

## Harmonic Serialism and Parallelism

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### 1. Introduction

In this paper, I will be presenting some results bearing on a question about the basic architecture of Optimality Theory. This question was first framed by Prince and Smolensky (1993) in the quotation below:

“Universal grammar must also provide a function Gen that admits the candidates to be evaluated. In the discussion above we have entertained two different conceptions of Gen. The first, closer to standard generative theory, is based on serial or derivational processing: some general procedure (Do- $\alpha$ ) is allowed to make a certain single modification to the input, producing the candidate set of all possible outcomes of such modification. This is then evaluated; and the process continues with the output so determined. ... In the second, parallel-processing conception of Gen, all possible ultimate outputs are contemplated at once. ... Much of the analysis given in this book will be in the parallel mode, and some of the results will absolutely require it. But it is important to keep in mind that the serial/parallel distinction pertains to Gen and not to the issue of harmonic evaluation per se. It is an empirical question of no little interest how Gen is to be construed, and one to which the answer will become clear only as the characteristics of harmonic evaluation emerge in the context of detailed, full-scale, depth-plumbing, scholarly, and responsible analyses.” (Prince and Smolensky 1993: 79)

In this quotation, Prince and Smolensky are describing two ways of implementing OT, serial and parallel. Their own work, and nearly all other research in OT, assumes a parallel implementation, which can be called *Harmonic Parallelism*. The serial alternative, *Harmonic Serialism*, has been little studied (though see Black 1993, Blevins 1997, Prince and Smolensky 1993: chapt. 2 and pp. 79-80fn.). The question Prince and Smolensky raise — which architecture is better? — remains wide open for empirical and theoretical investigation. The goal of this paper is to begin to address this question.

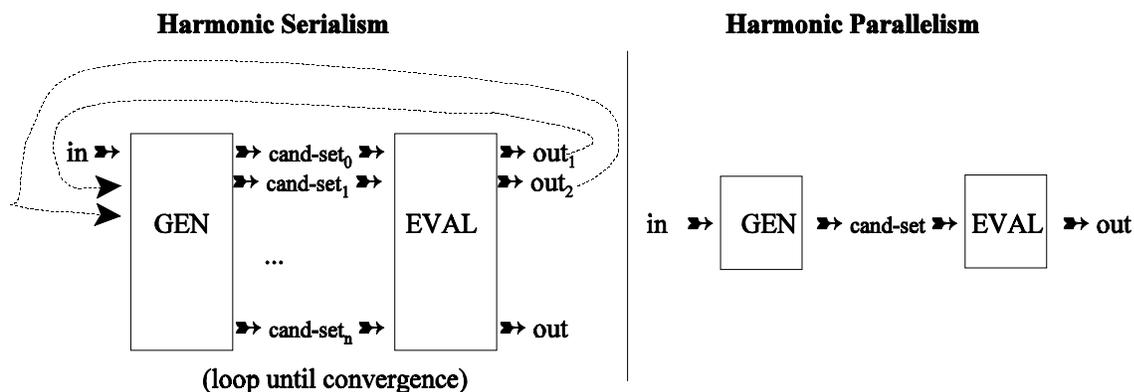
Why should this question claim our attention? From a theory-internal perspective, the basic architecture of OT is clearly a matter of great importance. But theory-externally, there is an even more compelling consideration. Unlike the better-studied parallel model, a serial

implementation of OT is much closer to the structure of several other prominent linguistic theories: rule-based generative phonology, GB, and Minimalism. Harmonic Serialism, then, offers an entre for sharper and more illuminating comparison of OT with these other approaches. Although the primary focus of this paper is not empirical investigation, several phonological phenomena will be examined at varying levels of detail, including opacity, chain-shifts, positional faithfulness, and markedness relations generally. I am afraid, however, that I cannot promise “detailed, full-scale, depth-plumbing, scholarly, and responsible analyses”; in fact, they may not even be necessary in this context.

## 2. Harmonic Serialism Explained

The following diagrams give a pretty good idea of how the serial and parallel architectures differ:

### (1) Serial and Parallel Architectures for OT



In Harmonic Serialism, Gen takes the input *in* and derives from it the candidate set *cand-set*<sub>0</sub>, which is submitted to Eval. The most harmonic member of *cand-set*<sub>0</sub>, as determined by Eval, is *out*<sub>1</sub>. It is not necessarily the “ultimate output”, however; it is returned to Gen for further processing as a new input. This process continues, looping back and forth, until there is convergence: the output of pass *n* is identical to the output of pass *n*–1.<sup>1</sup> The output of pass *n* is the ultimate output. In contrast, Harmonic Parallelism settles on the ultimate output after a single pass through Gen and Eval.

The essential difference between Harmonic Serialism and Harmonic Parallelism is that the former, but not the latter, recognizes intermediate outputs that may be distinct from the ultimate output. Harmonic Serialism shares this characteristic with serial rule-based phonology in the tradition of Chomsky and Halle (1968) as well as with derivationally-based syntactic theories like GB (Chomsky 1981) or Minimalism (Chomsky 1995).

The similarities between Harmonic Serialism and rule-based derivations can be extended by making some particular assumptions about Gen. Rule-based theories almost

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<sup>1</sup>This sense of *converge* is the opposite of *diverge*; Chomsky (1995) uses *converge* in a different sense, contrasted with *crash*.

always place restrictions on how much a single rule can do. Harmonic Serialism can mimic this by imposing similar restrictions on what Gen can do. (This is what Prince and Smolensky mean by “a certain single modification to the input”.) A restricted Gen will produce a limited candidate set, so that the intermediate output at each pass will differ only minimally from the output of the immediately preceding pass, until convergence is eventually obtained. In contrast, the Gen associated with Harmonic Parallelism must respect *inclusiveness* and *freedom of analysis* in the sense of McCarthy and Prince (1993) because “all possible ultimate outputs are contemplated at once”, so that some candidates will show the effects of diverse phonological processes simultaneously.

