*C_u$, must dominate the constraint that favors the loser, Dep.

Third, the ranking argument is secure only if there is no third constraint that could also be responsible for this winner beating this loser. In the Yawelmani example, such a constraint would have to meet two conditions to be problematic: like $*C_u$, it would have favor [ʔil**i**khin] over *[ʔilkhin]; and it could not be ranked below Dep. Suppose for the sake of argument that there were a constraint *lk that is violated by any [lk] consonant sequence. Because *lk has the same favoring relation as $*C_u$ on the pair [ʔil**i**khin] and *[ʔilkhin], it threatens to undermine the ranking argument we have constructed, leaving us with a less definitive disjunction: at least one of $*C_u$ and *lk dominates Dep. This disjunction could be resolved by independently showing that Dep dominates *lk, using a ranking argument based on the winner/loser pair [ʔilkal]/*[ʔil**i**kal] 'might sing'.

The elements of a ranking argument are illustrated with a **tableau**. Tableaux of two main types appear in the literature. Each type has its usefulness for certain purposes. When the goal is to argue for rankings, then the comparative tableau format of Prince (2002) is best (see (1)). In a comparative tableau, each cell (*row*, *column*) indicates the number of violations, if any, of constraint *column* incurred by candidate *row*. Furthermore, every cell in a loser row has symbols W and L showing whether the constraint favors the winner or the loser, or no symbol if it favors neither. For example, the constraint $*C_u$ favors the winner in (1) because the loser violates this constraint once, while the winner violates it not at all. Likewise, Dep favors the loser because the winner violates this constraint and the loser does not. The W and L annotations indicate the function of the constraint in the system. In a properly ranked comparative tableau, every loser row contains at least one W with no Ls to its left. (Readers may find it helpful to pause at this point and convince themselves that the previous statement follows from the properties of Eval.)

(1) Comparative tableau

/ʔilk-hin/	$*C_u$	Dep
a. → ʔil**i**khin		$_1$
b. ʔilkhin	W_1	L

The original violation tableau format of Prince and Smolensky (2004) is illustrated in (2).

(2) Violation tableau

/ʔilk-hin/	$*C_u$	Dep
a. → ʔil**i**khin		*
b. ʔilkhin	*!	

In a violation tableau, each violation of a constraint is indicated by an asterisk. When a constraint knocks a candidate out of competition, that result is signaled by an exclamation point. Cells are shaded when any violations that they may contain can have no effect on the outcome because higher-ranking constraints are decisive. Violation tableaux are not as good as comparative tableaux in showing how the constraints and their ranking function in a particular language. But they are more useful than comparative tableaux for determining which members of a given candidate set are possible winners under different rankings of a given set of constraints. (See (10) for an example.)

Every theory presents its own special challenges to the analyst, and OT is no exception. One rather difficult task is determining the range of candidates that must be considered. Overlooking a candidate that ties or beats the intended winner "invites theoretical disaster, public embarrassment, and unintended enrichment of other people's careers" (McCarthy and Prince, 1993:13), since the overlooked candidate has the potential to undermine the entire analytic edifice. Systematic exploration of some space of candidates is usually the best way to avoid this problem.[2] For example, once we have established that DEP is crucially dominated in Yawelmani, it makes sense to consider all of the ways in which GEN can alter /ʔilk-hin/ by epenthesis. We can quickly determine that candidates with absurdly repeated epenthesis like *[ʔil**i**khin**i**.**i**.**i**.**i**] are no threat, since they violate DEP more than the winner does and do not beat it on any known constraint. But a candidate like *[ʔil**i**k**i**hin**i**] has a more serious claim on our attention. It discloses that DEP must dominate the markedness constraint NO-CODA, which prohibits syllable-final consonants. Even more important is the candidate *[ʔilk**i**hin], since it ties with the intended winner [ʔil**i**khin] on both $*C_u$ and DEP. The analysis would not be complete without some constraint that decided between these two candidates.

Another special responsibility of the analyst in OT is the introduction of new constraints. In theory, CON is universal, so the analyst's job is just a matter of finding some ranking of CON that reproduces the data of the language in question. In practice, however, the details of the constraints in CON are the topic of on-going research and discussion. Since CON embodies all of the substantive properties of human language, our present inability to deliver a definitive theory of CON should come as no surprise to anyone willing to concede that there are things about language that are not yet fully undersood.

What this means for the analyst is that any actual analysis may very well involve some constraints whose status in universal grammar (i.e., CON) is not yet settled. For example, while there is probably a consensus among phonologists that CON includes a faithfulness constraint that militates against deleting elements of the input, there is disagreement about whether the anti-epenthesis constraint DEP is also needed, since many of its effects can be obtained from independently necessary markedness constraints. (See Gouskova (2007) and Urbanczyk (2006) for opposing views on this question.) Another example: different ways of rationalizing the ad hoc markedness constraint $*C_u$ depend on different theories of the relationship between syllabification and phonotactics that are almost entirely independent of OT.

These are all empirical questions, and OT provides the analyst with ample

[2] See Karttunen (2006) for some discussion of this point.

opportunities to test and refine any hypothesis about CON. Any newly proposed constraint must, of course, offer insight into the analysis at hand. But this is not enough; the proposer is also responsible for exploring the (un)intended consequences of the new constraint under ranking permutation. The source of this novel obligation on the analyst is OT's inherently typological character (see section 6.1): every language-particular hierarchy of *n* constraints is pregnant with *n!-1* other hierarchies, each of which is predicted to be the grammar of a possible human language. Fortunately, not all constraints conflict, so many different rankings will produce identical results, making the task of the analyst-*cum*-theorizer far less daunting that it might at first seem.

