4:

RULE INTERACTION AND CONSTRAINT INTERACTION

The basic elements of derivational and optimality grammars are the rules or the constraints, and the pattern of surface representations is derived from the interaction between these basic elements. To govern the interaction of basic elements, the derivational framework employs an ordering relation on rules, and the optimality framework employs an ordering relation (termed a "ranking") on constraints.

Once we draw an analogy between rules and constraints, we may compare systematically the interaction of rules in serial order with the interaction of constraints in rank order. We then find that although certain patterns are derivable either way, each system derives some patterns that are not replicated by the other. We will catalogue these convergences and divergences at length, correcting statements of previous commentators. Since there is empirical support both for patterns derived exclusively by serial rule interaction *and* for patterns derived exclusively by constraint interaction, a fully adequate phonological theory must combine the descriptive capacities of both approaches.

4.1 The Rule-Constraint Analogy

In this section we will first establish the foundational point that an analogy exists between rules and constraints. If rules and constraints can be correlated with each other in some way, then it will make sense to compare interactions among rules with interactions among constraints.

The analogy between rules and constraints lies in the fact that both rules and constraints *discriminate* between phonological representations - representations may be marked out as satisfying the structural description of a rule, or equally, marked out as violating a constraint. If

M is a structural configuration contained in some representations, then M may be employed as the structural description of a rule which maps representations containing M to representations which lack M. Or, M may be specified by a Markedness constraint, *M, which gives violation marks to representations containing M. In (1), we show the correlation between a degemination rule and a no-geminate constraint:

(1) a. *Rule*

```
  X   X
   \ ≠
[+cons]
```

b. *Markedness Constraint*

```
*X   X
   \  /
[+cons]
```

c. *Structural configuration shared by both*

```
  X   X
   \  /
[+cons]
```

Indeed, representations might contain M several times over: meeting the structural description of the rule several times over, or violating the constraint several times over. Since rules and constraints both discriminate among representations, they both define mathematical *relations* in the set of representations. In particular, markedness constraints determine that some representations are **less harmonic than** others, by virtue of the fact that they violate the constraint. And a rule determines that, within derivations, some representations are **immediately**

succeeded by new representations, by virtue of the fact that they meet the structural description of the rule. This is illustrated in (2) for a degemination rule and no-geminate constraint:

(2)	*Degemination Rule:*	*No-Geminate Constraint:*
	atta **immediately succeeded by** ata	atta **less harmonic than** ata
	attatta **immediately succeeded by** atatta	attatta **less harmonic than** atatta
	atatta **immediately succeeded by** atata	atatta **less harmonic than** atata

Since rules and markedness constraints both define relations in the set of representations, the relations may coincide. Immediate succession relations are more restricted than harmony relations, however, because they pick out one particular form as successor, whereas there are many forms that are more harmonic, even minimally more harmonic than a given representation. For example, a degemination rule may delink the first timing unit of the geminate or it may delink the second (1a), but *any* non-geminate structure is better than a geminate when evaluated against a no-geminate constraint (1b). Nevertheless, the relations coincide to the maximum extent if they pick out representations using the same structural configuration M, which is the case with the degemination rule and the no-geminate constraint. If a rule and a constraint overlap to the maximum extent, we shall say they are **strongly analogous**. Strong analogy means that all representations which meet the structural description *n* times over also violate the constraint *n* times over, and vice versa. This is expressed in algebraic form in the accompanying text box:

Strong Analogy

Let R be a rule and C an output constraint. C partitions the set of representations into equivalence classes C_0, C_1, C_2, C_3, ... where, for each $n\geq1$, all representations in C_n are isoharmonic, but all are less harmonic than representations in C_{n-1} (and hence in C_{n-2}, ..., C_0). R partitions the set of representations into equivalence classes R_0, R_1, R_2, R_3, ... where, for each n, R maps each representation in R_n to some member of R_{n-1}.

R and C are **strongly analogous** if they define identical equivalence classes in the representational set, $C_1 = R_1$, $C_2 = R_2$, ... and $C_n = R_n$, for n=1,2,3,… .

If R and C are not strongly analogous, then we can always define a strongly analogous rule and constraint R’ and C’ derivatively, such that R’ and C’ partition the set of representations into equivalence classes containing only those representations that are partitioned off by BOTH R and C. Thus,

$C'_1 = R'_1 =_{def} C_1 \cap R_1$,

$C'_2 = R'_2 =_{def} C_2 \cap R_2$, ...

In general, $C'_n = R'_n =_{def} C_n \cap R_n$, for n=1,2,3,…

A lesser correlation than that of strong analogy is conceivable. Compare a general degemination rule to a constraint against *voiced* geminates, or compare a degemination rule restricted to voiced geminates with a constraint against *velar* geminates. There is still consistent overlap, so that in the latter example, *voiced, velar* geminates would be marked off by both rule and constraint. Care is required here, however: overlap is not sufficient to draw a reasonable analogy because *all* rules and constraints have *some* overlap, even those with unrelated structural configurations, since one can always construct a representation that contains both of them. For example, a constraint against front rounded vowels and an unrelated rule voicing intervocalic consonants overlap in forms like /basity/. Rather, a reasonable systematic analogy obtains when the structural configurations are satisfied by the same section of structure, as is the case for the rule degeminating voiced geminates and the constraint against velar geminates.[1] In general, then, connection can be made between rules and constraints on the basis of the structural configuration they mention.

Our brief comparison demonstrates that while rules and constraints are not formally identical, they can still be identified with each other, since both discriminate between phonological representations, by referring to structural configurations. We can take individual generalisations, or collections of marked feature combinations in vowels (Calabrese 1995), or the class of phonetically grounded constraints (Archangeli and Pulleyblank 1994), or schemata such as Alignment (McCarthy and Prince 1993a), and put them to the test both as markedness constraints and as structural descriptions of rules.

Having isolated the notion of strong analogy between Markedness constraints and the structural descriptions of rules, we may now use the notion to compare the interactions between rules with the interaction of constraints. Since strong analogy can be defined independently of questions of substantive content, we abstract away from questions of whether rules/constraints are simple or complex, plausible or implausible, universal or language-specific, and other details, so that we can conduct a formal comparison of the systems in which these questions are *embedded*. This maximises the generality of the study, so that it has relevance over and above all controversies among phonologists about exactly what structural configurations are involved, and

[1] The "Phonological Level Hierarchy" (Paradis 1988) seems relevant here: the highest level of phonological structure ('X' timing units) is decisive in casting the analogy, whereas the features of voicing and velar place at lower levels in the structure are not decisive in drawing an analogy. Thus, rules/constraints with *geminate* configurations are all analogous, but rules that refer to *velar* geminates do not seem analogous to rules/constraints referring to labialised *velars*.

relevance across all subdomains of phonology. Failing to abstract the issue from these other considerations only holds up the advance of scholarship.[2]

4.2 An Analysis of Serial Rule Interaction

Having analysed the formal relationship between rules and constraints, we will now set out what we regard as the essentials of serial rule interaction. Once again, the basis for this is to consider rules as relations on the set of representations. This will clarify rule interaction, but also will lend itself to a fully generalised comparison with constraint interaction.