In recent work on rule-based phonology, there have been various proposals about how to limit what a single rule can do:

“The elementary rule types required for the processes above are linking, delinking, and default insertion... To summarize, the feature theory presented here assumes a small set of elementary rule types which carry out single operations on feature representations.” (Clements and Hume 1995: 265)

The rule parameters are {INSERT, DELETE} X {PATH, F-ELEMENT}. (Archangeli and Pulleyblank 1994: 286)

“Structure-changing rules are to be decomposed into deletion (delinking) plus structure-building...” (Kiparsky 1993) (citing Cho 1990, Mascaró 1987, Poser 1982)

Some measure of agreement is evident here: a rule can insert or delete a single autosegmental association line or feature, but no more than that. (Compare GB or Minimalism, which limit the operations to Move- $\alpha$  or Move and Merge, respectively.) Under Harmonic Serialism, it is possible to imagine imposing a similar restriction on Gen itself: output candidates can differ from the input by virtue of a single added or deleted feature or association line. With Gen limited in this way, Eval will have a much smaller candidate set to choose from, and the ultimate output may emerge only after a long chain of derivational steps.

Below, I examine Harmonic Serialism under various assumptions about the nature of Gen. In section 3, I look at a minimally different theory: Harmonic Serialism where Gen is unrestricted, exactly as in Harmonic Parallelism. In sections 4 and 5, I consider an approach closer to what Prince and Smolensky have in mind: Harmonic Serialism where Gen is limited to emitting candidates that differ in limited ways from the input. Various implementations of restricted Gen are considered *passim*, but the space of hypotheses is huge, and ultimately much more will have to be done to tease out the predictions of Harmonic Serialism under divergent conceptions of Gen.

A final remark before continuing. Harmonic Serialism should not be confused with *Stratal OT* (Booij 1996, 1997, Clements 1997, Cohn and McCarthy 1994, Hale and Kisseck 1998, Hale, Kisseck, and Reiss 1998, Kenstowicz 1995, Kiparsky 1997a, 1997b, 1998, McCarthy 1999b, to appear-a, McCarthy and Prince 1993: Appendix, Noyer 1997, Paradis 1997, Potter 1994, Roca 1997, Rubach 1997). Stratal OT is a fusion of OT harmonic evaluation with the co-grammars of Lexical Phonology or Harmonic Phonology (Goldsmith 1993). In Stratal OT, an intermediate output form serves as input to a *different* constraint

hierarchy than the one that produced it.<sup>2</sup> But in Harmonic Serialism, Eval applies *the same* constraint hierarchy to each of the successive candidate sets. Since the same constraints, in the same ranking, are potentially active at every step of the derivation, even Harmonic Serialism is, in some sense, a parallel theory.<sup>3</sup>

### 3. Harmonic Serialism with Unrestricted Gen

In this section, I will be looking at Harmonic Serialism under the assumption that Gen is unrestricted, exactly as in Harmonic Parallelism. This is not exactly what Prince and Smolensky are talking about in the quotation at the beginning. But it turns out to be easier to begin the study of Harmonic Serialism with unrestricted Gen, and then move on later to looking at the effects of imposing rule-like restrictions on what Gen can do.

The question I am asking can be rephrased as follows: under what circumstances will the Gen→Eval→Gen loop of Harmonic Serialism produce different results from the one pass through Gen and Eval that happens in Harmonic Parallelism, keeping all else equal? Yet another way to ask this question is this: when will the loop fail to converge immediately after the second pass (since if it converges after the second pass there will be no differences between Harmonic Serialism and Harmonic Parallelism)? The answer to this question, it turns out, is that there are a couple of limited circumstances where Harmonic Serialism with unrestricted Gen will work differently than Harmonic Parallelism. But one of these circumstances involves conditions that never arise and the other is, if anything, problematic for Harmonic Serialism.

The logic of the situation goes like this. Because of the way unrestricted Gen works in Correspondence Theory (McCarthy and Prince 1995, 1999), the candidate set contains exactly the same forms at each iteration of the Gen→Eval loop. The markedness violations of the respective candidate forms will not change at each pass through the loop, but of course their faithfulness violations will change (since faithfulness is re-computed relative to the new input at each pass). Building on these observations, the following schematic example gives the minimal conditions for a Harmonic Serialist derivation with unrestricted Gen to converge after the third pass through the Gen→Eval loop:

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<sup>2</sup> Nor should Harmonic Serialism be confused with cyclic constraint evaluation, where  $out_i$  gets an affix before being reintroduced to Gen.

<sup>3</sup>I am indebted to Alan Prince for suggesting this formulation.

(2) Three-Pass Convergence in Harmonic Serialism with Unrestricted Gen

a. Pass 1

/A/	F1	M	F2	F3
A		**!		
☞ E		*	*	
I	*!			

b. Pass 2

/E/	F1	M	F2	F3
A		**!		
E		*!		
☞ I				*

c. Pass 3

/I/	F1	M	F2	F3
A		**!		
E		*!		
☞ I				

F1, F2, and F3 denote faithfulness constraints; M is a markedness constraint.<sup>4</sup> The inputs and candidates — A, E, and I — are arbitrary, though it may help to think of them as the vowels *a*, *e*, and *i*.

On pass 1 through the Gen→Eval loop, candidate E is the winner. It avoids a violation of the markedness constraint M, but it also obeys the top-ranked faithfulness constraint F1. The fully faithful candidate A does worse on markedness; candidate I goes too far, satisfying the markedness constraint perfectly at the expense of fatally violating F1.

