OPTIMALITY THEORY: MOTIVATIONS AND PERSPECTIVES

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1 THE BASICS OF OT

The classic version of Optimality Theory, first described in detail by Prince & Smolensky (1993), is a phonological framework that privileges the simultaneous satisfaction of multiple, violable constraints by phonological representations over the gradual construction of correct representations from given inputs. At its core, an OT grammar implements a search procedure that finds the surface form that is most compatible with the relevant underlying representation, given the specific properties of the particular language. In OT, these language-specific properties are encoded as a series of rankable, violable *constraints*.

1.1 Constraints: CON

In formal terms, a *constraint* is most commonly understood as a function that maps from an ⟨input, output⟩ pair to an integer corresponding to the number of violations incurred by that pair. In practice, constraints are most commonly formulated as imperative statements of the form "Assign a violation mark [i.e., increment the return value of the function by 1] for each instance in ⟨input, output⟩ of a structure characterized by some property X". Thus, a constraints against postvocalic stops,

which in OT parlance could be written as *V[−son −cont], would penalize any substrings of an output candidate that contain a vowel, followed by a stop. A form like [tata], therefore, incurs one violation of the constraint; a form like [tapata] incurs two; and forms like [tat] and [saθa] incur zero: in the former case since no stop in the form is postvocalic, and in the latter case since there are no stops in the form at all.[1]

In standard OT, constraints come in two varieties: *markedness* and *faithfulness* constraints. As discussed by Moreton (2004), markedness constraints are distinguished by the fact the number of violations they assign does not depend on the properties of the input in the ⟨input, output⟩ pair. The constraint *V[−son −cont] is an example: it only refers to properties of the output, and always assigns the same number of violation marks (zero) to a candidate with output [taθa], irrespective of whether the input is [tata] or [taθa]. Markedness constraints, therefore, are statements about the preferred shape of surface representations.

Faithfulness constraints, on the other hand, demand that certain aspects of the input should be preserved in the output. Formally, a faithfulness constraint never assigns a violation mark to the *fully faithful candidate*: a constraint C is a faithfulness constraint if there are no ⟨input, output⟩ pairs such that the input is identical to that output and C assigns a violation mark to the pair. A common type of faithfulness constraint, for example, demands that input and output be identical in the value of some distinctive feature. A constraint like IDENT-IO([±continuant]) will therefore assign one violation mark to an input-output pair ⟨/ta**t**a/, [ta**θ**a]⟩ (since the highlighted segment changes its value of [±continuant]) but none to ⟨/tata/, [tata]⟩.

1.2 The candidates: GEN

The set of potential output forms, produced by the module GEN, is, in classic OT, assumed to be both infinite and independent of the properties of the input. The only restriction on GEN admitted in classic theory is the extent of "the basic structural resources of the representational theory" (Prince & Smolensky 1993: 6): in other words, GEN makes available, as potentially corresponding to any input, any phonological object that does not violate the tenets of representational theory.

This independence of outputs from inputs severely restricts the analyst's freedom to account for phonological phenomena in ways other than constraint (re)ranking. If some output is ungrammatical in a language (for a particular input), this cannot be — in classic OT — accounted for by assuming that this derives from some input property that restricts the range of potential outputs. The explanatory burden is thus shifted from restrictions on the set of forms to be considered to the evaluation procedure, described in the next section.

1.3 The evaluation procedure: EVAL

The fundamental concept of OT is *constraint ranking*. All the constraints are arranged in a relation of *dominance*, which is transitive: in each pair of constraints either one outranks the other or they are unranked with respect to each other, and if A ≫ B and B ≫ C then necessarily A ≫ C. The concept of ranking comes into play in the EVAL module, which chooses the correct output from the candidate set offered by the universal mechanism GEN.

In a nutshell, EVAL chooses the candidate that has the fewest violations of the highest-ranked constraint. In practice, one constraint is rarely enough to select the "winner", so the procedure is commonly described recursively. For each constraint and a pair of candidates, it is possible to determine if the constraint *favours* one of the candidates: the favoured candidate accrues fewer violations than the disfavoured one. Once the constraints are arranged in ranking order, the candidate set is winnowed by rejecting all candidates that are disfavoured by the highest-ranked constraint, in the sense that there exist other candidates that accrue fewer violations of that constraint. In classic OT, once a candidate is excluded from consideration by some constraint, it can never be a winner (domination is *strict*) — but see Krämer (this volume) for discussion of other alternatives. Those candidates that survive this procedure are passed on to the next constraint in the ranking, and the winnowing is repeated until either the bottom of the ranking is reached or there is only one candidate left.

This interplay of markedness and faithfulness has an important consequence for the scope of the theory. In OT, the concept of a phonological rule — a mechanism that rewrites part of an input string — is largely replaced by that of the unfaithful mapping, whereby the winning candidate is not identical to the input in one respect or another. Unfaithful mappings necessarily violate faithfulness constraints: therefore, they can only be allowed when the relevant faithfulness constraints are outranked by some markedness constraints. This is the basic markedness-over-faithfulnes (M ≫ F) schema. Consider the example of *gorgia toscana*: a process in Tuscan varieties of Italian whereby stops become fricatives in intervocalic positions (Giannelli & Savoia 1978; 1980; Giannelli & Cravens 1996; Kirchner 2000).[2] In isolation, input /kasa/ for 'home' is realized as [ˈkaːsa], whereas in a phrasal context after a vowel the initial

stop becomes a continuant, often [h]: [la ˈha:sa] ‘the home’. Ignoring for now the assignment of prosodic structure (specifically stress assignment and vowel lengthening) and /s/-voicing, the crucial mapping is /k/ → [h]. This mapping violates a faithfulness constraint that demands the preservation of [±cont] values (IDENT[±cont]). In the citation form, this constraint remains unviolated, but in the postvocalic context it cannot prevent the unfaithful mapping. Thus, for instance, IDENT[±cont] outranks the constraint *[−son −cont] that militates against surface stop consonants: in other words, it is more important to avoid changes in continuancy (e.g. spirantization) than to avoid the presence of stops in the output. In OT work, this is formalized as in (1).

(1) Faithfulness over markedness

	/kasa/	IDENT[±cont]	*[−son −cont]
a. ☞	[kasa]		*
b.	[xasa]	*!	

The diagram in (1), referred to in OT parlance as a *tableau*, demonstrates the derivation of [kasa] from /kasa/. Candidate (a.), which eventually wins, is favoured by IDENT over candidate (b.), where the [cont] value of the [k] is changed, acquiring one violation of the faithfulness constraint (marked by the asterisk). Since the fully faithful candidate (a.) is favoured by the IDENT constraint, candidate (b.) is knocked out of contention (as the exclamation mark indicates). Although the favouring relationship is reversed for the constraint [−son −cont], that constraint is ranked too low, i.e. below the IDENT constraint, to force the choice of candidate (b.)