In a grammar based on rules, serial derivations are built up from the application of one operation after another, if the conditions on application of the rules (traditionally, the "structural description") allow. A structural description may be **met at the outset**, or it may be **met by feeding** when structure is altered by the application of some particular prior rule. It may be **left unaltered**, or it may be **subject to alteration** if, after a rule has applied, another part of the structure meeting its structural description is altered by the application of some particular subsequent rule. Without the full structural context at a later derivational stage or at the surface, it is not clear why the process should have applied - an apparent "overapplication" (Roca 1997b:8, Idsardi 2000:338, McCarthy 1999a:3). This has also been called "non-surface-apparent" opacity (McCarthy 1999a:2) because a piece of the surface structure that differs from the lexical

[2]Thus we depart from the position of McCarthy (1999a) who claims, untenably, that it is impossible to give a *general* characterisation of where the two frameworks differ over the accommodation of certain patterns (in this case, generalisations that are non-surface-true): "On the OT side, the universality of constraints means that a markedness constraint [like ONSET] might be dominated for reasons that have nothing to do with opacity. And on the serialism side, the non-universality of rules means that we cannot in general know that generalisations like (i)[permitting onsetless syllables word-initially] are the result of derivational opacity instead of positing an epenthesis rule that is limited to medial syllables." (McCarthy 1999a:2-3 fn.1). For us, the question of universality should and *can* be kept separate. So of course we cannot *know* the rules of a language, but we do not need to maintain a studied uncertainty about the form of rules. Rather, we take a certain range of rule systems and consider whether all of them, or some subset, can be mapped into constraint systems without losing the same output.

source is attributed to a linguistic generalisation which is not itself apparent in that surface form, but takes effect at a level more abstract than the surface form itself.

For exemplification, let us confine our attention to the application of pairs of rules. The second rule's structural description might be met by the feeding of the first; the first rule's structural description might be rendered opaque by the second. This will give us four logical possibilities.

(a) Both met at the outset; Both left unaltered (mutually non-affecting)

One kind of pair of mutually non-affecting processes might be the formation of syllable nuclei from vowels and changes to vowel quality that are irrelevant to syllabification. In English, vowels are always tense when immediately followed by another vowel - e.g. *men**i**al, var**i**ous, affil**i**ate, man**u**al, grad**u**ate, tort**u**ous, sens**u**al* are [i,u] rather than lax [ɪ,ʊ] This may be specified by the following rule:

(3) English Prevocalic Tensing (Roca and Johnson 1999:567)

[-consonantal] $\rightarrow$ [+ATR] / _______ [-consonantal]

This rule will not alter the formation of syllable nuclei based on these vowels, nor will syllable nucleus formation alter the conditions giving rise to tensing – the two are mutually non-affecting.

(b) Second met by feeding; Both left unaltered (simple feeding)

Many structure-building operations feed and are met by feeding: formation of syllable nucleus feeds syllable onset formation; conditions for stress to be assigned to syllables are fed by the construction of syllables themselves. An example of a segmental process that may be fed by other rules is postvocalic spirantisation in Tiberian Hebrew (Idsardi 1998). In (4), the obstruents are fricatives when in post-vocalic environment, but stops in other environments.

(4) Tiberian Hebrew spirantisation

ḵaaθ̱áv	ʼhe wrote’	g̱aað̱ál	ʼhe was great’
jix̱ṯóov	ʼhe writes’	jiɣ̱ḏóol	ʼhe is great’

In one feeding interaction, some post-vocalic obstruents arise through word-final degemination. Geminates themselves do not undergo spirantisation (Schein and Steriade 1986), but degemination can lead to (i.e. feed) spirantisation, as in (5).

(5) Tiberian Hebrew Spirantisation met by feeding

a.	rav	‘much/large sg.’
	rabbim	‘many/large pl.’

b. Derivation of *rav*:

/rabb/	
rab	Word-final Degemination
rav	Postvocalic Spirantisation

The conditions for both processes remain transparent - the right-hand environment of word-finality, and the left-hand environment of a preceding vowel.

(c) Both met at the outset; First subject to alteration (counterbleeding)

A productive example of this interaction is supplied by Serbo-Croat. Epenthesis is used to break up unsyllabifiable consonant combinations (6a). It is also the case in Serbo-Croat that /l/ vocalises to /o/ word-finally (6b). The conditions for both epenthesis and l-vocalisation are met by word-final /Cl/. Epenthesis occurs, but the condition for its occurrence is removed when the /l/ is vocalised in (6c).

(6) Serbo-Croat (Kenstowicz 1994:90ff)

	Masculine	Feminine	Neuter	Plural	gloss
	mlad	mlad-a	mlad-o	mlad-i	‘young’
	zelen	zelen-a	zelen-o	zelen-i	‘green’
a.	ledan	ledn-a	ledn-o	ledn-i	‘frozen’
	dobar	dobr-a	dobr-o	dobr-i	‘good’
	jasan	jasn-a	jasn-o	jasn-i	‘clear’
b.	debeo	debel-a	debel-o	debel-i	‘fat’
	beo	bel-a	bel-o	bel-i	‘white’
	mio	mil-a	mil-o	mil-i	‘dear’
c.	okrugao	okrugl-a	okrugl-o	okrugl-i	‘round’
	nagao	nagl-a	nagl-o	nagl-i	‘abrupt’
	podao	podl-a	podl-o	podl-i	‘base’

The conditions for vowel epenthesis in Eastern Massachusetts English may similarly become opaque (McCarthy 1991,1999c, Halle and Idsardi 1997). Epenthesis breaks up unsyllabifiable consonant sequences of /j/ and a liquid. If the liquid is /r/, however, it is subject to coda *r*-deletion, removing the condition responsible for the epenthesis. Thus, *desire* is derived dɪzajɹ → dɪzajəɹ → dɪzajə, the underlying form /dɪzajɹ/ being supported by its rendering in the suffixed form *desirous* [dɪzajɹəs]. The altering of the conditions for epenthesis by consonant deletion is also found in analyses of Tiberian Hebrew (McCarthy 1999a).

In Tiberian and Modern Hebrew, the conditions for the formation of fricatives (spirantisation) may be subject to alteration (Idsardi 1997,1998). Fricatives occur following a vowel; plosives in other environments. However, fricatives survive even after their conditioning vowel is lost completely in syncope: Modern Hebrew bi-saPor (P a labial obstruent) → bi-safor (spirantisation) → [bis**f**or] (vowel syncope) ‘on counting’. Compare [lis**p**or] ‘to count’.