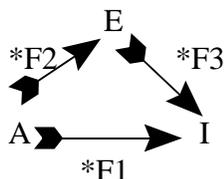
On pass 2, the input is now E, which was the output of pass 1. The markedness violations of the various candidates have not changed, but their faithfulness violations have. Now the candidate I is evaluated relative to the input E, and its F1 violation has disappeared. Think about vowel raising: changing *a* to *i* directly is less faithful than going through an intermediate step *e*. So I is the output of pass 2. Submitting I as input on pass 3 leads to convergence, since further markedness improvement is not possible.

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<sup>4</sup>Other faithfulness constraints, not shown, are violated by candidate A in pass 2 and candidates A and E in pass 3.

What we have here schematically is a situation that would distinguish Harmonic Serialism from Harmonic Parallelism. In Harmonic Parallelism, this particular constraint hierarchy, given the input A, would produce the output E. But with Harmonic Serialism this hierarchy produces the output I, because it does not converge immediately. The direct mapping from A to I violates the high-ranking constraint F1 but the indirect mapping that goes by way of E violates only low-ranking faithfulness constraints:

(3)



Now that we have described an abstract scenario where Harmonic Serialism with unrestricted Gen produces a derivation that is not simply the same as we get with Harmonic Parallelism, we need to ask what kinds of real-life situations will look like this. Only two situations seem relevant. One arises in the literature on chain-shifts. Suppose the high-ranking faithfulness constraint F1 is violated if and only if both of the low ranking ones F2 and F3 are also violated. Then the mapping from A to I will incur a worse violation mark than either of its individual component mappings. This can happen if F1 is the local conjunction (in the sense of Smolensky 1995) of F2 and F3, as in Kirchner's (1996) approach to chain shifts, or if F1 militates against large movements on a phonological scale while F2 and F3 militate against the smaller component movements, as in Gnanadesikan's (1997) approach to chain shifts.

The following tableaux lay out the kind of analysis that Kirchner gives for chain shifts. Suppose there is a process raising vowels by one step before a high vowel, so /a/ becomes *e* and /e/ becomes *i*, but /a/ cannot change all the way to *i*. The key to this approach is a high-ranking faithfulness constraint against changing the features [high] and [low] together, but with low-ranking constraints demanding faithfulness to these features individually:

(4) /CaCi/ → CeCi

/CaCi/	[IDENT(low)&IDENT(high)] <sub>seg</sub>	*V Ci [-high]	IDENT(low)	IDENT(high)
CaCi		**!		
☞ CeCi		*	*	
CiCi	*!		*	*

(5) /CeCi/ → CiCi

/CeCi/	[IDENT(low)&IDENT(high)] <sub>Seg</sub>	*V Ci [-high]	IDENT(low)	IDENT(high)
CaCi		**!	*	
CeCi		*		
☞ CiCi				*

In this way, an input low vowel becomes an output mid vowel, whereas an input mid vowel gets to become high. Either way, there is improvement in performance on the markedness constraint, but the input low vowel cannot achieve perfect performance because it is held back by the high-ranking faithfulness constraint. The approach taken by Gnanadesikan is identical, except that the locally conjoined constraint is replaced by a constraint against two-step shifts on the tongue-height scale.

The Kirchner-Gnanadesikan approach to chain shifts crucially depends on Harmonic Parallelism. To see why, imagine instead that this analysis is embedded in Harmonic Serialism, keeping everything else the same. Starting from an input low vowel, the grammar will give a mid vowel as the output of pass 1, exactly as in tableau (4). But it will not converge on the mid vowel. Taking that output as a new input, pass 2 through this grammar will look exactly like tableau (5), and on the third pass it will converge on the high vowel. What this means is that chain shifts cannot be analyzed in Harmonic Serialism using the techniques proposed by Kirchner and Gnanadesikan. Hence, their analysis of chain shifts is crucially parallel. In Harmonic Serialism, the markedness constraint keeps on tugging at the low vowel until it becomes high; it is *durable*, because the same grammar, with the same ranking of markedness above faithfulness, evaluates candidates at each pass. (More below on durability and the general problem that Harmonic Serialism has with counter-feeding interactions.) In Harmonic Parallelism, on the other hand, the markedness constraint gets one chance, and then it's through.

There is another scenario in which Harmonic Serialism with unrestricted Gen will work differently than Harmonic Parallelism. Suppose that faithfulness constraints can be sensitive to input context; for example, the constraint IDENT(high)<sub>low</sub> could be defined to mean “an input low vowel cannot change its value of [high]”. Substituting this constraint for the locally conjoined faithfulness constraint in (4) and (5) would produce exactly the same difference: a chain shift that can be analyzed in Harmonic Parallelism but not in Harmonic Serialism.

In reality, there is little reason to assume that faithfulness constraints are sensitive to input context. Positional faithfulness constraints (Beckman 1997, 1998, Casali 1997) are sensitive either to output contexts (e.g., stressed syllable) or to contexts that Gen cannot alter (e.g., root, which is fixed among all candidates by “consistency of exponence” (McCarthy and Prince 1993)). Relatedly, Prince (1998) shows the need for “full symmetry” in

faithfulness constraints, arguing that even the distinction between IDENT(+F) and IDENT(-F) leads to intolerable consequences.

To sum up, I have argued that allowing a classic OT grammar to loop until convergence is not an entirely pointless exercise: there are two situations where looping Harmonic Serialism (with unrestricted Gen) produces results that are different from Harmonic Parallelism. But neither situation supports Harmonic Serialism. The first shows that techniques for analyzing chain-shifts in Harmonic Parallelism do not carry over to Harmonic Serialism — suggesting that there may be no way to account for chain-shifts in the serial model. The other situation involves faithfulness constraints that are sensitive to input context, an enrichment of faithfulness theory that is probably unnecessary anyway. If not pointless, then, Harmonic Serialism with unrestricted Gen is at best unpromising, and so we turn in the next section to a version of Harmonic Serialism closer to the one contemplated by Prince and Smolensky.