When the input puts the stop in a postvocalic position, the mapping effected is unfaithful. This must be due to a different markedness constraint, militating against postvocalic stops. This constraint outranks the IDENT constraint.

(2) Markedness over faithfulness

		*V[−son −cont]	IDENT[±cont]	*[−son −cont]
/kasa/	a. ☞ [kasa]			*
	b. [xasa]		*!	
/la kasa/	c. [la kasa]	*!		*
	d. ☞ [la hasa]		*	

In the case of the input /kasa/, neither candidate violates the contextually determined markedness constraint, since neither contains the offending sequence of a vowel and a stop (in these case the constraint is sometimes said to be *vacuously satisfied*). The evaluation is passed on to the next constraint — IDENT — with the same results as in (1). As for /la kasa/, the constraint against postvocalic stops knocks out the faithful candidate and an unfaithful mapping ensues.

It is important to note a non-trivial shift in emphasis compared to rule-based phonology. There is no real analogue to a "faithful mapping" in a rule-based theory: if an output happens to be identical to its input, this is an epiphenomenon of the fact that no rule happens to apply to it, and it does not require a special account. In OT, a faithful mapping requires an explanation just as much as an unfaithful one: it becomes a phonological fact. In fact, the faithfulness of mappings plays a important role in

much of the work on learnability (Tesar 2013), which is likely to have been facilitated by the fact that it can be expressed formally within the theory.

However, not all phenomena of interest to the phonologist boil down to unfaithful mappings. A notable class of cases includes structure-building operations such as the construction of prosodic structure. The classic example is syllabification, which is commonly assumed to be driven solely by the interaction of several markedness constraints, such as ONSET (penalizing onsetless syllables) and NOCODA (penalizing codas). Faithfulness to syllable structure does not come into the picture: this is catered for by an assumption that faithfulness constraints to syllabic structure are not part of CON. This assumption is not vacuous: it predicts that there can be no lexical contrasts in syllabic affiliation — even if such a contrast were present in the input, the absence of a faithfulness constraint predicts that any underlying specifications would be overridden by the markedness constraints. This prediction is widely assumed to be correct (e.g. McCarthy 2007a), although see Clements (1986); Vaux (2003); Köhnlein (forthcoming) for potential counterexamples.

The main distinguishing features of the OT framework can be summarized as follows:

- Instead of descriptions of *processes*, OT focuses on descriptions of *desirable outputs*: processes emerge as the result of satisfying these descriptions at the cost of changing inputs to the extent allowed by the particular language;
- Instead of pattern-specific descriptions, violability allows the analyst to formulate the constraints in a more general way: pattern specificity arises from the competing demands of various general constraints;

- The number of "moving parts" in a theory of cross-linguistic variation is reduced: neither the input nor the structure-building mechanism are allowed to be language-specific, with ranking acquiring a crucial role in accounting for variation.

All of these will be treated in more detail in the following sections.

2 SOME ADVANTAGES OF OT

The "creation myth" of Optimality Theory often sees its flowering as the culmination of a dissatisfaction with the input-oriented, process-heavy framework rooted in the SPE model. In this view, rule-based approaches are vitiated by an emphasis on the properties of the input, which trigger the (non-)application of rules, and formal difficulties with expressing generalizations about the output of rules. It is common to cite a number of developments within rule-based phonology as being important precursors to constraint-based frameworks:

- Morpheme-structure constraints (Stanley 1967; Sommerstein 1974; Shibatani 1973), i.e. statements of what input shapes are allowed in a particular language;
- Conspiracies (Kisseberth 1970), i.e. situations where several formally disparate rules converge on outputs with a particular property (for a worked-out OT example, see Pater 1999);
- Autosegmental phonology (Goldsmith 1976 and much subsequent work), with its emphasis on the description of conditions that a representation must fulfil in order to be licit, and its further developments such as feature geometry (Sagey 1986; McCarthy 1988; Clements & Hume 1995);

- Developments in the analysis of templatic morphology (McCarthy 1979) and prosodic phenomena (Marantz 1982), which privileged descriptions of licit outputs over procedural parsing "directions" (or at least included both components)

The apparent inability of rule-based phonology to deal with these issues in a satisfactory manner is commonly seen as paving the way first for hybrid rule-and-constraint frameworks, starting already with Sommerstein (1974) and later in constraints-and-repairs theories (Paradis 1992; Calabrese 2005) and then for constraint-only formalisms, which include not only OT but also various flavours of Declarative Phonology (Scobbie et al. 1996; Scobbie 1997; Coleman 1998) and Government Phonology.

2.1 Factorial typology and harmonic bounding

Several other competitive advantages of OT flow from its computational properties. In classical OT, the universality of CON obviates the need to learn the constraints; the principles of candidate generation also preclude language-specificity in the choice of possible outputs; and adherence to Richness of the Base negates the unavoidably language-specific character of the lexicon. It follows that languages differ *only* in the relative ranking of the constraints, of which there is a finite number. For the analyst, this corollary opens up the tantalizing possibility of doing highly explicit typology. The inputs, potential outputs, and constraints (of which there is a finite number) are all fixed; the EVAL procedure is essentially guaranteed to produce an output for a given ranking; it is consequently feasible (at least in principle) to identify the input-output mappings given by all logically possible permutations of constraint orderings.

This enterprise is known as *factorial typology* (since n constraints can be ranked in $n!$ ways). Consider, for instance, our analysis of *gorgia toscana* above. The unfaithful mapping in Tuscan Italian is enabled by the ranking of a markedness constraint (*V[ptk]) over a faithfulness constraint IDENT-IO([cont]). This ensures that postvocalic stops change their [±continuant] value to satisfy the markedness constraint. In a toy grammar with two constraints, there are only $2! = 2$ permutations: the reverse ranking produces a faithful mapping with the stops intact

(3) No spirantization with reverse ranking

/gato/	IDENT-IO([cont])	*V[ptk]
a. ☞ [gato]		*
b. [gaθo]	*!	

It is thus predicted — correctly if rather trivially — that language with and without postvocalic spirantization should both exist: Standard Italian is an example of the latter.

Now consider the fact that in Tuscan Italian geminate stops resist spirantization: contrast [kaˈɸiθo] ‘understood’ with [ˈskritːo] ‘written’. This is a typologically common phenomenon that has received a variety of explanations (e.g. Schein & Steriade 1986; Kirchner 2000; Honeybone 2005). For the purposes of the argument, we can assume a rather descriptively formulated IDENT-IO_{gem} constraint family, which assigns a violation mark to all surface geminates that undergo featural change, and introduce it into our analysis of Tuscan.