Very commonly, vowels lengthen before voiced consonants, but it is also common that the postvocalic consonant itself is also altered, so that the voicing that conditions vowel length is not present in the surface representation (Dinnsen, McGarrity, O'Connor and Swanson 2000). This recurs not only cross-linguistically, but also during acquisition. In (7a), a child with a disordered phonology deletes final consonants that otherwise surface in an intervocalic context (7b). Since the consonants are omitted, the basis of the longer vowels for the forms on the left is absent.

(7) American English Child aged 7;2 (quoted in Dinnsen et al 2000)

a.	kæː	'cab'	ka	'cop'
	kɪː	'kid'	pæ	'pat'
	dɔː	'dog'	dʌ	'duck'
b.	kæbi	'cabby'	kapoʊ	'copper'
	kɪdoʊ	'kiddo'	pæti	'patty'
	dɔgi	'doggy'	dʌki	'ducky'

Other children may reduce final consonants to glottal stops, again removing the voicing distinction that conditions vowel length. Similarly, American adults neutralise /t/ and /d/ to a flap, giving [ɹaɪɾɹ̩] *writer* vs. [ɹaɪːɾɹ̩] *rider*, a minimal pair distinguished only by the resulting vowel length difference (Dresher 1981). Dinnsen et al (2000) concede that there could be some doubt as to whether vowel lengthening and consonant reduction are always discrete phonological alternations or, rather, effects of phonetic execution of the vowel-consonant sequences concerned, given the phonetic motivations for the changes involved (Chen 1970, Port and Crawford 1989). A minimally different pattern in Canadian English is often cited, where /t/-/d/ neutralisation alters the conditions behind vowel *raising* before *voiceless* consonants, so that *writer* [ɹʌidəɹ] and *rider* [ɹaidəɹ] differ in the diphthong, but not in the following consonant (Joos 1942, Halle 1962, Bromberger and Halle 1989, Kenstowicz 1994:99-100). However, the low and raised vowels do not actually alternate -[ɹʌit]/[ɹʌidəɹ], [ɹaid]/[ɹaidəɹ] - and there are even a few examples of [a] that contrast with [ʌ] e.g. [saiklaps] *cyclops,* although there are some alternations induced by voicing changes – [nʌif] *knife* but [naivz] *knives*. So, this pattern may be viewed as a subregularity of the lexicon, perhaps expressed by a 'lexical rule' (Kiparsky and Menn 1977). In conclusion, although the Serbo-Croat adjectival paradigm in (6) above seems to provide an instance where one general process alters the conditions that cause another, we have other examples in the literature that are not quite as robust, and which raise two, opposite, difficulties: they may represent historical developments in the lexicon of a language that do not reflect productive phonology, or; they may be entirely productive and well-motivated such that they could be conventionalised phonetic processes.

(d) Second met by feeding; First subject to alteration

The final possibility combines feeding and alteration of conditions into a single complex interaction between two processes. Although the phonology literature has not previously isolated and named this type, there are well-known examples of it.

One is from Klamath (Halle and Clements 1983:113, Clements 1985, Iverson 1989), already referred to in 1.2.1. Nasals change to laterals before a following lateral, but, in a sequence of two laterals, if the second lateral is voiceless or glottalised then the sequence is simplified to lateral-laryngeal [lh] or [lʔ]. The first process feeds the second by creating lateral-lateral sequences, /nl̥/→ ll̥ → [lh] and /nlˀ/ → llˀ → [lʔ], but the second process destroys the original lateral that is the condition for the first process, rendering it opaque.

Another example is from Turkish (Orgun and Sprouse 1999, Sprouse, Inkelas and Orgun 2001). Epenthesis breaks up consonant clusters in Turkish, e.g. devr-i ‘transfer’-acc. but dev<u>i</u>r ‘transfer’-nom. Epenthesis applies between consonant-final stems and consonant suffixes such as the 1sg. possessive suffix *-m* as shown in (8).[3]

(8) Turkish (Kenstowicz and Kisseberth 1979:192)

	Abs. sg.	Abs. pl.	3sg. Poss.	1sg. Poss.	Gloss
a.	arı	arı-lar	arı-sı	arı-m	‘bee’
	araba	araba-lar	araba-sı	araba-m	‘wagon’
b.	kız	kız-lar	kız-ı	kız-ı-m	‘daughter’
	yel	yel-ler	yel-i	yel-i-m	‘wind’
c.	ayak	ayak-ler	aya-ı	aya-ı-m	‘foot’
	inek	inek-ler	ine-i	ine-i-m	‘cow’
	kuyruk	kuyruk-lar	kuyru-u	kuyru-u-m	‘tail’

With vowel-final stems (8a), no epenthetic vowel is necessary in the 1sg. Possessive, rather it occurs with consonant-final stems (8b). In (8c), the final *k* of a polysyllabic stem is deleted intervocalically (Zimmer 1975), but stems with deleted final *k* take an apparently unnecessary epenthetic vowel in the 1sg. possessive. In these cases, epenthesis leaves stem-final *k* in an intervocalic environment and thereby feeds *k*-deletion, and in turn, deletion of the *k* removes the overt motivation for epenthesis.

[3]The traditional description of Turkish gives a maximal suffix form *-Im* and claims that the vowel is deleted following another vowel (Kornfilt 1997). The opposite analysis, where the suffix is taken to be *-m*, and vowel epenthesis is used to break up consonant clusters, is taken up by Inkelas and Orgun (1995) on the evidence of word minimality effects.

The interactions (a)-(d) discussed so far employ 'unbridled' serialism: rules apply if their structural descriptions are met. This can be done by ordering of the two rules consistently with their order of application, or it can be done in the absence of ordering. This alone leads to the possibilities of feeding, and of apparent overapplication. Further patterns can be generated when alternative rule ordering constraints cause some rules not to apply as expected. A rule whose structural description is met may still never apply, if it is ordered too early, or too late. Thus, a rule will not apply if it is **met by feeding** but is ordered before the rule that feeds it, rather than after. This is *counterfeeding*, and since the rule fails to apply while the structural context for it is present at subsequent derivational stages, it entails the apparent "underapplication" of the rule (Idsardi 2000:338). Whereas overapplication is a natural possibility in serial derivation, underapplication follows only from the presence of constraints that rule out application. A rule might also never apply if its structural description can be **altered** by another rule when the rule that renders the structural description opaque is ordered before rather than after. For two rules R1 and R2 whose structural descriptions are both met at some stage, R1 *bleeds* R2 if R1 applies first and removes the context for R2 to apply. Two changes are only produced when the rules apply in *counterbleeding* order, R2 then R1, running counter to bleeding order (interaction (c)). Although bleeding, like counterfeeding, involves the prevention of rule application, it does not constitute apparent underapplication. The non-application of a bled rule is not opaque, because its non-application at later stages is consistent with the fact that its structural description is not met at later stages.