As an example of this sort of reasoning, we can return to a question raised just above: is the faithfulness constraint DEP unnecessary because independently motivated markedness constraints do the same work? Take, for instance, a language like Timugon Murut that allows onsetless syllables. In this language, ONSET must be crucially dominated to rule out consonant epenthesis. Either ONSET is dominated by DEP or, in the DEP-less theory, ONSET is dominated by a set of markedness constraints that is sufficient to rule out every imaginable consonant that could be inserted to satisfy ONSET. For convenience, we can refer to this set of constraints as *C. The DEP-less theory requires the existence of *C, and therefore it makes certain predictions about the effects of ranking permutation. For example, by ranking *C above MAX, we could get a language that has no consonants whatsoever, only vowels (Gouskova, 2003:71ff.). No such language is known, and nearly everyone would agree that we do not want a theory to predict the existence of such a language. In this case as in so many others, tests against language typology act as a check and corrective on proposals about CON. (See section 6.1 for further discussion.)

Suggestions for further reading: The special challenges of analysis in OT are briefly addressed in McCarthy (2002:30-42). McCarthy (2007a) is a book-length treatment of this topic.

5. Illustrations

This section puts some flesh on the theoretical and analytic skeleton assembled in the previous sections. It does this by illustrating OT at work with two examples, one phonological and the other syntactic.

In Emai (Casali, 1996:62-68; Schaefer, 1987), ONSET is satisfied at V_1+V_2 juncture by changing V_1 into a glide, deleting V_1, or deleting V_2. The choice among these three options depends on whether V_1 is a high vowel and on whether the morphemes that contain V_1 and V_2 are lexical or functional:

(3) Synopsis of Emai alternations

At V_1+V_2 juncture:

a. If V_1 and V_2 are both contained in lexical morphemes and V_1 is a high vowel [i] or [u], then V_1 changes into the homorganic glide [j] or [w]:

/k**u** amɛ/	[k**w**amɛ]	'throw$_{\text{Lex}}$ water$_{\text{Lex}}$'
/f**i** ɔpia/	[f**j**ɔpia]	'throw$_{\text{Lex}}$ cutlass$_{\text{Lex}}$'

Otherwise:

b. If one of the morphemes is lexical and the other is functional, delete the vowel in the functional morpheme:

/ɔl**i** ebe/	[ɔlebe]	‘the$_{Func}$ book$_{Lex}$’
/ukpode **ɔ**na/	[ukpodena]	‘road$_{Lex}$ this$_{Func}$’

c. If both morphemes are lexical or both are functional, delete V_1:

/k**ɔ** ema/	[kema]	‘plant$_{Lex}$ yam$_{Lex}$’
/f**a** edi/	[fedi]	‘pluck$_{Lex}$ palm-nut$_{Lex}$’
/oa is**i** ɔi/	[oasɔi]	‘house$_{Lex}$ of$_{Func}$ his$_{Func}$’

The faithful candidates derived from these inputs violate ONSET: *[ku.a.mɛ], etc. The main analytic challenge is determining how ONSET is satisfied, and that is primarily a matter of determining the correct ranking of certain faithfulness constraints. One of them might be called IDENT(syllabic); it is violated when a vowel is replaced by a glide. The others are versions of the anti-deletion constraint MAX. In Emai, as in various other languages, the roots of major lexical category items (nouns, verbs, adjectives) are treated more faithfully than function words or affixes. This evidence shows that CON must contain a constraint MAX$_{Lex}$ that is violated only by deletion of segments from noun, verb, or adjective roots (McCarthy and Prince, 1995). MAX$_{Lex}$ is distinct and separately rankable from the general constraint MAX, which is violated by deletion of any segment, regardless of the lexical status of the morpheme that contains it. Similarly, many languages show greater faithfulness to segments in initial syllables, motivating the positional faithfulness constraint MAX$_{Init}$ (Beckman, 1997, 1999; Casali, 1996). It too is distinct and separately rankable from other MAX constraints.

With these typologically justified constraints in hand, we are now in a position to establish the ranking responsible for the alternations in (3). One observation is that a high vowel becomes a glide at the end of a lexical morpheme. Tableau (4) illustrates the conflict between IDENT(syllabic), which forbids the vowel→glide mapping, and MAX$_{Lex}$, which forbids deletion of the same vowel. Since deletion is disfavored, MAX$_{Lex}$ must dominate IDENT(syllabic):

(4) MAX$_{Lex}$ >> IDENT(syllabic)

/ku$_{Lex}$ amɛ$_{Lex}$/	MAX$_{Lex}$	IDENT
a. → kwa.mɛ		1
b. ka.mɛ	W$_1$	L

Given just the ranking in (4), we might expect to see other situations where glide formation is preferred to deletion, such as the following:

(5) e]$_{Lex}$ [$_{Lex}$a → e̯a *or* e]$_{Lex}$ [$_{Lex}$a → ja
a]$_{Lex}$ [$_{Lex}$i → aj

None of these alternations occur. The reason is that the outputs *[e̯a] and *[aj] would violate markedness constraints that are undominated and hence unviolated in Emai, while the mapping /ea/ → [ja] would violate an undominated faithfulness constraint, IDENT(height).