In (3), this constraint is vacuously satisfied by both candidates of interest, since there are no geminates in the input. Consider now an input with a geminate stop:

(4) No spirantization with geminates

/skrit:o/	IDENT-IO$_{gem}$([cont])	*V[ptk]	IDENT-IO([cont])
a. ☞ [skrit:o]		*	
b. [skriθ:o]	*!		*

The grammar in (4) is a superset of that in (2), but it also provides for geminate inalterability. It also includes three constraints rather than two, so technically there are $3! = 6$ potential rankings. However, the number of possible input-output *mappings* is not equal to the number of *rankings*. Consider a grammar of Standard Italian with the three constraints:

(5) No spirantization in any context

			IDENT-IO$_{gem}$([cont])	IDENT-IO([cont])	*V[ptk]
/gato/	a. ☞	[gato]			*
	b.	[gaθo]		*!	
/skrit:o/	a. ☞	[skrit:o]			*
	b.	[skriθ:o]	*!	*	

Note that the ranking in (5) is part of the 6-member factorial typology for the 3 constraints, although there is no actual evidence for the relative ranking of the two versions of IDENT-IO([cont]): the two constraints are never in conflict. In fact, it can easily be verified that *reversing* their ranking has no effect on the outcomes in (5). Similarly, in a grammar where *V[ptk] dominates both of the faithfulness constraints,

the relative ranking of the latter two is unimportant, because the high rank of markedness imposes an unfaithful mapping. In fact, the six logically possible rankings produce only three types of mappings, as summarized in Table 1.[3]

TABLE 1 HERE

In particular, note that when the more general faithfulness constraint dominates markedness, it also ensures a faithful mapping in cases covered by the more specific constraint, so that even if the latter is strictly speaking dominated by markedness, no unfaithful mapping can occur. The explicit prediction that follows from this (toy) factorial typology exercise can be reformulated as an implicational universal: spirantization in geminates implies spirantization in singletons but not vice versa. Another way to look at the predictions is in terms of possible mappings. The *possible* input-output mappings can be visualized in terms of a cline (similar to the traditional lenition trajectories)

- Spirantization everywhere: /| tt t → θ/
- Spirantization in singletons only: /tt | t → θ/
- No spirantization: /tt t | θ/

The impossible mappings are as follows:

- The chain shift: /tt → t → θ/
- The "saltation" (Lass 1997; Hayes & White 2015): /tt → θ/ with /t/ unchanged

These impossible mappings are said to be *harmonically bounded*, because there is no ranking under which they are better ('more harmonic') than some other candidate,

which thus set an 'upper bound' to the losing candidate's harmony under the available set of constraints.

Note that this type of interaction between specific and general constraints emerges with no additional stipulation from the universally defined mechanism of constraint interaction. More specifically, it emerges when two (or more) constraints stand in a *stringent* relationship, meaning that the set of violations assigned by one constraint is always a superset of the set of violations assigned by the other: in our case, any candidate that violates IDENT-IO$_{gem}$ must by necessity violate the simpler IDENT-IO (at least) as many times. Constraints in such a relationship do not, strictly speaking, conflict with each other, so their mutual ranking is not important: their ranking vis-à-vis other constraints, however, matters for the outcome.

This example shows, however briefly, the basic mechanism whereby factorial typology enables the analyst to do phonological typology. Typology is primarily seen in terms of possible input-output mappings.[4] Factorial typology, at least in principle, makes explicit — and therefore falsifiable — predictions about possible phonological grammars. It is therefore no surprise that OT has found particularly widespread use in domains for which the typological parameters are relatively well understood, such as syllable structure (already in Prince & Smolensky 1993), weight (e.g. Morén 2001), and metrical typology (e.g. McCarthy & Prince 1995a; Hyde 2001; Alber 2005). Applications of these methods in other areas (notably segmental phonology) have been less prominent, although cf. Causley (1999) and de Lacy (2006) for some results.

Of course, factorial typology is promising as a potential account of the full range of cross-linguistic variation only if the set of constraints CON is finite and at least potentially fully discoverable. In classic OT, this is achieved via the assumption that CON is not just finite but also *universal*. If this is correct, then all constraints are present in the grammars of all languages, and their (apparent) (in)activity should be accounted for by reference to their ranking.

The assumption of universality is not logically unavoidable: it is perfectly conceivable that constraints might be constructed by the learner as part of the acquisition process (cf. for instance Hayes & Steriade 2004; Pulleyblank 2006; Archangeli & Pulleyblank this volume). An OT framework with such emergent constraints is, of course, viable, but it loses the possibility of accounting for cross-linguistic differences *solely* by reference to constraint ranking via factorial typology. Even so, it retains some other properties that made the framework attractive in the first place.

2.2 Increased generality

Compared to other constraint-based frameworks, such as Declarative Phonology, OT's embrace of constraint violability offers the promise of increased generality of explanation. If constraints are inviolable, it is likely that every specific pattern requires a precisely described constraint which refers exactly to the contexts where the relevant phenomenon is in evidence. With OT's violable constraints, multiple patterns can be described with a rather smaller number of more general constraints. A candidate may violate some of these constraints and yet still be the winner, by virtue of constraint ranking or vacuous satisfaction.

One class of cases that is common to cite as exemplifying this advantage is referred to as *emergence of the unmarked* (McCarthy & Prince 1994). In this situation, evidence for some ranking of constraints is available only when some more highly ranked third constraint is, for some reason, inactive. One situation where this arises is when the third, dominating constraint is a faithfulness constraint, so that the interaction of the constraints it outranks only becomes evident when faithfulness is vacuously satisfied.

By way of example, consider a language whose surface inventory possesses both [i] and [u]. The existence of these vowels is militated against by constraints on the co-occurrence of their respective features, call them for brevity *[−bk +hi] and *[+bk +hi]. The fact that the vowels contrast in the language indicates that relevant faithfulness constraints (such as, say, IDENT-IO[±bk]) dominate the two markedness constraints. For this reason, the relative ranking of the two markedness constraints cannot be easily recovered, since they do not participate in choosing a winner candidate. Now imagine, however, that the language also possesses a process of vowel epenthesis, which by definition involves the appearance of a vowel that does not correspond to anything in the input. In this case, IDENT-IO is vacuously satisfied, and the choice of the quality of that vowel falls to other constraints — perhaps to the two markedness constraints just identified. Now if the epenthetic vowel happens to be [i], this provides evidence that the constraint against surface [u] outranks the constraint against surface [i]: the relative (un)markedness of the two vowels is "submerged" by the high ranking of faithfulness, but emerges if the latter is rendered inactive. Crucially for the question of generality, note that there is no need to introduce any mechanisms specific to the situation of epenthesis: all the work is done by the ranking, using constraints that, under OT assumptions, are independently

needed to describe the language's surface contrasts. This increased generality of constraints is part of the reason that OT is at all viable as an instrument of cross-linguistic explanation, making typological arguments of the sort exemplified in section 2.1 possible.