We summarise the possible interactions in the table in (9), giving the names of the unconstrained order of application with a capital (Feeding, etc.) and that of the constrained order of application without a capital (bleeding, etc.).

(9)

	Both met at outset	**Second met by feeding**
Both left unaltered	(a) (no interactive effect)	(b) Simple Feeding / counterfeeding
First altered	(c) Counterbleeding / bleeding	(d) Overapplication-Feeding / counterfeeding

Recent work examining phonological rule interactions repeatedly overlooks what we call overapplication-feeding (Roca 1997b, Kager 1999, McCarthy 1999a, Idsardi 2000). It seems that the four-way terminological distinction between feeding, counterfeeding, bleeding, and counterbleeding rule orders used by phonologists leads to the erroneous assumption that the effect of overapplication arises solely in counterbleeding. The analysis of rule interaction here overcomes this weakness.[4]

A further advantage may accrue to this account. It has been noted (McCarthy 1999a) that the literature on rule interaction and rule ordering in generative phonology has focussed on pairs of rules, and concomitantly failed to test whether complex interactions between larger sets of rules overgenerate or undergenerate in comparison to empirically attested sound patterns. Perhaps study of larger rule sets has been hampered by the lack of a fully adequate description of rule interactions. The present account, already proven superior as an account of pairwise interactions, might be extended to describe the interaction of multiple rules since they pick out the relationship between each rule's structural description and the effects of preceding rules (feeding) and subsequent rules (alteration).

[4]Two more arcane possibilities suggest themselves, neither of which is amenable to serial rule interaction. Two processes might each appear to be fed by the other, and yet both apply (see 4.3.2). Two processes might each alter the context of the other, and yet both still apply (cf. Hyman 1993).

4.3 Rule Interaction Versus Constraint Interaction

4.3.1 Translation from Rules to Constraints

Having set out and exemplified serial rule interactions, we will examine them in abstract form enabling a general translation to patterns of constraint interaction.

(10) **Two Rule Applications**

Consider a representation p_0.

Let p_1 be a representation derivable from p_0 by means of some operation O1.

Let p_2 also be a representation derivable from p_0 by means of some operation O2.

Suppose, for simplicity, that O1 and O2 alter *distinct* pieces of the structure in p_0.

Let p_{12} be the representation that results from employing both O1 and O2.

In the terms of chapter three, such a mapping will be representative and veritable, so operations will not be obscured by their use in combination with each other. In general, then, the numeral subscripts indicate which changes have been incorporated into the representation relative to p_0. Employing O1 and O2 in either order leads to p_{12}, as (11) illustrates.

(11)

$$\begin{array}{ccc} p_0 & \xrightarrow{O1} & p_1 \\ \downarrow_{O2} & & \downarrow_{O2} \\ p_2 & \xrightarrow{O1} & p_{12} \end{array}$$

Using (11) as our base, we now reconsider the four interactional possibilities (a)-(d) in abstract form. They are represented by the four pairs of rules shown in (12).[5]

(12)

(a) **Both met at outset; both left unaltered**

Rules: R1: $p_0 \rightarrow p_1$; $p_2 \rightarrow p_{12}$ R2: $p_0 \rightarrow p_2$; $p_1 \rightarrow p_{12}$

Derivation: $p_0 \rightarrow^{R1} p_1 \rightarrow^{R2} p_{12}$ or $p_0 \rightarrow^{R2} p_2 \rightarrow^{R1} p_{12}$ or $p_0 \rightarrow^{R1,R2} p_{12}$.

(b) **One met by feeding; both left unaltered**

Rules: R1: $p_0 \rightarrow p_1$; $p_2 \rightarrow p_{12}$ R2: $p_1 \rightarrow p_{12}$ only

Derivation: $p_0 \rightarrow^{R1} p_1 \rightarrow^{R2} p_{12}$ (if R1 precedes R2: feeding);

$p_0 \rightarrow^{R1} p_1$ (if R2 precedes R1: counterfeeding)

(c) **Both met at outset; one altered**

Rules: R1: $p_0 \rightarrow p_1$ only R2: $p_0 \rightarrow p_2$; $p_1 \rightarrow p_{12}$

Derivation: $p_0 \rightarrow^{R1} p_1 \rightarrow^{R2} p_{12}$ (if R1 precedes R2: counterbleeding);

$p_0 \rightarrow^{R1,R2} p_{12}$ (if R1,R2 unordered: simultaneous)

$p_0 \rightarrow^{R2} p_2$ (if R2 precedes R1: bleeding)

(d) **One met by feeding; the other altered**

Rules: R1: $p_0 \rightarrow p_1$ only R2: $p_1 \rightarrow p_{12}$ only

Derivation: $p_0 \rightarrow^{R1} p_1 \rightarrow^{R2} p_{12}$ (if R1 precedes R2: overapplication feeding)

$p_0 \rightarrow^{R1} p_1$ (R2 precedes R1: counterfeeding)

Mutually non-affecting rules (12a) may apply to any of the forms in (11). In a simple feeding interaction (12b), the second rule could not apply to p_0 but it can apply to p_1 after the first rule

[5]We assume in all four cases (a)-(d) that the representation p_{12} is not subject to the further application of the rules.

has applied. In a counterbleeding interaction (12c), the first rule can only apply first to p_0 otherwise it cannot apply. Overapplication feeding (12d) is a combination of the previous two. This specifies the possible interactions between rules at the greatest possible level of generality, even more so than the schematised versions of context-sensitive string-rewriting rules, A→B/X_Y and the like, that persist in general discussion of phonological rules (Roca 1997b:3ff, Halle and Idsardi 1997:345, Idsardi 1997:373, McCarthy 1999a, 2003). Having specified the pairs of rules in this way, we can now translate them into the strongly analogous constraints. This will demonstrate with full generality which rule interactions are replicated by constraints and which are not. Recall that a constraint is strongly analogous to some rule if it is violated by precisely those forms which would be subject to the application of the rule (see 4.1). This means that if a rule applies to p_0 , for example, then p_0 will violate the strongly analogous constraint and will be less harmonic than other forms.

(13) **Type (a) Both met at outset; both left unaltered**

Rules: R1: $p_0 \rightarrow p_1$; $p_2 \rightarrow p_{12}$ R2: $p_0 \rightarrow p_2$; $p_1 \rightarrow p_{12}$

Constraints: C1: p_0 , $p_2 \prec p_1$, p_{12} C2: p_0, $p_1 \prec p_2$, p_{12}

Tableau:

	C1	C2
p_0	*	*
p_1		*
p_2	*	
☞p_{12}		

Just as order of application made no difference to the outcome of the rules (12a), so ranking does not affect the evaluation of forms against C1 and C2, since they do not conflict over any forms. Ranking would merely settle the non-crucial matter of relative harmony among suboptimal forms, $p_1 \prec p_2$ or $p_2 \prec p_1$.