#### 4. Harmonic Serialism and Phonological Opacity

Suppose, for the reasons given in section 2, that Harmonic Serialism incorporates a restricted Gen which emits candidates differing from the input only in some minimal respect. For now, in order to avoid overly delicate assumptions about what this restriction is, let us suppose that Gen can affect only a single segment at a time. So, if the initial input is the segmental string /ABC/, the candidate set after the first pass through Gen might include XBC, AYC, and ABZ, but not XYC, XBZ, XYZ, etc.

With Gen restricted in this way, Harmonic Serialism will often produce derivations similar to those of rule-based phonology. The goal of this section is to investigate whether this approach will allow OT to accommodate a class of phenomena that have proven less tractable in Harmonic Parallelism than rule-based phonology: opacity. It turns out that, despite Harmonic Serialism's superficial similarities to rule-based derivation, the opaque interactions it can handle are surprisingly limited. (On opacity in OT generally, see Archangeli and Suzuki 1996, 1997, Black 1993, Booij 1997, Cho 1995, Chomsky 1995, Clements 1997, Goldsmith 1996, Halle and Idsardi 1997, Idsardi 1997, 1998, Jensen 1995, Kager 1997, to appear, McCarthy 1996, 1999a, 1999b, to appear-b, McCarthy and Prince 1993, Noyer 1997, Paradis 1997, Prince and Smolensky 1993, Roca 1997, Rubach 1997.)

The concept of opacity and the original definition come from Kiparsky's work:

(6) Opacity (Kiparsky 1973: 79)

A phonological rule  $\mathcal{P}$  of the form  $A \rightarrow B / C\_D$  is **opaque** if there are surface structures with any of the following characteristics:

- a. instances of  $A$  in the environment  $C\_D$ .
- b. instances of  $B$  derived by  $\mathcal{P}$  that occur in environments other than  $C\_D$
- c. [...neutralization case suppressed...not relevant...]

A phonological rule is opaque if there are either surface forms that look like they should have undergone that rule but didn't (clause a), or surface forms that did undergo that rule but look like they couldn't have (clause b). These two cases correspond approximately to two kinds of ordering in rule-based phonology. The first is exemplified in (7), a counter-feeding order:

(7) Type (6a), Counter-Feeding Opacity

Schematic Example		Bedouin Arabic Example (McCarthy 1999b, to appear-b & refs. there)	
Underlying	/ABC#/	Underlying	/badw/
B→D /__E	<i>does not apply</i>	Raising (a→i /__CV)	<i>does not apply</i>
C→E /__#	ABE#	Glide Vocalization	badu
Surface	ABE#	Surface	badu

The rule changing B to D applies before the environment E has been created. The result is a surface form that looks like it should have undergone the first rule, but didn't. In other words, the first rule is non-surface-true.

The other kind of opacity is exemplified in (8):

(8) Type (6b), Counter-Bleeding Opacity

Schematic Example		Hebrew Example (McCarthy 1999b & refs. there)	
Underlying	/ABC#/	Underlying	/deʃʔ/
B→D /__C	ADC#	Epenthesis	dešeʔ
C→E /__#	ADE#	ʔ-Deletion	deše
Surface	ADE#	Surface	deše

In this situation, a phonological process applies and then a later rule wipes out the conditions that made it applicable. As a result, the first rule is non-surface-apparent; that is, the conditions for its application are not apparent in surface structure.

We will be looking at both kinds of opacity in terms of Harmonic Serialism. We will start with counter-feeding opacity, where a process is not true at the surface. As it turns out, Harmonic Serialism doesn't help at all with this kind of opacity. Informally, the reason is that the derivation will not converge until all processes have "had a chance" to apply. The argument below develops this formally.

In (9), I've given some elementary constraint rankings to simulate the effects of the processes in (7). The first ranking deploys a markedness constraint against the sequence BE above a faithfulness constraint that militates against changing B to D. The next ranking in

(9) is similar, simulating the effect of the other process in (7). Finally, there's a ranking between the two markedness constraints, which is necessary to get things rolling.

(9) Constraint Rankings to Simulate (7)

- a. \*BE >> F(B≠D)
- b. \*C# >> F(C≠E)
- c. \*C# >> \*BE

The tableaux in (10) show how this grammar evaluates the input ABC in Harmonic Serialism:

(10) Tableaux for Counter-Feeding Opacity Under Harmonic Serialism

a. Pass 1: /ABC#/ → ABE# (cf. rule-based derivation (7))

/ABC#/ /badw/	*C#	F(C≠E)	*BE	F(B≠D)
i. $\begin{array}{l} \text{☞ ABE#} \\ \text{☞ badu} \end{array}$		*	*	
ii. $\begin{array}{l} \text{ADC#} \\ \text{bidw} \end{array}$	*!			*
iii. $\begin{array}{l} \text{ABC#} \\ \text{badw} \end{array}$	*!			

b. Pass 2: /ABE#/ → ADE# — satisfaction of \*BE can't be prevented

/ABE#/ /badu/	*C#	F(C≠E)	*BE	F(B≠D)
i. $\begin{array}{l} \text{☞ ADE#} \\ \text{☞ bidu} \end{array}$				*
ii. $\begin{array}{l} \text{ABC#} \\ \text{badw} \end{array}$	*!			
iii. $\begin{array}{l} \text{ABE#} \\ \text{badu} \end{array}$			*!	

c. Pass 3: /ADE#/ → \*ADE# — converges on transparent, not opaque, result.

/ADE#/	*C#	F(C≠E)	*BE	F(B≠D)
i.    ADE# bidu				
ii.    ADC# bidw	*!			
iii.    ABE# badu			*!	