2.3 OT and markedness

The OT mechanism provides an explicit formalization of the age-old idea — going back at least to Baudoin de Courtenay — that the form of speech utterances represents a compromise between the needs of the speaker (such as minimizing effort) and the needs of the hearer (such as ambiguity avoidance). In OT, the "needs of the speaker" are largely expressed via markedness constraints, which tend to require that surface representations have certain properties (such as having only open syllables or lacking front rounded vowels) and, by implication, that they do not have some other properties (such as syllable codas and front rounded vowels). In itself, such a requirement has little to do with "markedness" as understood in pre-OT literature with reference to properties such as typological distributions or particular types of phonological behaviour. Nevertheless, as the corpus of OT analyses grew, it became apparent that the (possibly universal) set of markedness constraints available to learners must include constraints with a clear affinity to the phonetic factors commonly implicated in accounting for (un)markedness in phonological behaviour.

The establishment of the link between "phonetic knowledge" (Kingston & Diehl 1994) and phonological grammar opened up a significant field of inquiry. Accounts of markedness effects proved notoriously difficult to incorporate directly into rule-based accounts. Markedness-based asymmetries could be introduced via additional

submodules of the grammar (such as the "markedness conventions" of Chomsky & Halle (1968) or the "grounding" conditions of Archangeli & Pulleyblank 1994) or through language-specific representational underspecification (Archangeli 1988; Steriade 1987), which eluded comprehensive cross-linguistic theorizing. In OT, the theory of markedness is part and parcel of the theory of constraints; and a theory of CON is perhaps the most important part of the theory of grammar, since all other components of the mechanism (the GEN mechanism, the rich base, the evaluation mechanism) are essentially fixed.

The OT formalism itself does not put a restriction on the substantive content of markedness constraints. The default position is to make them refer to orthodox pieces of phonological structure, such as features and suprasegmental constituents; however, various authors have proposed that they could also refer directly to phonetic properties such as formants (Flemming 2002) or cues (Steriade 2001), articulatory effort values (Kirchner 1998), and properties of entire (sub)inventories (Padgett 2003). In all cases, however, OT offers clear advantages to any theorist who wishes to account for markedness effects via some property of Universal Grammar — although this aspiration is not universally shared (e.g. Hale & Reiss 2008).

2.4 Conspiracies and the "duplication problem"

Another commonly cited advantage of OT is the resolution of the "duplication problem", whereby apparent restrictions on the form of underlying representations are reproduced in dynamic alternations. Consider the case of velar fronting in Modern Standard Russian. Generally, sequences of a non-palatalized velar [k g x] and a front vowel are disallowed in underlying forms of morphemes.[5] In parallel, a rule of velar

palatalization ("velar fronting" in the tradition initiated by Halle 1959) maps the sequences /ki gi xi ke ge xe/, when they arise via (some kinds of) suffixation, to /kʲi gʲi xʲi kʲe gʲe xʲe/: /potolok/ 'ceiling' but [patalˈkʲi] 'ceiling-NOM.PL', [patalˈkʲe] 'ceiling-LOC.SG'.

In a serial framework, the first restriction is either left unexpressed — treated as an accident of history — or enforced by some mechanism specific to underlying representations, whereas the second appears to necessitate a phonological rule, although the outcome of these two mechanisms is identical. In mainstream OT, neither of these techniques is allowed because of the postulate of Richness of the Base, which bans positing any restrictions on inputs, whether accidental or in a dedicated submodule of the grammar. Under this régime, the apparent restriction on underlying forms is illusory: it is incumbent on the grammar to rule out a situation whereby (potential) underived forms containing the offending structure are mapped to the surface faithfully. This can be done by a proper ranking of some markedness constraint militating against this structure — which is the same mechanism needed to enforce alternations. Thus, OT proponents argue that restrictions on underived forms and alternations are accounted for by a single mechanism.

Another area in which OT is claimed to excel is resolving the issue of "homogeneity of target, heterogeneity of process", sometimes known as the issue of "conspiracies" (Kisseberth 1970; Kenstowicz & Kisseberth 1979). The classic case here is Yowlumne (Yawelmani Yokuts), in which several phenomena — rules of vowel shortening and epenthesis, as well as additional conditions on syncope and apocope rules — all "conspire" to produce a set of surface forms with no complex codas. In an input-oriented framework, expressing this requires reference to the output of the rule,

which is not possible without additions to the formalism. In OT, on the other hand, the homogeneity of target is directly expressed by the relevant constraint, whereas homogeneity of process arises as a consequence of differences in the shape of inputs (which render some faithfulness constraint vacuous) and the ranking of faithfulness constraints.

2.5 Computational advantages

The area of phonological research that has probably seen the most significant advances compared to the pre-OT results is the study of learning algorithms for phonology. With the advent of OT, problems such as the learning of phonotactic restrictions, alternations, and underlying representations have been subject to mathematically explicit analyses, clarifying both the limits of the OT formalism and the possible ways in which a phonological system may be acquired by a learner.

It became clear rather early on that the use of OT formalism as such does not, in principle, afford significant computational advantages, as the problem of generating the set of winners was shown to be NP-hard (e.g. Eisner 1997; Wareham 1998) – that is to say, there is no difference in computational complexity between OT and standard implementations of rule-based phonology (see Heinz 2011b for an overview of these issues).

Nevertheless, the use of well-understood optimization techniques makes it possible to offer learnable versions of OT grammars. This is largely thanks to the fact that harmonic bounding ensures only that the notionally infinite candidate set contains a smaller subset of "viable" candidates, as there is no need for the grammar to ever consider a large subset of candidates that can never be winners (Seeker & Quernheim

2009; Riggle 2009; Heinz et al. 2009). Issues related to computational complexity, tractability, and suitable algorithmizations continue to be debated in the literature: for instance, they play an important role in some scholars' endorsement of Harmonic Grammar, with its constraint weighting, over OT's logic of strict domination (e.g. Pater 2009b; Potts et al. 2010) — although see Magri (2013) for a rejoinder, and Krämer (this volume) for more discussion.