(14) **Type (b) One met by feeding; both left unaltered**

Rules: R1: $p_0 \rightarrow p_1$; $p_2 \rightarrow p_{12}$ R2: $p_1 \rightarrow p_{12}$ only

Constraints: C1: p_0 , $p_2 \prec p_1$, p_{12} C2: $p_1 \prec p_0$, p_2, p_{12}

Tableau:

	C1	C2
p_0	*	
p_1		*
p_2	*	
☞p_{12}		

The constraints rate p_{12} better than p_1 on any ranking – matching the outcome of the rules in feeding order. Neither ranking of constraints correlates in outcome with the counterfeeding order of rules.

In (15), we introduce Faithfulness constraints F1 and F2. Since p_1 and p_2 differ from p_0, there must be for each a violation of some Faithfulness constraint (only an identity mapping lacks any Faithfulness constraint violations). In order for the processes to go ahead, these Faithfulness constraints are ranked below the respective Markedness constraints C1 and C2, but their influence is felt here because the relevant Markedness constraints fail to discriminate between p_2 and p_{12}.

(15) **Type (c) Both met at outset; one altered**

Rules: R1: $p_0 \rightarrow p_1$ only R2: $p_0 \rightarrow p_2$; $p_1 \rightarrow p_{12}$

Constraints: C1: $p_0 \prec p_1, p_2, p_{12}$ C2: $p_0 , p_1 \prec p_2, p_{12}$

F1: $p_1 , p_{12} \prec p_0, p_2$ F2: $p_2 , p_{12} \prec p_0, p_1$

Tableau:

	C1	C2	F1	F2
p_0	*!	*		
p_1		*!	*	
☞ p_2				*
p_{12}			*!	*

The strongly analogous constraints C1 and C2 alone leave both p_2 and p_{12} as maximally harmonic, precisely matching the fact that neither of the analogous rules would apply to p_2 or p_{12} . However, when we consider the ever-present Faithfulness constraints we observe that p_2 will be optimal because it is more faithful. This means that the constraint interaction coincides with the bleeding interaction by which R2 would produce p_2. Any ranking of the analogous constraints achieves that same outcome, so the counterbleeding rule interaction, which produces p_{12}, is not replicated.

(16) **Type (d) One met by feeding; the other altered**

Rules: R1: $p_0 \rightarrow p_1$ only R2: $p_1 \rightarrow p_{12}$ only

Constraints: C1: $p_0 \prec p_1, p_2, p_{12}$ C2: $p_1 \prec p_0, p_2, p_{12}$

F1: $p_1, p_{12} \prec p_0, p_2$ F2: $p_2, p_{12} \prec p_0, p_1$

Tableau:

	C1	C2	F1	F2
p_0	*!			
p_1		*!	*	
☞p_2				*
p_{12}			*!	*

The tableau is rather similar to that in (15), where the strongly analogous constraints leave both p_2 and p_{12} as maximally harmonic, but p_2 is more faithful. This time, the tableau outcome is entirely at variance with the outcome of the rules in either order. R1 followed by R2 gives p_{12}, but a counterfeeding order would give p_1.

The comparison thus far is summarised in the table (17):

(17)

Outcome of rules replicated?	**Both met at outset**	**One met by feeding**
Both left unaltered	YES	Simple Feeding – YES / counterfeeding - NO
One altered	Counterbleeding - NO / bleeding - YES	Overapplication Feeding - NO / counterfeeding - NO

Rules that are left transparent pose no difficulty for replication in terms of constraints. This holds whether they are both met at the outset or one met by feeding. In contrast, where structural descriptions are altered the outcome is not replicated. This holds whether they are both met at the outset or one met by feeding. So this possibility is a distinctive feature of rule interaction not shared by constraint interaction. Furthermore, when rule ordering constrains rule applications that would otherwise proceed, bleeding, which is transparent, *is* replicated, but counterfeeding, which creates apparent underapplication, is not. Finally, we may observe that the outcome of overapplication-feeding-pattern rules (one met by feeding, one altered) is not replicated at all for either the unconstrained or constrained orders of application.

A formal comparison based on strongly analogous rules and constraints demonstrates that the two frameworks make different predictions as to the *outcomes that would follow from the same pair of linguistic generalisations being present in a grammar*. So far, this favours serial rule application since there is empirical support for the overapplication effects it creates (counterbleeding, and overapplication-feeding) given earlier in 4.2.1. In both subtypes we have the instantiation of a double-change to p_{12} from the basic representation p_0 , rather than a single change to p_2 as predicted by constraint evaluation. In a constraint evaluation, we would have to find an additional constraint or constraint interaction mechanism, to eliminate p_2 and get the desired result p_{12}. In this way, there may be strategies in optimality theoretic analysis that reproduce the same patterns as serial rule interactions for certain restricted subcases, but not in general. Extensions of optimality theory, Sympathy theory (McCarthy 1999a) and Enriched Input theory (Sprouse, Inkelas and Orgun 2001) achieve simulation of serial rule interaction in many cases, but (for better or worse) not all, so the similarities fall short of isomorphism.

While there are effects of serial rule interaction that are not directly replicated by constraint interaction, the same is true the other way, as we now show.

4.3.2 Mutual Interdependence

One possible - and attested - pattern that does not fall into the range of interactions already considered is that of mutually interdependent generalisations. This pattern will not work as a serial rule interaction, since paradoxically each would appear to be fed by the other, but it can be made to work as a constraint interaction.

An example of this is provided by one aspect of the Lardil nominative pattern (Prince and Smolensky 1993:102-103,124-125), where coda syllabification and onset augmentation work in this way. In the uninflected nominative, short stems are subject to word-final augmentation to bring them up to the minimum disyllabic word form, but if the stem-final consonant is a licit coda of the language - either a nasal homorganic to the following onset (17a.,b.), or a nonapical coronal (17c.) - then the stem is augmented not only with the epenthetic vowel *a* but also with an accompanying epenthetic onset. If, however, the stem-final consonant is not a licit coda (17d.) then it is placed in the onset itself.

(17)	Stem	Nominative	Gloss
a.	/kaŋ/	.kaŋ.ka. (*.ka.ŋa.)	'speech'
b.	/t^{j}aŋ/	.t^{j}aŋ.ka. (*.t^{j}a.ŋa.)	'some'
c.	/maɽ̡/	.maɽ̡.ta. (*.ma.ɽ̡a.)	'hand'
d.	/yak/	.ya.ka.	'fish'

The following diagram (18) represents the coda syllabification operation (downwards) and onset augmentation operation (rightwards) for (17a) [.kaŋ.ka.]. The operations are shown mapping from a basic form (containing only the uncontroversial syllabifications of the segments /k/,/a/, and epenthetic /a/) to the surface form.