High vowels do not become glides when they occur at the end of functional morphemes; they delete instead. So, as long as the contents of lexical morphemes are not threatened, deletion is preferable to a vowel→glide mapping. From this fact, we can deduce that IDENT(syllabic) dominates the unrestricted version of the MAX constraint:

(6) Ident(syllabic) >> Max

	/ɔli$_{Func}$ ebe$_{Lex}$/	Ident	Max
a. →	ɔ.le.be		$_1$
b.	ɔ.lje.be	W$_1$	L

The winning candidate in (6) has deleted a vowel from a functional morpheme. This is a violation of general Max but not high-ranking Max$_{Lex}$. The ranking so far, then, is [Max$_{Lex}$ >> Ident(syllabic) >> Max].

When glide formation is not an option, one of the vowels must delete. Because of Max$_{Lex}$, the encounter between a functional morpheme and a lexical morpheme, in either order, is always resolved in favor of preserving the vowel in the lexical morpheme, as the examples in (3)b demonstrate. When Max$_{Lex}$ is not decisive because both morphemes are lexical or neither is, the data in (3)c show that Max$_{Init}$ favors preservation of morpheme-initial vowels:

(7) Max$_{Init}$ as tie-breaker

	/kɔ$_{Lex}$ ema$_{Lex}$/	Max$_{Lex}$	Max$_{Init}$
a. →	kema	$_1$	
b.	kɔma	$_1$	W$_1$

In (7), the two candidates tie in violating Max$_{Lex}$, but Max$_{Init}$ favors the one where a word-final vowel has been deleted and a word-initial vowel has been preserved.

Tableau (7) does not supply any argument for ranking Max$_{Lex}$ relative to Max$_{Init}$; these two constraints do not conflict over this pair of candidates because Max$_{Lex}$ agrees in its assessment of them. Max$_{Lex}$ and Max$_{Init}$ are rankable on the basis of other data, however. To get a conflict and therefore a ranking argument, we need an example where the choice is between deleting a Lex vowel that is noninitial and deleting a Func vowel that is initial. Alternations like /ukpode$_{Lex}$ ɔna$_{Func}$/ → [ukpodena] are just what is required. Since the Func-initial vowel is deleted to preserve the Lex-final vowel, Max$_{Lex}$ must dominate Max$_{Init}$:

(8) Max$_{Lex}$ >> Max$_{Init}$

	/ukpode$_{Lex}$ ɔna$_{Func}$/	Max$_{Lex}$	Max$_{Init}$
a. →	u.kpo.de.na		$_1$
b.	u.kpo.dɔ.na	W$_1$	L

The diagram in (9) illustrates the rankings that have been determined so far. In such a diagram, if there is a strictly downward path from A to B, then A dominates B by direct argument or by transitivity of the domination relation.

(9)

- Max$_{Lex}$
  - Max$_{Init}$
  - Ident(syllabic)
    - Max

Diagram (9) shows that the known rankings in Emai are not a total ordering of the constraints under discussion. In theory, every OT grammar is some total ordering of Con, but in actual analytic practice it is often impossible to fix all of the details of ranking, and sometimes a properly partial ordering like (9) is the best that we can do. Sometimes, the ranking of a pair of constraints will be indeterminate as a matter of principle; this happens if two constraints never conflict and if there is no chain of ranking arguments to rank them by transitivity. The Emai situation is a bit different, however. The ranking of Max$_{\text{Init}}$ and Ident(syllabic), which is not specified in (9), could in principle be established with additional data. These two constraints will conflict with inputs like hypothetical /taki$_{\text{Lex}}$ ana$_{\text{Func}}$/. As tableau (10) shows, this input presents the choice between changing the Lex-final [i] into a glide or deleting the Func-initial [a]. Schaefer (1987) does not provide a transcription for any sequences like this, so we have no way of knowing what the actual winner is. In a situation like this, a violation tableau is the appropriate tool, since it allows us to see the difference in possible winners depending on the ranking of these two constraints:

(10) Max$_{\text{Init}}$ >> Ident(syllabic) or the opposite?

/taki$_{\text{Lex}}$ ana$_{\text{Func}}$/	Max$_{\text{Lex}}$	Max$_{\text{Init}}$	Ident	Max
a. →? ta.kja.na			*	
b. →? ta.ki.na		*		*
c. ta.ka.na	*!			*

One important detail remains: the role of Onset in the analysis. Given the ranking of faithfulness constraints in (9), it makes sense to begin by asking whether Onset dominates the one that is top-ranked, Max$_{\text{Lex}}$, since if Onset dominates the top-ranked constraint it must dominate all of the rest by transitivity. Examples like /kɔ$_{\text{Lex}}$ ema$_{\text{Lex}}$/ → [kema] prove that Onset can compel deletion of vowels from lexical morphemes, so it must indeed dominate Max$_{\text{Lex}}$:[3]

(11) Onset >> Max$_{\text{Lex}}$

/kɔ$_{\text{Lex}}$ ema$_{\text{Lex}}$/	Onset	Max$_{\text{Lex}}$
a. → ke.ma		$_1$
b. kɔ.e.ma	W$_1$	L

As was just noted, this ranking argument entails that Onset also dominates all of the constraints ranked below Max$_{\text{Lex}}$. This consequence of transitivity can be confirmed by direct ranking arguments. Examples like /ukpode$_{\text{Lex}}$ ɔna$_{\text{Func}}$/ → [ukpodena] show that Onset dominates Max$_{\text{Init}}$, while /ku amɛ/ → [kwamɛ] shows that it dominates Ident(syllabic).