The candidate ABE is the winner on the first pass through Gen and Eval. Of the various candidates that can be reached by altering a single segment of the input, this is the one that satisfies the undominated markedness constraint against final C. The other unfaithful candidate in pass 1, ADC, has altered a different input segment. The remaining candidate, ABC, is fully faithful.

Taking the output of pass 1 as input to pass 2, we see that immediate convergence is not obtained. A further shift from B to D happens, satisfying the markedness constraint against BE sequences at the expense of violating only the bottom-ranked faithfulness constraint. The grammar therefore converges at pass 3 on the transparent result ADE, rather than the desired opaque result ABE.

Why has Harmonic Serialism failed to simulate the opaque derivation of rule-based phonology? In counter-feeding opacity, some process is non-surface-true. This means that the intended output form violates some high-ranking markedness constraint. (In the tableaux above, that high-ranking markedness constraint is \*BE.) In Harmonic Serialism, just as in Harmonic Parallelism, there is no other constraint available to compel that markedness violation. In fact, counter-feeding opacity presents the same problem for Harmonic Serialism as it did for the rule ordering theories of the 1970's, which maximized rule application by allowing rules to apply and reapply freely until convergence (e.g., Koutsoudas, Sanders, and Noll 1974). Like free reapplication or persistent rules (Chafe 1968, Myers 1991), constraint ranking in Harmonic Serialism is *durable*. In other words, each pass through the Gen–Eval loop applies the same constraint hierarchy as previous passes. This means that even Harmonic Serialism is, in some sense, a “parallel” theory, because the full grammar is brought to bear at each step of the derivation.

Harmonic Serialism also has problems with counter-bleeding opacity. In (11), I give the markedness-faithfulness rankings corresponding to the counter-bleeding derivation in (8):

- (11) Constraint Rankings for (8)
  - \*BC >> F(B≠D)
  - \*C# >> F(C≠E)

The tableaux in (12) show how this grammar evaluates the candidates derived from the input ABC:

(12) Tableaux for Counter-Bleeding Opacity Under Harmonic Serialism

a. Pass 1: /ABC#/ → ABE#

/ABC#/	*BC	*C#	F(B→D)	F(C→E)
i. ABE# deš?				*
ii. ADC# deše?		*!	*	
iii. ABC# deš?	*!	*!		

b. Pass 2: /ABE#/ → \*ABE# — converges on transparent, not opaque, result.

/ABE#/	*BC	*C#	F(B→D)	F(C→E)
i. ABE# deš?				
ii. ADE# deše			*!	
iii. ABC# deš?	*!	*!		

The winning candidate at pass 1 is ABE. It incurs no markedness violations and only one low-ranking faithfulness violation. The desired output, ADE, isn't even among the candidates available at pass 1 because it differs by two steps from the original input. At pass 2, the desired output is in the candidate set, but it still loses to ABE, which violates neither markedness nor faithfulness relative to the pass 2 input ABE.

Why has Harmonic Serialism again failed to simulate the opaque derivation of rule-based phonology? Unlike the rule “package”, OT decouples targets, which are markedness constraints, from operations, which are unfaithful mappings. There are excellent typological reasons for doing this, as the OT literature abundantly attests (see, e.g., Lombardi 1995, Myers 1997, Pater 1999, Prince 1998), but it is also the source of this problem with Harmonic Serialism. The unfaithful /C/→E mapping is sufficient to satisfy both of the high-ranking markedness constraints, so the further /B/→D unfaithful mapping would be utterly gratuitous. In other words, there is no way to ensure that violation of \*BD will always trigger the /B/→D map, emphasizing that markedness/faithfulness interactions are not always

equivalent to rewrite rules like B→D/C\_\_E. In this respect, Harmonic Serialism is no different from Harmonic Parallelism.

To sum up, I have looked at counter-feeding and counter-bleeding opacity, and I have shown that Harmonic Serialism is not very successful at dealing with these interactions. In fact, Harmonic Serialism encounters basically the same problems with opacity as classic parallel OT does. This shows, somewhat unexpectedly, that the intermediate stages of a serial derivation are not by themselves sufficient for analyzing opaque interactions. The problems that Harmonic Serialism encounters come from other aspects of its architecture, aspects that it shares with Harmonic Parallelism: the unity or durability of the constraint hierarchy and the decoupling of markedness and faithfulness. This means that alternative accounts of opacity in OT need to be considered, such as those in McCarthy (1999b, to appear-b) or Goldrick and Smolensky (1999).

Before leaving the topic of opacity in Harmonic Serialism, some possible refinements might be mentioned. In a limited and rather arbitrary set of cases, Harmonic Serialism can handle counter-bleeding opacity. The trick is to make sure that no candidate available at pass 1 satisfies both markedness constraints. In other words, there is no “fell-swoop” candidate equivalent to ABE in (12). That will happen if the fell-swoop candidate is not so fell, because it cannot be obtained in a single pass through Gen.

For instance, most work in autosegmental phonology assumes that deletion of a segment is a two-step process, involving separate rules deleting the segment’s featural root-node and its skeletal slot. Under this view, syncope of a vowel requires prior reduction of the vowel to featureless  $\emptyset$ , as in the following derivation:<sup>5</sup>

(13) A Hypothetical Example

Underlying	/darabat/
Post-vocalic Spirantization	daravat
Vowel Reduction	dar $\emptyset$ vat
Syncope of $\emptyset$	darvat

In addition to illustrating the two-step nature of syncope under this assumption, (13) is a counter-bleeding derivation, since the process of post-vocalic spirantization is made opaque when the vowel eventually deletes.