(18)

```
kaŋa (?→)   kaŋka
 (?↓)          ↓
kaŋ a →     kaŋka
```

The difficulty is that each operation is dependent on the other, as if each were fed by the other. For nasals can only be syllabified in the coda in Lardil in the presence of a following homorganic onset. Augmentation of an onset only occurs if the stem consonant is syllabified in the coda (otherwise the stem consonant forms the onset). So each could apply to the intermediate representation where the other operation had applied - coda syllabification in the presence of a homorganic onset / augmentation of homorganic onset after stem consonant coda syllabification - yet neither could apply to the initial representation in (18). This means that the intermediate representations themselves are unobtainable derivationally, so that a serial analysis is logically precluded. As Prince and Smolensky (1993:124-125) recount, neither cyclic, ordered, nor persistent syllabification rules would place a stem nasal in the same syllable as the rest of the stem. This is not a problem for (17c) .maŗ.ta. since /ŗ/ is always a licit coda and might be put in the coda on one cycle, and epenthetic .ta. added on the next. It is not a problem for (17d) .ya.ka. since /k/ is a completely illicit coda, so would go straight in the onset. Unable to sanction a nasal coda, a derivational system would inevitably make (17a) pattern with (17d): *.ka.ŋa. . Not so with a constraint system.

When we consider this kind of interaction in terms of four representations p_0, p_1, p_2, p_{12} related to one another as before, we have the following.

(19) **Both met by feeding (Mutual Interdependence)**

Rules: R1: $p_1 \rightarrow p_{12}$ only R2: $p_2 \rightarrow p_{12}$ only

Constraints: C1: $p_1 \prec p_0, p_2, p_{12}$ C2: $p_2 \prec p_0, p_1, p_{12}$

Tableau:

	C1	C2
☞p_0		
p_1	*!	
p_2		*!
p_{12}		

The strongly analogous constraints C1 and C2 rule out p_1 and p_2 respectively, but fail to distinguish between p_0 and p_{12} . If it were then a matter of faithfulness, then the constraint system would deliver maximally faithful form p_0 – just as the rule system would simply fail to modify p_0 with the rules R1 and R2.

Adopting *ad hoc* constraints which describe the conditions which prompt the two processes of onset augmentation and coda placement in (18) creates the situation in (20). We have: *C.V, which rules out a coda consonant followed by an onset syllable (forcing C-epenthesis) and PARSEN/_[T, which rules out unsyllabified nasals before a homorganic stop onset.

(20)

	*C.V	PARSEN/_[T
kaŋ a		
kaŋka		*!
kaŋ a	*!	
kaŋka		

If we were to add the very simple proviso that segments may not be left unsyllabified (*STRAY, Clements 1997:318), the first form will be ruled out. The optimality of .kaŋ.ka. at the expense of other possibilities like *.ka.ŋa. (where the ŋ is placed in the onset), etc. can be achieved with the constraints ALIGNR(Stem,Syllable) “the right edge of every stem coincides with the right edge of a syllable”, ONSET “syllables have onsets”, CODA-COND “nasals only go in the coda if homorganic to a following stop”, NOCOMPLEX “onset and coda each contain no more than one consonant” (cf Prince and Smolensky 1993:118). These constraints also subsume our original formulations *C.V (subsumed by ONSET) and PARSEN/_[T (subsumed by *STRAY) which described the particular conditions for the two processes considered here, corresponding more directly to the putative - but completely unsuccessful - rules.

Other instances of mutually interdependent processes have been cited in the optimality theory literature (McCarthy 1993b:1), and have been dubbed “chicken-egg effects” (McCarthy 2002:144). In Southern Paiute, reduplicative prefixes are formed by copying the initial CV or CVC of the root to form a syllable, but nasals are admitted into syllable coda only if they agree with a following stop or affricate. These two conditions are mutually interdependent, so that in *wi-winni* 'to stand' the *n* is not copied since it fails the coda condition, but in *pim-pinti* 'to hang onto' it is copied but must be *m* so that it is assimilated to the following *p*. In serial terms, "it is impossible to know how much to copy until nasal assimilation has applied, but it is impossible to apply nasal assimilation unless the nasal has been copied" (McCarthy 2002:144). For cases of mutually interdependent processes, a constraint system provides a solution where a rule system cannot.

Thus far, then, each system offers descriptive capacity that cannot be replicated by the other. Serial rule interaction alone offers the possibility of overapplication, by allowing a structural description to be altered by another rule, and constraint interaction alone offers the possibility of mutual interdependent processes, by evaluating candidates against different conditions simultaneously rather than just one.

4.3 Conflicting Structural Outcomes

In all the cases seen, which are pairwise interactions that occur when two processes affect different pieces of the same structure, rank order between the strongly analogous constraints never makes a difference. We will now consider cases where two processes offer opposite structural outcomes.

4.3.1 Reciprocal Outcomes

Suppose that two constraints, that are each responsible for processes in a language, conflict. That is, for some representations p_0 and p_1, one constraint C1 evaluates p_0 suboptimal and the other C2 evaluates p_1 suboptimal. Given p_0 as an input, only the ranking of C1 and C2 can decide whether p_0 or p_1 is optimal.

Strongly analogous rules supporting the same reciprocal outcomes would employ mutually-reversing structural changes. If both apply, R2 literally reverses the mapping of R1, mapping from p_1 back to the original representation p_0 - a Duke of York gambit so-called by Pullum (1976), though here we are only considering a simple subcase of the Duke of York gambit, where there are no intervening rules making other changes to the representation and where each structural change is the exact inverse of the other (we shall relax this latter condition in the next section, 4.3.2). In this simple case, we have a straight conflict between the two possible outcomes p_0 and p_1 in both a serial rule account and a ranked constraint account, and under these conditions serial rule order and rank order of constraints *do*, finally, correlate with each other over the possible outcomes.

(21) **Reciprocal Outcomes** (a simple "Duke-of-York gambit")

Rules: R1: $p_0 \rightarrow p_1$ R2: $p_1 \rightarrow p_0$

Derivations: $p_0 \rightarrow^{R1} p_1 \rightarrow^{R2} p_0$ (R1 precedes R2)

$p_0 \rightarrow^{R1} p_1$ (R2 precedes R1)

$p_0 \rightarrow^{R1} p_1 \rightarrow^{R2} p_0 \rightarrow^{R1} p_1 \rightarrow^{R2} p_0$ ... (R1,R2 unordered)

Constraints: C1: $p_0 \prec p_1$ C2: $p_1 \prec p_0$

Tableaux:

	C1	C2	FAITH
p_0	*!		
☞p_1		*	*
	C2	C1	FAITH
☞p_0		*	
p_1	*!		*

Then we have a correlation between the two forms of interaction. The outcome p_0 comes from C1 is dominated by C2 and from R1 precedes R2; while the outcome p_1 comes from C2 is dominated by C1 and from R2 precedes R1. In this very specific case of exactly reciprocal outcomes, we have a kind of structure preservation across serial rule grammars and constraint evaluation grammars, in as much as the relative order of the analogous grammatical elements matches the outcomes.