[3] Examples like /fi ɔpia/ → [fjɔpia] show that Emai tolerates vowel sequences word-internally. Although Schaefer (1987) does not say how these sequences are syllabified, presumably at least some are heterosyllabic: [fjɔ.pi.a]. Onsetless syllables are therefore tolerated in word-medial position, though they are eliminated word-intially. This is an indication that the high-ranking markedness constraint in Emai is specific to word-initial syllables. Flack (2006) has identified a number of languages that require onsets word-initially but not medially, and this leads her to distinguish between Onset$_{\text{Word}}$ and Onset$_{\text{Syllable}}$ constraints. Emai's tolerance for onsetless syllables phrase-initially (e.g., [ɔlebe]) has a similar etiology.

In the parlance of 1970's phonological theory, Emai would be said to have a **conspiracy** (a term originally due to Haj Ross). In a conspiracy, several distinct rules act in concert to achieve the same output result (Kisseberth, 1970). Emai would require at least three rules — glide formation, deletion of the first vowel, and deletion of the second vowel — all in service of eliminating onsetless syllables. A conspiracy is really just a description of something that rule-based phonology is unable to explain. In OT, on the other hand, there are no rules and hence no conspiracy. The output constraint ONSET favors candidates without onsetless syllables, and the ranking of the various faithfulness constraints determines which unfaithful candidates are the winners. The output constraint is central to the analysis and not just a post hoc rationalization of why this particular language should have these three particular rules.

Grimshaw's (1997) account of *do*-support in English illustrates a very different kind of analysis in OT. The goal is to explain the economy of unstressed *dŏ*: why does it appear only when it is needed? Unstressed *dŏ* is required in inversion and negation constructions but forbidden in simple declaratives:

(12) a. Dĭd Robin leave?
b. When dĭd Robin leave?
c. Robin dĭdn't leave.
d. *Robin dĭd leave.

Dŏ's only-when-needed distribution means that there must be a markedness constraint that militates against it, to force its absence from surface structure except when some higher ranking constraint compels its presence. For Grimshaw, the constraint with anti-*dŏ* effect is FULL INTERPRETATION (FULL-INT), which is violated by any lexical item in surface structure that does not contribute to the interpretation of that structure.

FULL-INT is sometimes in conflict with the constraint OBLIGATORY HEADS (OB-HD), which is violated by any projection that lacks a head. When a construction lacks a head that contributes to interpretation, the choice is between supplying a head that violates FULL-INT or tolerating the breach of OB-HD. In English, *do*-support is the result of a constraint hierarchy in which OB-HD ranks higher:

(13) OB-HD >> FULL-INT

	OB-HD	FULL-INT
a. → [$_{CP}$ When dĭd$_i$ [$_{IP}$ Robin e$_i$ [$_{VP}$ leave t]]]		1
b. [$_{CP}$ When e [$_{IP}$ Robin e [$_{VP}$ leave t]]]	W$_2$	L
c. [$_{CP}$ When e [$_{IP}$ Robin dĭd [$_{VP}$ leave t]]]	W$_1$	1

Although it is ranked below OB-HD and does not affect the outcome in (13), FULL-INT is not inactive. There are situations, such as simple declaratives, where every projection has a head without further ado, so to speak. In that case, FULL-INT emerges to ban *dŏ* from the output:

(14) Economy of *dŏ*

	OB-HD	FULL-INT
a. → [$_{VP}$ Robin left]		
b. [$_{IP}$ Robin dĭd [$_{VP}$ leave]		W$_1$

For the same reason, *dŏ* is impossible in combination with another auxiliary: **When will Robin dŏ leave?*

Exactly parallel situations are found in phonology (Gouskova, 2003): in Lillooet, for instance, the vowel [ə] appears only when it is needed for markedness reasons, in words that would otherwise be vowelless and in clusters that would otherwise violate sonority-sequencing requirements. Grimshaw and Gouskova show, for syntax and phonology respectively, how such economy effects follow from intrinsic properties of OT rather than stipulated economy principles. With English *do*-support, and likewise with Lillooet [ə], the source of the economy effect is minimal violation of constraints like FULL-INT. Minimal constraint violation is a *sine qua non* of OT; it is inherent to OT's core component, EVAL. (See also section 6.2.)

6. Some questions and answers about OT

Many of the most commonly asked questions about OT touch on fundamental aspects of the theory. These questions therefore serve as an excellent framework for further exploration of OT's concepts and consequences. (For other lists of frequently asked questions about OT, see McCarthy (2002:239-245), Smolensky, Legendre, and Tesar (2006:523-532), and Prince and Smolensky (2004:232).)

6.1. Language universals

Since all constraints are violable, how does OT account for universals of human language? In general, what sorts of predictions does OT make about possible and impossible languages?

In answering this question, it is helpful to begin with a distinction due to Prince (1997b). Some predictions follow from just OT's basic properties; other predictions follow from OT's basic properties under some specific assumptions about the contents of CON. Universals of the first type can be called "formal", and those of the latter type can be referred to as "substantive".