One area where the advent of OT has undoubtedly led to significant progress is the study of learnability. Algorithms with well-understood properties have been developed to make progress with phonotactic learning (the acquisition of the ability to distinguish felicitous and infelicitous surface forms), the resolution of structural ambiguity (choosing the correct candidate among a set of candidates that do not differ visibly but have different structural parses), resolving the subset problem (choosing the most parsimonious grammar out of the set of grammars consistent with the surface data), and — to a somewhat lesser extent — the learning of underlying representations and of morphophonological alternations.

One basic idea in OT learnability work is the notion of *constraint demotion* (Tesar & Smolensky 2000, chap.3). A constraint is demoted if the learner encounters a datum that cannot be accommodated within the grammar they have arrived at (an *inconsistency*). Specifically, it is demoted below a constraint that allows the "correct" candidate to emerge as the winner (but not further down the ranking). This *inconsistency resolution* can be leveraged in a variety of ways, not just for phonotactic learning, but also, for instance, for the acquisition of lexically specific phonological phenomena (Pater 2009a).

Constraint demotion is able to detect inconsistencies, but it is not robust to errors in the data, since any inconsistent datum triggers a reranking. An alternative approach is the Gradual Learning Algorithm (Boersma & Hayes 2001), which uses ambient data not to effect a full-on change of ranking but rather to change the probability of a particular constraint being ranked in a particular way, thus ensuring that the influence of inconsistent data is proportionate to their frequency (in particular, the prediction is that since true errors are rare, they will not unduly influence the acquisition process). The downside of this robustness, however, is that the GLA is unable to detect global inconsistencies (i.e. inconsistencies that arise from more than a pairwise ranking of constraints), which are useful in resolving structural ambiguity (Tesar 2004).

All these, and other related issues, continue to be the subject of active research. The construction of explicit algorithms with well-understood computational properties promises to close the gap between phonological theory and many broader concerns in cognitive science, as well as clarifying the scope of phenomena that phonological theory should — or indeed can — be concerned about. The advent of OT has played a significant role in the development of this highly necessary work.

2.6 Quantitative gradience

Another area of active research in OT concerns the encoding of quantifiable, gradient phonological phenomena. This is facilitated by several properties of the OT architecture.

First, factorial typologies make explicit predictions as to what phenomena are possible (including, crucially, how different phenomena may interact). Second, since the number of grammars generated by reranking a finite number of constraints is also

finite, the number of grammars including a particular output (or constellation of outputs) can be estimated. Thus, for instance, Multiple Grammars Theory (Anttila 1997) uses the insights of factorial typology to account not just for the contextual restrictions on variable processes but also for the quantitative aspects of variation: it predicts that the frequency of a particular variant is proportional to the share of grammars allowing that variant in the factorial typology.

More sophisticated results can be achieved by a more nuanced approach to constraint ranking. Anttila (1997) shows that non-trivial predictions about variation can be made if a "grammar" is allowed to include partial rather than total ordering of constraints (see Krämer, this volume for more discussion). Another example is Stochastic OT (briefly referred to above in connection with the Gradual Learning Algorithm), where the rankings of constraints for each utterance are determined probabilistically, deriving non-trivial quantitative predictions for within-speaker variation.

Gradient phonological knowledge is also apparent in continuous phonotactic effects. Phonotactic knowledge is apparent in many phenomena, ranging from over- or underrepresentation of certain patterns relative to chance level, effects of well-formedness in production and perception experiments, loanword adaptation, and so on. Many aspects of this knowledge appear to be gradient, in that it is possible to distinguish between "degrees" of well- or ill-formedness (e.g. Schütze 1996). Many proponents of OT take seriously the proposition that this gradience is not "just" a performance effect, but instead should be derived from the same mechanisms as those that underlie categorical grammatical phenomena (e.g. Hayes 2000; Coetzee 2008). Once again, OT provides the means of quantifying such patterns, either through an

inspection of the numerical consequences of categorical constraint rankings or introducing a stochastic element into the evaluation procedure.

3 CHALLENGES AND ISSUES

It will be noted that many of the arguments advanced for OT are ones of theoretical elegance rather than empirical coverage. This is, in principle, not surprising, given that it may be difficult to distinguish the *empirical* coverage of OT from that of other theories, since most of them can be shown to describe (sub)regular relations (Heinz 2011a). In fact, the explicitness of predictions made by OT has uncovered a number of serious challenges to its status as a fully adequate theory of phonological competence. Other issues have arisen as a consequence of choices made by analysts within and outwith the OT tradition in terms of focus.

3.1 Opacity

Opaque interactions have been perhaps the most prominent empirical problem for OT. In the classic typology opaque processes can be described in terms of either overapplication (application in the absence of the context on the surface) or underapplication (non-application despite the presence of the triggering context). Both of these are problematic for classic OT, but especially overapplication, because in that case the desired winning candidates are harmonically bounded and thus predicted to *never* win.

A classic case of overapplication is the interaction of palatalization and syncope in Bedouin Arabic, where palatalization of velars can be counterbled by syncope targeting medial open syllables:

(6) /ħaːkim-iːn/ ‘rulings’ → /ħaːkʲimiːn/ → [ħaːkʲmiːn]

Assume for the sake of the argument that palatalization violates a constraint IDENT-IO[±bk] and is triggered by a constraint AGREE[±bk], requiring that a consonant and a following vowel have the same [±bk] value, whereas syncope is triggered by a constraint ranking referred to as FTSTRUC (expressing a preference for disyllabic feet), we can attempt to construct the following tableau:

(7) Harmonic bounding in Bedouin Arabic counterbleeding opacity

	/ħaːkimiːn/	FTSTRUC	AGREE[±bk]	IDENTIO[±bk]	MAX
a.	[ħaːkimiːn]	*!	*		
b. ☞	[ħaːkmiːn]				*
c.	[ħaːkʲimiːn]	*!		*	
d.	[ħaːkʲmiːn]			*!	*

The intended winner, candidate (d.), is harmonically bounded by (b.): they both undergo the unfaithful mapping involving deletion, but the candidate with both palatalization and syncope cannot win, since it incurs entirely gratuitous violations of the IDENTIO constraint. Thus, parallel OT makes the prediction that counterfeeding opacity should be impossible. This is more than a little problematic, since the existence of such mappings is probably the most significant result of generative phonology, setting it apart from most if not all other phonological frameworks.[6]

Responses to the opacity problem in the literature have been varied. Frameworks such as Sympathy Theory (McCarthy 1999) and Virtual Phonology (Bye 2001) enrich the representational arsenal by reintroducing the possibility of reference to non-surface forms. A more constraint-focused approach is offered by Comparative Markedness (McCarthy 2003), which allows constraints to distinguish the status of various candidates. Several approaches exploit the frequent relationship between opacity and morphology. One example here is Cophonology Theory (Orgun 1999; Orgun & Inkelas 2002; Inkelas 1998), which allows all affixation to trigger morphologically specific phonological effects. Another option is allowing morphologically related words to influence the phonological form of each other, as in Output-Output Correspondence (Benua 1997) and Optimal Paradigms (McCarthy 2004a). Stratal approaches (Kiparsky 2000; Bermúdez-Otero 2011, this volume) use the insights of Lexical Phonology and Morphology (Kiparsky 1982; 1985) to provide a restricted theory of morphological influence on phonological processes. Finally, theories such as OT-CC (Optimality Theory with Candidate Chains) and Harmonic serialism abandon the principle of unrestricted GEN in favour of a stepwise derivation that restricts the "distance" an output may diverge from its input (McCarthy 2007a; 2008b; McCarthy & Pater forthcoming).