Suppose a similar restriction is imposed on Gen in Harmonic Serialism. Then deletion of /a/ cannot be accomplished in a single pass, so the transparent, fell-swoop candidate *darbat* isn’t available at pass 1. The constraints and rankings in (14) will produce this derivation:

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<sup>5</sup>This example was suggested by Alan Prince

## (14) Constraints and Rankings for (13)

## a. Markedness Constraints

SPIR  $\equiv$  \*VC<sub>Stop</sub>RED  $\equiv$  \*V<sub>V-Place</sub>CV<sub>V-Place</sub>SYNC  $\equiv$  \*VC $\emptyset$ CV

## b. Rankings

SPIR  $\gg$  IDENT(cont)*Post-vocalic spirantization.*RED  $\gg$  MAX(V-Place)*Alternate vowels reduce to  $\emptyset$ .*SYNC  $\gg$  MAX-V*No  $\emptyset$  in two-sided open syllable.*SPIR  $\gg$  RED*Explained below.*RED  $\gg$  SYNC*Explained below.*

Take particular note of the last two rankings, which establish a hierarchy among the three markedness constraints. Their importance will be explained shortly.

The following tableaux show how the grammar in (14) produces the opaque derivation of *darvat* from /darabat/, under the assumption that Gen cannot map /a/ to  $\emptyset$  in a single step:

(15) Deriving /darabat/  $\rightarrow$  *darvat* in Harmonic Serialisma. Pass 1: /darabat/  $\rightarrow$  *daravat*

/darabat/	SPIR	IDENT(cont)	RED	MAX(V-Place)	SYNC	MAX-V
i. $\text{daravat}$		*	*			
ii. $\text{dar}\emptyset\text{bat}$	*!			*	*	
iii. $\text{darabat}$	*!		*			

b. Pass 2: /daravat/  $\rightarrow$  *dar $\emptyset$ vat*

/daravat/	SPIR	IDENT(cont)	RED	MAX(V-Place)	SYNC	MAX-V
i. $\text{dar}\emptyset\text{vat}$				*	*	
ii. $\text{darabat}$	*!	*	*			
iii. $\text{daravat}$			*!			

c. Pass 3: /dar $\emptyset$ vat/  $\rightarrow$  *darvat*

/dar $\emptyset$ vat/	SPIR	IDENT(cont)	RED	MAX(V-Place)	SYNC	MAX-V
i. $\text{darvat}$						*
ii. $\text{daravat}$			*!			
iii. $\text{dar}\emptyset\text{vat}$					*!	

d. Pass 4: /darvat/ → *darvat* — convergence.

/darvat/	SPIR	IDENT(cont)	RED	MAX(V-Place)	SYNC	MAX-V
i. darvat						
ii. darəvat					*!	
iii. darbat		*!				

In the first pass through the grammar, a candidate with post-vocalic spirantization wins. It violates the markedness constraint RED. The second candidate obeys RED, but it violates the markedness constraint SPIR, which demands post-vocalic spirantization. Because SPIR dominates RED, the candidate with spirantization rather than reduction is the winner. The ranking between SPIR and RED produces an effect similar to rule ordering. These two markedness constraints describe different “problems”. Because Gen is limited to making single modifications, it is not possible to “fix” both of these problems at once. The ranking of these two markedness constraints says which one to fix first.

We’re now up to pass 2. The input is *daravat*, and the output is a candidate with vowel reduction. This output does worse than the faithful candidate on the markedness constraint SYNC, which bans schwa from two-sided open syllables. For this reason, RED must be ranked above SYNC. This ranking could not be justified in Harmonic Parallelism, because RED and SYNC do not conflict in the parallel theory, when the mapping is from the input directly to the ultimate output.

In pass 3, SYNC is at last satisfied, and only the lowest-ranking faithfulness constraint is violated. (Observe how the shading of the winning candidate progresses to the right, as greater harmony is achieved in successive passes through Gen→Eval.) And at pass 4, the derivation converges on the ultimate output, *darvat*.

This hypothetical example shows that Harmonic Serialism can address a subset of counter-bleeding cases, but that subset appears to be linguistically arbitrary and uninteresting. Perhaps the most curious feature of this example is the use of constraint ranking to produce an ordering effect. Not surprisingly, this strategy will not always work, because sometimes the ranking needed to get the opaque ordering is incompatible with rankings that are independently motivated in the language. A real-life situation like this occurs in Yokuts. Vowel harmony precedes lowering of long high vowels in derivational analyses. Using ranking to produce this ordering in Harmonic Serialism requires that the responsible markedness constraints (ALIGN(Color) and LONG/–HIGH in Archangeli and Suzuki (1997)) be ranked as ALIGN(Color) >> LONG/–HIGH (assuming that Gen cannot simultaneously alter a vowel’s height and length). But independent ranking arguments show, by transitivity of domination, that the ranking of these constraints is the other way around (McCarthy 1999b). This paradox suggests that the ranking-as-ordering strategy for dealing with opacity in Harmonic Serialism is fundamentally misconceived. The problem, as above, is that constraint ranking in Harmonic Serialism is *durable*. Rule ordering gives the early rule one-time priority over the late rule. But in Harmonic Serialism, each pass through GEN→EVAL

applies the same constraint hierarchy, with the same durable priority relationships, as previous passes. In this respect, even Harmonic Serialism is a parallel theory, with the full grammar being brought to bear at each step of the derivation.

## 5. Harmonic Serialism and Harmonic Ascent

Classic OT grammars share a general property called *harmonic ascent* (Moreton 1996, Prince 1997). A classic OT grammar, following Prince and Smolensky (1993), is a ranking of markedness and faithfulness constraints, and nothing else. Because violation is minimal, unfaithfulness is only possible to achieve markedness improvement relative to some language-particular ranking of the markedness constraints in UG. So, if a language has an unfaithful mapping  $/A/ \rightarrow B$ , then B must be less marked, relative to that language's hierarchy, than the fully faithful candidate A. (See Moreton 1996 for a formal proof of this result.)