The simplest example of a formal universal in OT is **harmonic improvement**. Since CON contains only markedness and faithfulness constraints, a necessary condition for an unfaithful candidate to win is that it be less marked than the faithful candidate — in other words, an unfaithful winner must improve harmonically over a faithful loser. This property follows from the basic structure of OT. If the input is /bi/, then every faithfulness constraint favors faithful [bi] as the output. For unfaithful [be] to win, then, some higher-ranking markedness constraint M must favor [be] over [bi]. OT's basic assumptions entail that unfaithfulness is possible only when it improves markedness, where improvement is measured relative to the universal markedness constraints as they are ranked in the language in question.

Moreton (2003) develops a formal proof of this result and explores its empirical consequences. One is that no OT grammar can analyze a language with a system of circular mappings like /bi/ → [be] and /be/ → [bi]. The reason is that no single constraint ranking can simultaneously assert that [be] is less marked than [bi] (to get the /bi/ → [be] mapping) and [bi] is less marked than [be] (to get the /be/ → [bi] mapping).[4] Another consequence is that no OT grammar can analyze a system of unbounded growth, like /bi/ → [biʔi], /biʔi/ → [biʔiʔi], … The reason is that, because the number of markedness constraints in CON is finite, a point must be reached where further addition of syllables is not harmonically improving.

Substantive universals are mainly concerned with language typology. Everything in OT is invariant across languages — GEN, EVAL, CON, and the inputs — except for the constraint ranking. Therefore, the various ways of ranking CON define the permitted range of between-language variation. This is **factorial typology**: the claim that every permutation of CON is a possible grammar of a human language, and every actual human language has a grammar that is a permutation of CON. Claims about typology are substantive universals because they depend in an obvious way on what constraints CON does and does not contain.

Consider a simple substantive universal like the fact that no language satisfies ONSET by epenthesizing a consonant cluster, mapping e.g. /apati/ to [trapati]. If [trapati] is in /apati/'s candidate set, as is standardly assumed (McCarthy and Prince, 1995, 1999), then the explanation for this universal requires that [trapati] not be the optimal member of /apati/'s candidate set under any permutation of CON. This mapping is correctly predicted to be universally impossible if, say, CON does not include a markedness constraint that favors initial consonant clusters over single initial consonants.

The most interesting substantive universals are usually more subtle than this one. The OT literature is replete with examples of theorizing about language typology that share the logic though not the obviousness of this example. Because substantive universals depend on specific assumptions about CON, disagreement among analysts is expected. In fact, typology is an essential check on all hypothesized changes to the make-up of CON. No newly-proposed constraint is secure until its consequences under ranking permutation have been checked for typological plausibility (see section 4).

Suggestions for further reading. For further discussion of formal universals in OT, see Prince (1997b) and McCarthy (2002:109-111). Almost any of the suggested readings at the end of section 3 is a good place to learn more about factorial typology and substantive universals. The use of factorial typology to draw or confirm inferences about CON is (or at least should be) ubiquitous in the OT literature.

6.2. Constraints versus parameters

How is constraint ranking different from constraint parameterization? Isn't a low-ranking constraint effectively turned off, just like a parameter?

This issue was already touched on at the end of section 2, but it is important

[4] The Southern Min or Taiwanese tone circle has been cited as a potential counterexample to this claim. There is, however, a body of work arguing "that Taiwanese tone sandhi is better viewed as a set of essentially arbitrary alternations between stored allomorphs" (Myers and Tsay, 2002:4). See Myers and Tsay for extensive references.

enough to bear repeating. Crucial domination of a constraint is no guarantee of inactivity. There are some very special circumstances where inactivity can be guaranteed (Prince, 1997a:3; Prince and Smolensky, 2004:97-99, 130-132, 264-265), but otherwise a low-ranking constraint is always *potentially* active. A low-ranking constraint will be active *in fact* when it decides among several candidates that tie on all higher-ranking constraints. This is decidedly unlike the behavior of parameterized constraints: when such a constraint is turned off, it is never active under any circumstances.

Constraints that are low-ranking but active are particularly important in OT's explanation for economy effects. Faithfulness constraints ensure a kind of economy of derivation. Even when a faithfulness constraint is crucially dominated, such as DEP in Yawelmani, violation is always minimal, and so gratuitous epenthesis is ruled out: /ʔilk-hin/ → [ʔil**i**khin], *[ʔil**i**k**i**hin**i**]. Certain markedness constraints effect a kind of economy of representation in both syntax (Grimshaw, 2002) and phonology (Gouskova, 2003) (see section 5).

There are other, more subtle differences between ranking and parametrization. To cite a phonological example that also has syntactic analogues, consider structures of the form $[\ldots(\ldots)_{\text{foot}}\ldots]_{\text{word}}$. There are constraints that require every foot to be aligned at the left or right edge of the word, ALIGN-L(foot, word) and ALIGN-R(foot, word). ALIGN-L(foot, word) favors [(ˈpata)kama] over [pa(ˈtaka)ma] and [pata(ˈkama)]. ALIGN-R(foot, word) favors [pata(ˈkama)] over [(ˈpata)kama] and [pa(ˈtaka)ma]. It might seem, then, that [(ˈpata)kama] or [pata(ˈkama)] are the only possible winners, depending on whether ALIGN-L(foot, word) or ALIGN-R(foot, word) is ranked higher. But this quasi-parametric conception of ranking overlooks candidates like [(ˈpata)], which manage to satisfy both of the alignment constraints at the expense of eliminating some input material. For a real-life example, reduplication in Diyari, see McCarthy and Prince (1994).