4.3.2 Sub-reciprocal Outcomes

The match between serial rule interaction and ranked constraint interaction quickly falls down when we consider a variant on the reciprocal-outcomes pattern, however. Consider deletion and insertion. If deletion can affect any one of a class of phonemes in some context, it is nevertheless the case that insertion can only ever put one particular phoneme in. In many languages, syncope processes take out vowels and epenthesis processes put vowels in. If syncope and epenthesis rules were to apply one after the other in the same context, the vowel contrasts would all collapse and only the epenthetic vowel quality would be attested there, e.g. {i,e,a,o,u} → ∅ → {i}, as discussed in 3.4.4. However, *ranked constraint interaction would not allow the inventory to collapse in this way*. Instead, if a phoneme is to occur in a given context, default features will not be used because faithfulness constraints will retain the original features.

There is a difference between rules and constraints here. In this kind of pattern, we have a *set* of outcomes p_0 , $p_{0'}$, $p_{0''}$, $p_{0'''}$.. set against an alternative p_1 (e.g. forms with vowels present vs. forms identical but for the lack of a vowel). This generalises the simpler cases of exactly reciprocal outcomes p_0 and p_1 . In (22), we demonstrate the general divergence between the systems under these general conditions.

(22) **Sub-reciprocal Outcomes**

Rules: R1: $p_0 \rightarrow p_1$ $p_{0'} \rightarrow p_1$ $p_{0''} \rightarrow p_1$ $p_{0'''} \rightarrow p_1 \ldots$ R2: $p_1 \rightarrow p_0$

Derivations: $p_{0'} \rightarrow^{R1} p_1 \rightarrow^{R2} p_0$ (R1 precedes R2)

$p_{0'} \rightarrow^{R1} p_1$ (R2 precedes R1)

$p_{0'} \rightarrow^{R1} p_1 \rightarrow^{R2} p_0 \rightarrow^{R1} p_1$ ... (non-terminating, R1,R2 unordered)

Constraints: C1: p_0 , $p_{0'} \prec p_1$ C2: $p_1 \prec p_0, p_{0'}$

Tableaux:

$/p_{0'}/$	C1	C2	FAITH
$p_{0'}$	*!		
☞p_1		*	*
p_0	*!		**

$/p_{0'}/$	C2	C1	FAITH
☞$p_{0'}$		*	
p_1	*!		*
p_0		*	*!*

On one order, R2 precedes R1 / C2 dominated by C1, the result is the same: p_1 . On the other order, a difference is found: if R1 precedes R2, the rules collapse the inventory p_0 , $p_{0'}$, $p_{0''}$, $p_{0'''}$.. down to p_0. However, if C1 is dominated by C2, the original members of the inventory are preserved, as the tableaux show. The constraints will not collapse the inventory.

The rule theory predicts that the existence of processes with sub-reciprocal outcomes can cause an inventory of possibilities to collapse down to the default possibility. The constraints theory predicts that, in languages with two processes with sub-reciprocal outcomes, inventories cannot collapse in any context.

The prediction of constraint theory is borne out. As argued in 3.4.4, inventories do not collapse in certain positions. Where syncope and epenthesis are both attested, as in Yawelmani Yokuts, their application is disjoint, specifically precluding inventory collapse:

> Vowel Epenthesis inserts a vowel in just those contexts where failure to do so would yield an unpermitted consonant cluster. On the other hand, Vowel Deletion serves to delete just those vowels *not* required by the constraints on consonant clustering. Observe that the context VC_CV *excludes* all the environments where deletion of the vowel would yield unpermitted clustering; - *#CC, *CC#, *CCC. (Kisseberth 1970a:298-299)

So in the data in (23), both /i/ and /a/ (the two commonest vowels in Yokuts) are syncopated, but there are no occurrences in the language of vowels being replaced by epenthetic /i/ resulting from syncope and epenthesis applying in series:

(23) Kisseberth (1970a)

hall-hat**i**n-i:n → [hallatnen] *hallitnen *hillitnen *hallitnin *hillitnin

‘lift up’-desiderative-future

kili:y-**a**-ni → [kileyni] *kiliyni

‘cloud’-protective-indirect.objective

Thus, constraints supporting the presence of vowels in C_CC contexts (maximum retention of consonants *plus* restriction to just one consonant in syllable onset and one in syllable coda: MAX-C and NOCOMPLEXONSET/CODA) win out over the constraint favouring absence of medial short vowels generally (minimisation of syllables outside of a maximally simple foot structure: PARSE-Syllable-to-Foot), so syncope can only occur in contexts other than those which would produce CCC, that is in VC__CV contexts. If the maximum retention of consonants (MAX-C) also dominates DEP-V, then consonant deletion will not be used to break up untenable consonant clusters, vowel epenthesis will. Then the minimisation of syllables outside feet is a *default* generalisation, and syncope applies as a default. And vowel quality of short medial vowels where they still occur is settled by faithfulness to the qualities provided by underlying forms. Constraints on syllable structure tell us why epenthesis would apply (if needed to break up unsyllabifiable consonant clusters) and why syncope would be blocked (to avoid creating unsyllabifiable consonant clusters) in one fell swoop. The generalisation that syncope applies if the result is syllabifiable but is blocked just in case the output has *unsyllabifiable* consonants holds true across different languages with different syllable canons (Myers 1991:318), including English (e.g. Kenstowicz 1994:48), Amerindian languages Yokuts (Kisseberth 1970a) and Tonkawa (Kisseberth 1970b), Uto-Aztecan Southeastern Tepehuan (Kager 1997), Semitic languages Egyptian Arabic (Broselow 1976), Tiberian Hebrew (McCarthy 1979), Palestinian Arabic and Maltese (Brame 1974).