Harmonic Serialism is just a classic OT grammar looped back on its own output, so each pass has to respect harmonic ascent. Furthermore, since the same grammar is being applied on each pass through the loop, we can compare the markedness of outputs at any pass to any other pass, through transitivity. Each intermediate stage of the Harmonic Serialist derivation must be less marked, relative to the language-particular hierarchy in which it's embedded, than all of its derivational predecessors. For instance, if the successive passes of a Harmonic Serialist derivation produce  $/A/ \rightarrow B \rightarrow C \rightarrow D \rightarrow E \rightarrow E$ , then B is less marked than A, C is less marked than A and B, and so on. In contrast, Harmonic Parallelism requires only that E be less marked than A, B, C, and D. This difference between Harmonic Serialism and Harmonic Parallelism has several interesting consequences.

We have already seen one consequence: in order to ensure steady markedness improvement throughout the derivation, Harmonic Serialism might need to rank constraints that don't conflict in Harmonic Parallelism. Recall the situation in (15). Under the parallel regime, it is enough that the ultimate output *darvat* be less marked than faithful *darabat* and the other candidates *darəbat*, *daravat*, and *darvat*. But to produce the serial derivation in (15), further markedness relations are required: it is crucial that *darəvat*, with vowel reduction but without syncope, be less marked than *daravat*, without reduction or syncope. That is why (15) requires the ranking RED >> SYNC, even though these constraints do not conflict in the parallel theory.

This consequence has a further ramification: even markedness constraints that are undominated in Harmonic Parallelism might need to be crucially dominated in Harmonic Serialism. For example, under some construals of what it means for Gen to perform a "single modification", the analysis of Lardil truncation (cf. Prince and Smolensky 1993) must recognize several intermediate stages:  $/muŋkumuŋku/ \rightarrow muŋkumuŋk(u) \rightarrow muŋkumuŋ(ku) \rightarrow muŋkumu(ŋku)$ . (This is essentially the way Hale's (1973) original rule-based analysis works: it eats up the word one segment at a time from the right edge.) Because of harmonic ascent, implementing Prince and Smolensky's analysis in Harmonic Serialism would require that FREE-V, which compels truncation, be ranked above \*COMPLEX and CODA-COND — even though no ultimate output form of Lardil ever violates those two constraints. This ranking

is necessary because deletion of the final vowel on Pass 1 will expose phonotactically impermissible consonants, and they can't be fixed until subsequent passes through the Gen→Eval loop.

These considerations impose strong conditions on the adequacy of markedness rankings under Harmonic Serialism. The general character of these conditions is this. If A becomes C *via* B in Harmonic Serialism, then all independently motivated rankings of markedness constraints in the language must also be consistent with saying that B is less marked than A.

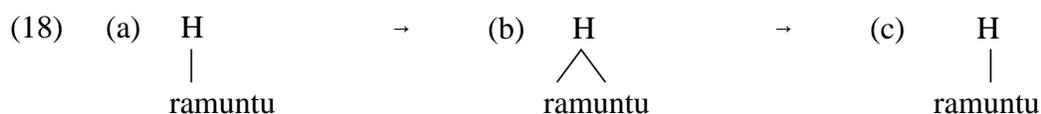
It's not too hard to find problematic examples in the literature. In (16) and (17), I summarize an example coming from Myers (1997). In Rimi, there is a process of tone shift or “flop”, moving the high tone from the prefix onto the first syllable of the root. Myers attributes the tone shift to the force of ALIGN-R, which is crucially dominated by constraints that stop the tone from spreading rather than shifting (NO-LONG-T), from shifting too far (LOCAL), and from deleting instead (MAX(T)):

- (16) Constraints for Rimi (after Myers 1997: 876)
  - a. ALIGN-R = Align(H, R, PP, R)      ≡ (cf. p. 857) the right edge of the rightmost syllable associated with any H tone must be aligned with the right edge of the phonological phrase.
  - b. LOCAL      ≡ “If an input tone *T* has an output correspondent *T'*, some edge of *T* must correspond to some edge of *T'*.”
  - c. NO-LONG-T      ≡ “A tone may be associated with at most one syllable.”
  - d. MAX(T)      ≡ No tone deletion
  - DEP(A), MAX(A)      ≡ No insertion/deletion of association lines.

(17) Tableau for /rá-muntu/ → ramúntu (after Myers 1997: 877)

<div style="text-align: center;">H   ramuntu</div>	NO-LONG-T	LOCAL	MAX(T)	ALIGN-R	MAX(A)	DEP(A)
<div style="text-align: center;">H   a. ramuntu</div>				*!*		
<div style="text-align: center;">H   b. ramuntu</div>				*	*	*
<div style="text-align: center;">H   c. ramuntu</div>		*!			*	*
<div style="text-align: center;">H / \ d. ramuntu</div>	*!					**
<div style="text-align: center;">e. ramuntu</div>			*!			

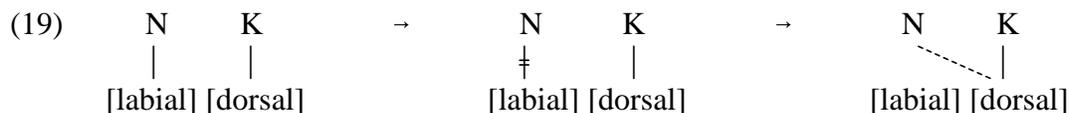
Of course, Myers's analysis is embedded in the parallel architecture. Suppose we try to replicate it in Harmonic Serialism.<sup>6</sup> Research in autosegmental phonology (see section 2) has generally regarded flop as a two-step process, consisting of spreading followed by delinking, as in (18):



A similar restriction can be imposed on Gen: no candidate can simultaneously add and remove an association line.<sup>7</sup> Nonetheless, this derivation cannot be replicated in Harmonic Serialism, given a grammar like the one Myers proposes. The problem is that the shift from (18a) to (18b) is not a reduction in markedness; on the contrary, it is an increase in markedness because the constraint against spread tones, NO-LONG-T, dominates the constraint demanding rightward alignment of tones, ALIGN-R. So, even though the ultimate output is less marked than the ultimate input, the intermediate stage is more marked. This makes the intended ultimate output inaccessible, at least by way of the intermediate stage in (18b). (Another derivational path, delinking followed by relinking, is considered in (20) below.)