Cases like this are particularly relevant to the comparison of OT with parametric theories, as Samek-Lodovici (1996:216) argues. In a parametric theory of stress like Hayes (1995), the direction of foot assignment is a parameter with two values, left-to-right and right-to-left. Nothing further follows from this. In OT, however, the constraints ALIGN-L(foot, word) and ALIGN-R(foot, word) together entail a further possibility: satisfaction of both constraints in words consisting of exactly one foot. Here, as in many other cases, OT's nonparametric approach to between-language variation has economy of structure as an unavoidable — and welcome — side effect.

Suggestions for further reading. The difference between ranking and parameterization is a particular focus of Grimshaw (2002), McCarthy (2002:11-12, 109-110, 127-108 et passim), McCarthy and Prince (1994), Prince and Smolensky (2004:164-167), and Samek-Lodovici (1996), among others.

6.3. The lexicon

What is the role of the lexicon in OT?

To a great extent in syntax, and to a lesser extent in phonology, the lexicon has been seen as the proper repository of all that is language-particular. OT turns that assumption on its head.

One of OT's basic premises is called **richness of the base** (Prince and

Smolensky, 2004:205, 225). The “base” is the set of inputs to the grammar (an allusion to the base component of Chomsky (1957)). It is “rich” because, by hypothesis, it is not subject to any language-particular restrictions. The import of richness of the base in phonology is clear: there can be no morpheme structure constraints, stipulated underspecification, or similar devices that preemptively remove forms from the set of possible inputs to the grammar. In syntax, richness of the base means that systematic differences between languages cannot be attributed to systematic differences in the contents of their lexicons. Because of richness of the base, all aspects of well-formedness are under the control of EVAL and the constraint hierarchy, and all systematic differences between languages must be obtained from differences in constraint ranking. Richness of the base is also central to OT’s resolution of the so-called duplication problem in phonology (McCarthy, 2002:71-76).

Richness of the base has been a source of some confusion in criticisms of OT. It does not mean, absurdly, that all languages have the same vocabulary, nor does it mean, equally absurdly, that learners posit something like /ʕʛkætǂ/ as the underlying form for [kæt] *cat*. Rather, it simply means that the lexicon as a system is not subject to any language-particular requirements. Furthermore, it means that explanations for linguistic phenomena cannot involve carefully contrived limits on the inputs to the grammar. An example from phonology: between-language differences in the behavior of laryngeal features must derive from differences in ranking rather than differences in lexical specification of [voice] and [spread glottis] (Beckman and Ringen, 2004). An example from syntax: between-language differences in fronting of *wh* words must derive from differnces in ranking rather than differences in whether *wh* words are lexically specified with a strong or weak feature (Smolensky, Legendre and Tesar, 2006:529).

Suggestions for further reading. Since richness of the base is ubiquitous in the OT phonology literature, I focus here on syntax. Richness of the base in syntax receives special attention from Aissen (1999), Bakovic and Keer (2001), Bresnan (2001a; 2001b), Grimshaw (1997; 2001), Grimshaw and Samek-Lodovici (1995; 1998), Legendre, Smolensky, and Wilson (1998), and Samek-Lodovici (1996:219).

6.4. Ungrammaticality

In a theory where all constraints are violable, how can any linguistic representation be absolutely ill-formed? For example, how is it possible for English phonology to rule out *[bnɪk] as phonotactically impossible, and how is it possible for English syntax to rule out **Who did he say that left?* as ungrammatical?

Although other theories use inviolable constraints and crashing derivations to account for ungrammaticality, they are not indispensable. In OT, ungrammaticality is a consequence of inferiority to other candidates rather than an apparatus of inviolable constraints. The linguistic representation *[A] is ungrammatical in some language if and only if [A] is not the optimal candidate for any input, given that language’s constraint hierarchy. That is, for any input /X/ that has [A] in its candidate set, there is some output candidate that is more harmonic than [A] according to the grammar of the language in question.

An input that merits particular attention is /A/ itself, such as /bnɪk/. Since every faithfulness constraint favors the mapping /bnɪk/ → [bnɪk], some higher-ranking

markedness constraint is necessary to rule it out in English. This constraint is presumably a prohibition on onset clusters of two stops, and if it dominates DEP, then [bənɪk] will be more harmonic than *[bnɪk]. ([bənɪk] is not a real word of English, but it is phonotactically possible, and that is the point of the example.) This is not quite enough to secure the absolute ill-formedness of *[bnɪk], however; that requires showing that *no* input will map most harmonically to *[bnɪk]. That demonstration ultimately requires more careful examination of the full space of possible inputs.
Suggestions for further reading. Absolute ill-formedness is the topic of a forthcoming anthology, Rice (2007). Earlier work that focuses specifically on this topic includes Legendre, Smolensky, and Wilson (1998:257), McCarthy (2002:76, 176, 194-199, 239), Orgun and Sprouse (1999), Pesetsky (1997), Prince and Smolensky (2004:57ff.), Raffelsiefen (2004), Rice (2003; 2005), and Smolensky, Legendre, and Tesar (2006:528-530).

6.5. Infinity

If the number of candidates is infinite or even very large, then how do speakers find the optimal candidate in a reasonable length of time? For instance, the phonological GEN described in section 3 can iterate epenthesis forever (GEN(/pa/) ⊃ {pa, paə, paəə, paəəə, …}), so the candidate set is unbounded in size.