Another characteristic response of OT proponents to the issue of opacity is essentially a denial of its reification as a single phenomenon that is problematic for OT. For instance, Baković (2007) proposes a revised typology of opaque generalizations and argues that OT is more suited to dealing with certain classes of opaque phenomena than rule-based theories, while Łubowicz (2012) proposes a parallel OT account of a

large class of underapplication phenomena without purporting to solve the entire "opacity" problem.

3.2 Representations

The advent of OT has coincided with a retreat from much work in representational theory characteristic of the late 1980s. This is particularly true for the study of subsegmental representations, such as feature geometry and underspecification. To a certain extent this may perhaps be viewed as a matter of a new swing of Anderson's (1985) "representation/computation pendulum", whereby OT's focus on the computational device of constraint ranking as an explanatory factor in phonology has led to a fall-off in focused representational work. Architecturally, the OT algorithm does not impose strict logical requirements on the representational properties of inputs and outputs. In practice, however, the emphasis on constraint ranking as the sole explanatory mechanism encourages the use of commonly agreed, cross-linguistically invariant featural representations — which, in practice, has tended to mean the SPE feature set (Chomsky & Halle 1968).

The reasons for the decreased emphasis on underspecification are different. With the premium that OT puts on minimizing the number of violations, a common assumption in much of the literature is that the learning mechanism is geared to produce a set of inputs that can be fed into the correct ranking to produce the right outputs with as few violations as possible. Since the change from an underspecified input to a specified output most often involves the violation of a faithfulness constraint,[7] even when there is no alternation, a fully specified input accrues fewer violations than an underspecified one, in a process referred to by Prince & Smolensky (1993) as

"Stampean occultation" (see, however, Krämer 2012; Tesar 2013 for critical discussion of this idea). This is shown in (8). For an output form [da] that does not show any alternations, assuming an identical input /da/ means only markedness constraints are violated in the input-output mapping. On the other hand, assuming an input /Da/, with the first segment underspecified for [±voi], means that in addition to those markedness violations the mapping will also incur a violation of faithfulness, because of the insertion of a [±voi] specification absent in the input. Therefore, in the absence of alternation evidence full specification is preferred.

(8) Stampean occultation: output non-alternating [da]

		DEP[voi]	*[+voi −son]
a. ☞	/da/ ~ [da]		*
b.	/Da/ ~ [da]	*!	*

Under this régime, input underspecification can only be countenanced if the option of full specification is not available for some reason. It has been proposed (Inkelas 1994; Krämer 2000) that this is necessary in the case of ternary contrasts, where full specification cannot be shown to derive the correct behaviour. For instance, in Île de Groix Breton (Ternes 1970; Krämer 2000) initial obstruents in lexical items demonstrate three kinds of behaviour:

- Voiceless in isolation, triggers of regressive assimilation in sandhi
- Voiced in isolation, triggers of regressive assimilation in sandhi: [**b**a:k] 'boat', [atʃypa**ʒ** **b**a:k] 'boat crew'
- Voiced in isolation, undergoers of bidirectional devoicing in sandhi: [**b**ənak] 'any', [atʃypa**ʃ** **p**ənak] 'any crew'

The behaviour of the first two classes can be derived if they are underlyingly specified as [−voi] and [+voi] respectively, which means the third set cannot have either specification; instead, Krämer (2000) argues, it is underlyingly underspecified for [±voi] and receives the voicing specification via an interaction of markedness constraints regulating the distribution of [±voi] on the surface. Here, underspecification is used as a device to derive ternary behavioural distinctions, when an underlying binary distinction is not analytically viable; this is quite different from the use of underspecification as a representational device to express (lack of) contrast current in much pre-OT work.

It would not be fair to say that work in OT has been entirely unconcerned with questions of phonological representation.[8] In fact, representational questions are crucial to the operation of numerous types of OT analysis. For instance, an important early debate concerned the question of containment vs. correspondence. In much early OT work, the relationship between input and output was a matter of simple containment. This precluded operations such as deletion or insertion: elements appearing to have undergone deletion were assumed to have remained unparsed prosodically (violating constraints of the family PARSE), whereas epenthetic material was assumed to represent empty structural positions unfilled by other material (violating constraints of the family FILL). In Correspondence Theory, on the other hand, inputs and outputs were represented separately and their elements related via a many-to-many correspondence relationship: this allowed operations such as deletion (input element with no output correspondent), insertion (output element with no input correspondent), coalescence (multiple input elements corresponding to a single output) and fission (multiple output elements corresponding to a single input). The

correspondence relationship can also be extended to pairs of representations other than input-output, including base-reduplicant (McCarthy & Prince 1994), segments in morphologically related forms ("output-output correspondence"; Benua 1997), and surface segments in the same form, as in Agreement by Correspondence (Gunnar Ólafur Hansson 2001; Rose & Walker 2004). The question is clearly a representational one, albeit driven largely by OT-specific concerns rather than the pre-OT preoccupation with contrast. (The question is, incidentally, unresolved: while Correspondence is often the silently assumed option, a line of recent work has resurrected Containment in the guise of Coloured Containment; van Oostendorp 2007; Trommer 2011; Trommer & Zimmermann 2014)

Representational work in OT can also be motivated by the fact that traditional representations may create empirical problems within the OT computational system. An example is the theory of Feature Classes (Padgett 2002), devised to solve a "pathology" — an undesirable prediction of the factorial typology — that arises with representations based on autosegmental mechanisms such as spreading, namely the so-called "sour grapes" problem: with traditional representations, the factorial typology includes grammars where multiple features spread except when something prevents one of them from spreading and consequently *all* the features fail to do so. It is also possible to find examples where representations are leveraged to achieve certain constraint violation profiles, which are then in turn utilized to build particular factorial typologies: these can be either traditional autosegmental representations (Causley 1999; Iosad 2012) or "bespoke" ones, as in the "xo Theory" of de Lacy (2006).