Inaccessibility because of harmonic ascent has significant consequences for language typology. If A changes into C via B in Harmonic Serialism, then universal grammar must supply *some* markedness constraint which says that B is less marked than A. If there is no such constraint, and if there is no alternative path to the same destination, then C will be unattainable from A, even if C is less marked than A. This is a major difference between Harmonic Serialism and Harmonic Parallelism, since Harmonic Parallelism allows the A to C mapping if C is less marked than A and B — not requiring that B also be less marked than A.<sup>8</sup>

In general, serial derivations do not have this property of monotonic markedness improvement, as Goldsmith (1993) emphasizes. Rules often create marked structures that subsequent rules repair. For example, as I noted in section 2, work in autosegmental phonology fairly standardly assumes that feature-changing assimilation involves separate derivational steps of delinking and spreading, as in (19):



<sup>6</sup>I am indebted to Paul de Lacy for pointing out the relevance of tonal flop processes.

<sup>7</sup>It is sometimes implied that flop processes can be accomplished by literal movement of the association line from one segment to another. This is a formal absurdity, however; association lines represent relations between elements rather than elements themselves.

<sup>8</sup>One good consequence of this arises in Lardil. Harmonic Serialism immediately explains why Lardil /wiʔe/ → *wi.ʔe*, \**wi.r□(e)*, without invoking the ranking FILL-NUC >> FREE-V (Prince and Smolensky 1993: 112, cf. fn. 62 for alternatives).

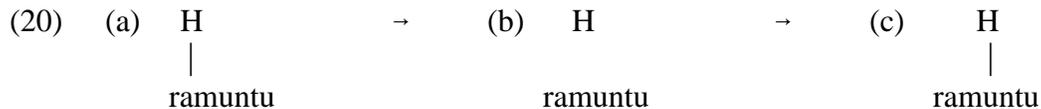
To produce this derivation in Harmonic Serialism, given a similarly restricted definition of Gen, would require that the unspecified coda nasal be less marked than the specified one. This seems like an unlikely prospect. In contrast, Harmonic Parallelism has no worries about loser candidates like *Nk*; they're harmonically bound by their competitors.

Generalizing from these considerations, we obtain the following prediction about Harmonic Serialism: if one language has the mapping  $A \rightarrow B \rightarrow C$ , then another will have the mapping  $A \rightarrow B$  (where  $B$  is the ultimate output). This follows from ranking permutation, given the logic of the situation: the Harmonic Serialism derivation  $A \rightarrow B \rightarrow C$  implies the existence of

- (i) some faithfulness violation \*F that  $C$  incurs but  $A$  and  $B$  don't, and
- (ii) some markedness violation \*M that  $A$  incurs but  $B$  and  $C$  don't.

So the  $A \rightarrow B$  map avoids \*F and \*M.

In this light, consider now an alternative derivational path for Rimi tone flop:



For the reasons just given, if Rimi has this derivation under Harmonic Serialism, then some other language can have the mapping from (20a) to (20b), where (20b) is the ultimate output. This seems quite improbable, since it involves spontaneous, evidently unconditioned creation of a floating tone. This kind of situation, where derivations temporarily contain impossible configurations or allow impossible mappings, is common in rule-based phonology but cannot be replicated in Harmonic Serialism for reasons having to do with the basic architecture of OT.<sup>9</sup>

## 6. Conclusion

It is worth considering the derivational implementation of OT called Harmonic Serialism, if only because of its similarity to other derivational theories. Here, I looked at two approaches to Harmonic Serialism, one with unrestricted Gen and another that restricts Gen to making one modification at a time. We saw in section 3 that Harmonic Serialism with unrestricted Gen differs from parallel OT only in very particular circumstances that either do not occur or that seem to favor the parallel approach. In section 4 we looked at how Harmonic Serialism with single-modification Gen addresses phonological opacity. Despite having derivations with intermediate stages, Harmonic Serialism is not very successful in

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<sup>9</sup>Paul de Lacy notes that this discussion suggests another way to study Harmonic Serialism: starting from observed phonological systems and a theory of markedness constraints, determine which primitive operations Gen must contain to be consistent with harmonic ascent. For instance, the Rimi case shows that Gen must allow flop as a primitive operation, since the available decompositions of flop in (18) and (20) cannot be reconciled with harmonic ascent. If the practical difficulties attendant on this enterprise can be overcome, it might show whether Harmonic Serialism can be implemented with a coherent theory of Gen or even one that is different from Harmonic Parallelism. In a sense, this is the issue raised by Prince and Smolensky in the quotation at the beginning of this paper.

treating opacity. It runs into problems because of the durability of the constraint hierarchy and the markedness/faithfulness split, basic characteristics that it shares with the parallel implementation of Optimality Theory. We then looked in section 5 at the consequences that harmonic ascent has for Harmonic Serialism with single-modification Gen. They sharply distinguish Harmonic Serialism from Harmonic Parallelism on the one hand and rule-based phonology on the other. The predictions that Harmonic Serialism makes seem perilous and unlikely to survive further scrutiny.

Two final remarks. It seems clear that Prince and Smolensky have been richly vindicated in their decision to focus most of their attention on Harmonic Parallelism. But it also seems clear that Harmonic Serialism is worth studying, and may very well reward further examination under assumptions different from those that I have entertained here.

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