This question is based on two tacit assumptions. One of them is that some other theory of language is more plausible psychologically than OT. Presumably, we are to imagine a speaker mentally applying a sequence of rules before producing an utterance and to compare this with the image of a speaker hopelessly trying to evaluate an infinite set of candidate utterances. The problem is that the image of the speaker applying a sequence of rules has just as little claim to psychological plausibility. The failure of the Derivational Theory of Complexity shows this, at least in syntax (Fodor, Bever and Garrett, 1974); the same seems to be true in phonology as well (Goldsmith, 1993).

The other assumption underlying this question is an implicit denial of the competence/performance distinction. In other words, the question presupposes that a generative grammar is a model of a speaker's actual processing behavior as well as a speaker's linguistic knowledge. Yet this is not the stated goal of generative grammar. For example, Chomsky (1968:117) writes that "...although we may describe the grammar *G* as a system of processes and rules that apply in a certain order to relate sound and meaning, we are not entitled to take this as a description of the successive acts of a performance model … — in fact, it would be quite absurd to do so. … If these simple distinctions are overlooked, great confusion must result."

Issues of efficient generation and parsing are of course important, but they do not bear directly on the theory of competence. They are properly addressed using the ideas and methods of fields like computational linguistics. See the suggested readings for some examples.

Suggestions for further reading. There has been a great deal of research and progress on computational modeling of OT and determining its computational complexity. Tesar (1995) is probably the earliest work on these topics, and there is much more (Becker, 2006; Eisner, 1997; Ellison, 1994; Fanselow et al., 1999; Frank and Satta, 1998; Gerdemann and van Noord, 2000; Gibson and Broihier, 1998;

Hammond, 1997; Karttunen, 1998; Riggle, 2004; Wareham, 1998; etc.).

6.6. Learning

Since the number of permutations of *n* constraints is *n!*, how is it possible for learners to find the right ranking for their language out of the gigantic space of possible rankings?

The ranking is actually the easiest part of language learning in OT. Given the right kind of data, the constraint demotion learning algorithm rapidly and efficiently finds a ranking that will correctly reproduce the data (Tesar and Smolensky, 1998, 2000). The basic idea is this: every constraint that favors a loser over the intended winner must be dominated by some constraint that favors the winner over that loser. This requirement follows from the nature of EVAL, and it is the basis of ranking arguments like those in section 4. Learning proceeds by demoting every loser-favoring constraint below some winner-favoring constraint, until all loser-favoring constraints are crucially dominated. The losers that drive this learning algorithm can be obtained from the grammar itself: they are outputs produced by the incorrectly ranked grammar before learning is complete.

The data needed for the constraint demotion learning algorithm is more than just the phonetic signal that the learner hears; it must also contain information about hidden structure. In both syntax and phonology, learners may have multiple options for parsing expressions of the ambient language, and getting the parse right is crucial to getting the ranking right. In phonology, the ranking also depends on the accurate recovery of underlying representations from paradigmatic alternations. There has been significant progress on the hidden structure problem in OT; the main idea is that learners use their nascent grammar to produce hypotheses about hidden structure, and further learning reveals whether these hypotheses are correct (Tesar, 1998, 1999; Tesar and Prince, 2004).

A particularly welcome consequence of OT is its success in making connections among phonological theory, learnability, and empirical research on language acquisition. With the exception of Natural Phonology (Donegan and Stampe, 1979; Stampe, 1973), pre-OT generative phonology was confounded by the facts of language acquisition: children’s reduced pronunciations required that child phonology have many rules for which there is no evidence in the adult language. In OT, children’s reduction processes are a result of satisfying high-ranking universal markedness constraints. The very same markedness constraints that, through ranking, characterize differences between languages are also responsible for differences between children and adults within a single language.

Suggestions for further reading. There are two anthologies that are relevant to this topic: Kager, Pater, and Zonneveld (2004) and Dinnesen and Gierut (2007). The former includes work on learnability as well as acquisition. The latter deals with disordered as well as normal acquisition of phonology. McCarthy (2002:232) has a nearly exhaustive list, compiled by Joe Pater, of the OT literature on acquisition before 2002.

6.7. Derivations

In OT, inputs are mapped to outputs without any intermediate steps. Aren't there linguistic phenomena, in both phonology and syntax, that require derivations with intermediate steps (Chomsky, 1995:223-225, 380 and many others)?

It is quite correct that the mapping from the input to the output of an OT grammar does not involve any intermediate steps. For example, the mapping from underlying /ktub/ to surface [ʔuktub] 'write!' in Arabic involves a two-step derivation in rule-based phonology (15), with vowel epenthesis creating the context that necessitates [ʔ] epenthesis. In OT, on the other hand, the grammar compares candidates that may show the simultaneous effects of two or more epenthesis operations, and [ʔuktub] is among them (16).

(15) Arabic /ktub/ → [ʔuktub] with rules

Underlying	/ktub/
Vowel epenthesis	uktub
[ʔ] epenthesis	ʔuktub
Surface	[ʔuktub]

(16) Arabic /ktub/ → [ʔuktub] in OT

/ktub/	Onset	*#CC	Dep
a. → ʔuktub			2
b. ktub		W$_1$	L
c. uktub	W$_1$		L$_1$

Why does OT have flat derivations? There are empirical arguments (many of which are summarized in McCarthy, 2002:138-163), but the main reason is theoretical parsimony. Nonflat derivations are often a way of establishing priority relationships among linguistic requirements, and OT already has a way of setting priorities, ranking. For example, in the Wakashan language Nootka, there is a process that labializes certain consonants after a round vowel, and there is another process that delabializes them at the end of a syllable (Campbell, 1973). When a consonant meets both of these conditions, what does it do? In derivational approaches, the rule that applies last gets to decide, as shown in (17). In OT, priority is determined by constraint ranking (see (18)).