Many such representational devices proposed by OT are driven by the non-serial nature of the computation. For instance, the inherently iterative character of autosegmental spreading sits rather poorly with the fell-swoop OT grammar, and thus a variety of options were offered to capture the same insights using representational rather than derivational options, such as Optimal Domains theory for tone (Cassimjee & Kisseberth 1998), strictly local spreading in vowel harmony (Ní Chiosáin & Padgett 2001), and Binary Domains Theory (Jurgec 2010). It remains to be seen to what extent such representational reimaginings of serial derivation will remain relevant with the reintroduction of serial derivation in more recent versions of the framework (McCarthy 2010).

Finally, it must be emphasized that OT is not inherently inimical to more traditional representational work, as shown, for instance, by the existence of OT analyses making use of featural underspecification motivated by contrast (Hall 2007; Mackenzie 2013; Youssef 2015). Similarly, Hyde (2009) provides a careful comparison of a parallel and a serial account of metrical stress patterns and identifies a well-known representational device (Weak Layering, i.e. the possibility of unfooted syllables within a prosodic word) as the source of some predictions rather than the OT mechanism in use.

3.3 Overgeneration and explanatory power

Another area in which the explicitness of OT's predictions came to be presented as a challenge for the theory is the question of overgeneration. The OT formalism is powerful enough to accommodate as real phonological processes input-output mappings that are highly implausible. Recent work in computational complexity

shows that phonological patterns are at most regular mappings, and even likely to be restricted to a subregular class (Heinz & Idsardi 2011; Heinz 2011b), which means that most of the computational power of OT (which may extend to context-free grammars — Frank & Satta 1998; Karttunen 1998) goes unused. This creates a serious overgeneration problem, given the default OT position that constraint ranking and harmonic bounding is the only mechanism available to exclude certain mappings (apart from the vaguely defined restrictions on GEN).

Even these considerations aside, it quickly became apparent that "homogeneity of target, heterogeneity of process" — initially seen as an advantage — could be problematic. The classic case is final devoicing. In a rule-based theory, its existence is accounted for by the possibility of a rule that does just that — maps an input voiced obstruent to a voiceless one. The fact that certain other processes in the same position appear to be unattested can, if desired, be accounted for by assuming that the relevant rules are impossible: for instance, Kiparsky (2008) argues that a rule of final obstruent voicing is an impossible one.

In OT, however, unfaithful mappings occur when a markedness constraint dominates some faithfulness constraint. The markedness constraint (or set of ranked constraints) identifies the structure that is to be avoided — such as a word-final voiced obstruent — but the nature of the chosen repair depend on what faithfulness constraint is low ranked: this is the essence of the separation between constraints and repairs. This has long been known to lead to overgeneration: for instance, a word-final voiced obstruent could be repaired by any number of processes, including devoicing, nasalization, outright deletion of the offending segment, epenthesis of material that takes the offending segment out of word-final position, etc., many of which appear to

be poorly attested (Steriade 2001; Lombardi 2001).[9] This is known as the too-many-solutions problem, and numerous solutions have been proposed to deal with it, from careful construction of the constraint set CON to match the typology (e.g. Lombardi 2001) to the introduction of new constraint types — e.g. "targeted constraints" (Wilson 2001) or constraints on input-output mappings (Blumenfeld 2006) — to the embrace of gradual derivations (e.g. McCarthy 2007a), which excludes a class of extraneous solutions that arise due to the fell-swoop nature of derivation in classic OT.

Where opacity presents an undergeneration problem, and thus an important empirical challenge to OT, overgeneration is an issue that endangers the theory's claim to theoretical elegance. As discussed in section 2, a large part of OT's initial attraction was precisely the greater explanatory power it appeared to offer over the highly powerful rule-based derivations. The explicitness of OT factorial typologies has demonstrated the potential for numerous "pathologies", i.e. predictions that do not correspond well with the set of attested patterns, such as the "midpoint pathology" (predicting that constraints may conspire to push stress as close as possible to the middle of a form), or the "sour grapes" problem mentioned above. It is commonly accepted that, *ceteris paribus*, an analysis that makes fewer (or no) pathological predictions is to be preferred — although it might be objected that the parity of the *cetera* necessary to effect this comparison can be difficult to achieve.

3.4 Modularity

The parallel computation of classic OT sits rather awkwardly with the feed-forward cognitive architecture assumed in most generative work. In a feed-forward

architecture, the computational mechanisms involved in the production and perception of a phonological expression may operate on that expression in several passes. It is usual to assume at least one pass of some kind of strictly phonological component — or several, in interactionist frameworks such as Lexical Phonology and Morphology. In addition, there may be a gradient component sensitive to factors such as frequency, or perhaps a "usage" component responsible for socially determined variation.

In parallel OT, only a single pass of the computation is available. This may create empirical problems, as in the case of opacity, but it may also be seen as a conceptual difficulty. As emphasized by Scheer (2010; 2011), the single pass gives rise to the "scrambling trope", where all the factors that influence a particular phonological expression have to interact with one another within a single ranking. Examples of this include direct reference to articulatory or acoustic measures, as in much "phonetically-based phonology" work, lexical frequency, morphological affiliation (e.g. whether a particular segment belongs to an affix or a root), lexical stratification (e.g. the status of a morpheme as borrowed or native), and so on. This, of course, massively expands the set of interactions that may be predicted to be possible, opening the way, for instance, to morphologically conditioned phonetics, which many proponents of generative theories of phonology would consider to be impossible (Bermúdez-Otero 2010).

The "scrambling trope" is *not* a logically necessary component of OT, as demonstrated by the existence of proposals that explicitly restrict what kind of information can interact; see, for instance, Oostendorp (2007) and Bermúdez-Otero (2012) for proposals explicitly couched in a modular framework; as Bermúdez-Otero

(2010) points out, some frameworks restrict this more implicitly, via a excluding some types of constraints from CON, giving Bidirectional Phonology (Boersma & Hamann 2008; Hamann 2009) as an example. Nevertheless, many widely accepted proposals do rely on this kind of "mixing of levels" to resolve important issues in OT, and the possibility (and desirability) of a fully modular OT also remains a live issue at this point.

4 OT AS A THEORY OF SYMBOLIC COMPUTATION

To sum up this discussion, it is worth revisiting the issue of what it means for a phonological theory to possess explanatory adequacy. Historically, the appeal of OT has only partially been based on better empirical coverage compared to earlier frameworks: to the extent such empirical advances were made — we may mention learnability and the analysis of quantitative aspects of phonological knowledge — they appeared some time after the broader adoption of the theory. In bread-and-butter areas of phonological analysis, OT's advantages were largely perceived as conceptual rather than empirical, and they came with trade-offs in the shape of empirical challenges, perhaps most notably opacity (cf. Vaux 2008).

The future development of OT will be determined by a number of competing pressures. First, like much of formal phonological theory, mainstream OT faces the challenge of justifying its scope and the quality of the underlying data in the face of empirical advances made in the laboratory (Cohn, Fougéron & Huffman this volume) and in quantitative studies (Hammond this volume). For OT, this is both a challenge — as the empirical foundations of much of phonological theory become increasingly

problematized — and an opportunity, given its pedigree and ethos of incorporating quantitative analysis into phonological grammar. Second, the empirical problems — such as opacity and some important pathologies — have not yet achieved a commonly accepted resolution. These problems continue driving the theory forward, motivating developments such as the (re)introduction of serial derivation in various guises, a shift to constraint weighting, and further work on constraint architecture (Ramsammy, this volume; Krämer, this volume).

Perhaps the most important question that still requires an answer is the scope of the OT computation. At heart, OT is not a proprietary theory of phonology, but a rather general decision-making algorithm. It thus appears to be suitable for the analysis of a broad range of phenomena within a single mechanism. It is this possibility of a single solution for a whole host of issues that appears to have played such an important role in its adoption. Yet many of the issues OT purports to resolve do lend themselves to other remedies. For instance, as discussed in section 2.4, OT offered a solution to the so-called "duplication problem"; yet this can only be counted in its favour if one accepts that the "problem" exits and is relevant for an account of phonological knowledge — see Paster (2012) for an argument that it is not, but is instead better understood in a diachronic context. Similarly, many phenomena presented as insurmountable empirical problems that require the introduction of some theoretical device or another can be reanalysed with a change of assumptions. For instance, in discussing the case of counterbleeding opacity in Bedouin Arabic palatalization, McCarthy (2007a) dismisses an account based on "coalescence" (i.e. the preservation of the [−back] feature of the palatalization trigger through its realization on the consonant), but only adduces conceptual, rather than empirical arguments against

such an analysis. Another example is the treatment of frequency-sensitive exceptionality, as in the paradigm case of English *comp*[ə]*nsation* vs. *cond*[ɛ]*nsation* (Chomsky & Halle 1968) — treated by Pater (2000) as requiring lexical indexation, this phenomenon has been reanalysed in an OT framework, yet without recourse to indexation, by Bermúdez-Otero (2012) through a reconsideration of lexical insertion processes.

In sum, I suggest there are two viable directions for the development of OT, which we might call "expansionist" and "minimalist". Under the "expansionist" view, OT and its relatives such as Harmonic Grammar are promising because they offer the possibility of a grand theory of all aspects of phonological knowledge, including not just traditional areas of concern to phonologists such as phonotactics and morphophonological alternations (including typological aspects – see, for instance, Pater forthcoming for discussion of the typological merits of constraint weighting) but also quantitative aspects of phonological behaviour, external interfaces, exceptionality, and so on. Under the "minimalist" view, on the other hand, OT occupies a rather more restricted, but perhaps better-defined, place in a theory of phonology, alongside well-articulated theories of interactions between phonology and phonetics, phonology and morphology, phonological computation and lexical access, perhaps also phonological representations or the interaction of phonological and social knowledge, and so on (for some examples, see Blaho 2008; Bermúdez-Otero 2012). It remains to be seen which, if any, of these directions prevails in work on OT; both of them, however, crucially depend on further development of the kind of empirical and theoretical research informed by the questions that OT has raised that is described in the following two chapters of this volume.

5 FURTHER READING

The original paper in which OT was introduced (Prince & Smolensky 1993) (also published in 2004 by Blackwell) is fairly accessible and provides a good introduction, although many of the specific technical devices it introduces (such as fixed constraint rankings or containment) have since been effectively abandoned or at least problematized. Many key notions, notably 'emergence of the unmarked', correspondence, and alignment, are discussed in the influential papers by McCarthy & Prince (1995a; 1995b; 1999). A key paper in the treatment of underspecification and the shape of inputs is Itô, Mester & Padgett (1995).

An article-length introduction to OT is provided by McCarthy (2007b), while McCarthy (2002) offers a survey of the state of what we might call 'classic', fully parallel OT by the start of the 2000s. The reader by McCarthy (2004b) presents a carefully edited selection of some of the most influential original papers from the 'classic' period in the 1990s, also giving a good overview of the field. Much of this literature from the early OT period is available online through the Rutgers Optimality Archive (http://roa.rutgers.edu). Book-length, pedagogically oriented treatments are provided by Kager (1999) (an undergraduate-level textbook) and McCarthy (2008b) (perhaps more suitable for graduate-level study).

Many chapters in the handbook edited by de Lacy (2007) offer OT-focused overviews of several phonological subfields; in particular, Prince (2007) offers an introduction to the formal study of OT grammars *qua* theoretical objects. The paper by Vaux (2008), while highly critical of the OT enterprise, is highly useful in bringing together a large number of references to literature that intends to explicate the advantages of 'classic

OT'. Scheer (2011) also provides a useful historical perspective on the development of OT within the broader phonological context.

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[1]Constraints can also be thought of as functions mapping structures to truth values (True or False, or "Violation" and "No Violation"): for a concrete proposal couched in model theory, see Potts & Pullum (2002). As Pullum (2013) points out, the OT architecture as a whole still remains procedural and thus largely incompatible with a model-theoretic approach to grammar. However, Heinz et al. (2009) discuss how it may be possible to provide a correct model of OT without explicitly resorting to the stepwise evaluation procedure.

[2]*Gorgia toscana* is sometimes taken to refer only to the spirantization of voiceless stops; however, many relevant varieties also show spirantization of voiced stops as well, in common with other Italo-Romance varieties (Ramsammy this volume).

[3]Abbreviations: M = markedness (here *V[–son –cont]), F = faithfulness (here IDENT-IO), PF = positional faithfulness (here IDENT-IO_{gem}).

[4]The more traditional approach focusing on inventories (cf. Hyman 2008) can also be accommodated: a gap in the inventory is created when the fully faithful candidate is defeated for the unattested input, so that input is mapped to something else.

[5]I disregard here a very small number of borrowings, many of which have parallel forms conforming to the restriction.

[6]For discussion of counterfeeding opacity, which *can* be accommodated in parallel OT, albeit at significant analytical cost, see McCarthy (2007a, sec.2.3.3).

[7]Potentially with some exceptions, as in the discussion of syllabification above.

[8]I thank Joe Pater for discussion of this point.

[9]Flynn (2007) provides some healthy skepticism on this point, however.