(17) Nootka /m^{ʔ}o:q/ → [m^{ʔ}o:q] with rules

Underlying	/m^{ʔ}o:q/
q→q^w /o__	m^{ʔ}o:q^w
q^w→q /__.	m^{ʔ}o:q
Surface	[m^{ʔ}o:q]

(18) Nootka /m^{ʔ}o:q/ → [m^{ʔ}o:q] in OT

/m^{ʔ}o:q/	*q^w.	*oq	Ident(round)
a. → m^{ʔ}o:q		1	
b. m^{ʔ}o:q^w	W$_1$	L	W$_1$

Nothing intrinsic to OT excludes the possibility of a different kind of derivation, one in which several different OT grammars are linked serially, with the output of one becoming the input to the next. This has obvious relevance in any situation where we are dealing with separate modules of the grammar, such as the syntax and the phonology. It has also been recruited in phonology to account for phenomena such as within-language differences between word and sentence phonology (Bermúdez-Otero, 1999; Cohn and McCarthy, 1994/1998; Hale, Kissock and Reiss, 1998; Ito and Mester, 2001, 2003a; 2003b; Kenstowicz, 1995; Kiparsky, 2003; McCarthy, 2000; McCarthy and Prince, 1993:Appendix; Orgun, 1996; Potter, 1994; Rubach, 2000; and others).

Suggestions for further reading. McCarthy (2007b) includes an overview and bibliography of most work related to derivations in OT phonology. Many of the contributions to Hermans and van Oostendorp (1999) and Roca (1997) are also relevant.

6.8. OT Syntax

In phonology, it's reasonably clear what GEN and the faithfulness constraints should look like. But what about syntax? How do we go about establishing the nature of GEN and faithfulness in domains other than phonology?

I will not presume to answer this question except in the most general way: what do OT's basic principles tell us about the necessary properties of GEN and the faithfulness part of CON in *any* empirical domain? One important idea is that the input and GEN together define the space of candidates that compete to be the surface realization of that input. This places lower and upper bounds on GEN's freedom of analysis, its capacity to create output candidates that are different from the input (see section 3). If a hypothesized GEN is not free enough, then some inputs might have only observationally ungrammatical expressions among their output candidates. No adequate theory of GEN should ever do this, since every candidate set must contain *some* winner (section 6.4). If a hypothesized GEN is too free, on the other hand, then some observationally grammatical realization of an input might lose to another, more harmonic candidate.[5] Clearly, assumptions about the nature of the input as well as assumptions about the nature of GEN will affect how these criteria work out in practice.

Another important idea is that any property of the input that GEN can alter — that is, any property that can vary among the output candidates for a given input — must be protected by some faithfulness constraint if it is to affect the output of the grammar. The reason: apart from possible restrictions on GEN's freedom of analysis, faithfulness constraints are the only mechanism in OT for transmitting information from the input to the output.

From these statements, both of which derive from basic assumptions of the theory, it follows that a hypothesis about any one of the input, GEN, the candidate set, and the faithfulness constraints will go a long way toward determining all of the rest. Legendre, Smolensky, and Wilson (1998) show how this can be done in a real-life example, *wh* movement.

Suggestions for further reading. There are two recent anthologies of papers on OT syntax, Legendre, Grimshaw, and Vikner (2001) and Sells et al. (2001). Barbosa

[5] This criterion must be used with care, because of the possibility of variable constraint ranking (Anttila, 1997; Boersma and Hayes, 2001; and others).

et al. (1998) is an earlier anthology that contains papers on both OT and Minimalism. (Blaho, Bye, and Krämer (2007) is a collection of papers on GEN and freedom of analysis from a phonological perspective.)

7. Where to go next

Readers whose interest in OT has been piqued by this brief overview should plan on reading Prince and Smolensky (2004), especially parts I and III if their interests are not primarily phonological. This exercise is perhaps best preceded or accompanied by reading a more didactic treatment, such as Kager (1999), McCarthy (2002), or one of the other relatively accessible works cited at the end of section 3.

The next step after that depends on the individual reader's interests. If they tend toward phonology, then the papers collected in McCarthy (2003b) are probably the best place to start. Two other useful anthologies, Lombardi (2001) and Féry and van de Vijver (2003), are focused on segmental and syllabic phonology, respectively. Readers of a syntactic bent could not do better than to consult the anthologies cited at the end of section 6.8. In addition, there are now several anthologies on OT semantics and pragmatics (Blutner and Zeevat, 2004; Blutner, de Hoop and Hendricks, 2005; de Hoop and de Swart, 1999), and one on historical linguistics (Holt, 2003).

Finally, readers should be aware of two remarkable compendia of research on OT. One is the Rutgers Optimality Archive (http://roa.rutgers.edu). ROA, which was created by Alan Prince in 1993, is an electronic repository of "work in, on, or about OT". By the time this article is published, ROA will probably have its 1000th entry. The other notable compendium is the two volume set *The Harmonic Mind*, edited by Paul Smolensky and Géraldine Legendre (2006). In almost 1200 pages, it collects the work of the editors and their collaborators on topics in language, human cognition, the mind, and the brain, much of it centered on Optimality Theory.

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