Rule theory, in addition to making the odd prediction that it is possible to have a Yokuts-like language in which syncope is less restricted, leading to words filled with epenthetic vowels like **hillitnin*, faces the further problem in Yokuts itself as to how to restrict syncope correctly so that its application and that of epenthesis are disjoint. One could follow McCarthy (1979), who proposes that "a phonological rule may apply if and only if its output conforms to the canonical syllable structures of the language" (McCarthy 1979:13)[6]. For this to work, however, conformity to syllable structure must be settled by checking the output of syncope against syllabification

[6]This statement could be interpreted as saying that the syllable structure of the language defines a series of derivational constraints on sequences of C's and V's, which could then be used for local blocking of unacceptable cluster formations, as per Kisseberth. However, no-one has explicitly suggested this, and it does not make sense of McCarthy's theory that syllable structure preservation depends on the "basic mechanism" that syllabification is "repeated throughout the course of the derivation" (McCarthy 1979:13), and requires that "a rule may apply if and only if its output can be syllabified by the syllable canons of the language" (McCarthy 1979:33). These tend to imply the interpretation in the main text.

rules to see whether the surrounding consonants can be resyllabified to neighbouring syllables. And it must specifically be the onset and coda **formation rules** that are taken into consideration, and not epenthesis or stray erasure (consonant deletion) operations, for if stray erasure of unsyllabified consonants or syllabification of consonants by vowel epenthesis <C>→ .CV. is included in the subsequence, then all phoneme strings are syllabifiable ultimately and syncope will never be blocked. This is an added dimension of complexity antithetical to the basic derivational approach of computing step by step (Chomsky 1998, see 2.2.1 above). In a system of constraints, the same constraint on syllable form (NOCOMPLEXONSET/CODA) will both trigger epenthesis and block syncope, and this analysis will intrinsically guarantee their disjoint application.

One case I am aware of that might be construed as supporting the rule theory's prediction that inserted material may replace deleted material is in Icelandic. C*r* clusters are broken up by -*u*- epenthesis, while others (C*v* or C*j*) are simplified by deletion. Both processes are present in the following noun paradigms (Kenstowicz 1994:79):

(24)					
		'medicine'	'storm'	'bed'	'song'
	nom.sg.	lyf-u-r	byl-u-r	beð-u-r	söng-u-r
	acc.sg.	lyf	byl	beð	söng
	gen.sg.	lyf-s	byl-s	beð-s	söng-s
	dat.pl.	lyfj-um	bylj-um	beðj-um	söngv-um
	gen.pl.	lyfj-a	bylj-a	beðj-a	söngv-a

Deletion simplifies the stem in the first three rows, e.g. *bylj* to *byl*, but in the nominative singular, *u*-epenthesis also applies. We could have had deletion blocked, and *j* parsed in the syllable nucleus to give .*by.li-r*., but instead deletion and epenthesis both occur. On grounds unrelated to the issue at hand, Itô (1986:187) attributes -*u*- epenthesis to the word stratum, but the deletion of *j* as an effect of syllabification of the stem that applies in the lexical stratum, which precedes the word stratum. Then genitive singular *byl-s* has *j* deleted as a lexical process, as does nominative singular *byl-r*, though only the latter receives the epenthetic -*u*- at the word level. By contrast, the *j* in the dative plural *bylj-um* is not deleted since it is syllabifiable as an onset. If so, it would show that the default interaction holds sway between opposite outcomes *within a given domain of application*. Even this may not be necessary, however, since one could put the case that in Icelandic *j* is a consonant, a palatal approximant, which - just like *v* in the stem *söngv* – will not be permitted to vocalise and form a syllable nucleus. Then *j*-deletion and *u*-insertion do not count as sub-reciprocal outcomes at all. [7]

4.3.3 The Extent of Structure Preservation Between Rules and Constraints

We have argued that the conflict between sub-reciprocal outcomes universally produces default generalisations as predicted by constraint interaction, and not the feeding effect predicted by rule interaction. Thus we have distinguished the case of *sub*-reciprocal outcomes, where rule interaction and constraint interaction differ, from *exactly* reciprocal outcomes, for which serial order and rank order bring about the same effects. The extent of the structure preservation is now summed up in the text boxes following.

[7] In many languages, it is clear that sounds transcribed as /j,w/ are realisations of high vowels that are positioned in syllable onset (Hayes 1989, Rosenthall 1994, Roca 1997c). For an argument in favour of the existence of consonantal approximants /j,w/ as distinct from high vowels /i,u/ in Bantu, see Zoll (1995).

Rules with Exactly Reciprocal Outcomes

Let R1 be a one-to-one function, then the inverse of R1, that is $R1^{-1}$, is also a function. *For example*:

- A vowel deletion process is not a one-to-one function, it is many-to-one, for it rewrites any vowel to zero, $\{i,e,a,o,u\}\rightarrow\varnothing$. When inverted this gives $\varnothing\rightarrow\{i,e,a,o,u\}$, which does not map to a unique output, so is not a function - unlike real epenthesis processes e.g. $\varnothing\rightarrow$ i, which are functions.
- English coda *r*-deletion (Halle and Idsardi 1997), however, is a one-to-one function, for only *r* is rewritten as zero, ɹ$\rightarrow\varnothing$. This has an inverse which is a function, which maps $\varnothing$ to ɹ.

Only a rule which is a one-to-one function may have a counterpart rule whose outcome is exactly reciprocal. This is the case if, given R1, a one-to-one function, there is a rule R2 which is a one-to-one function such that R2 intersects with $R1^{-1}$.

- *r*-insertion (Halle and Idsardi 1997) reverses coda *r*-deletion.

Conditions for Structure Preservation

For any rule *x*, let *x'* be the strongly analogous constraint. For any pair of rules *x*,*y* , say that [*xy*] = *x* <u>precedes</u> *y*; {*x'y'*} = *x'* <u>is dominated by</u> *y'*. If *p* is a representation, say that *xy*(*p*) and *x'y'*(*p*) are the outcomes of the grammars *xy* and *x'y'* given *p*.

If *a*,*b* are one-to-one functions such that *b* has a non-empty intersection with a^{-1} (and *a* with b^{-1}), then, for $x,y \in \{a,b\}$, $[xy](p) = \{x'y'\}(p)$. That is, if *a* and *b* support exactly reciprocal outcomes, then the outcome is the same across both systems *for either ordering* of *a* and *b*.

4.4 Conclusion

Serial order and rank order may be compared due to a systematic analogy between rules and constraints. Serial order and rank order correlate in their form and their effects in the particular case of processes with exactly reciprocal outcomes.

Outside the confines of this particular case, each of the two kinds of system offers different effects that are not replicable in the other. On the one hand, *overapplication* is an effect of rule interaction that cannot be replicated in constraint interaction (4.2.2), but on the other hand, *mutual interdependence* is an effect that can be handled as a constraint interaction but fails as a rule interaction (4.2.3). Pairs of processes with sub-reciprocal outcomes – in particular, syncope and epenthesis – produce *default* effects, behaving as rank order would predict, not serial order (4.3.2). Neither the system of rule interaction nor the system of constraint interaction is sufficent to derive all these effects – overapplication, mutual interdependence, and default – suggesting that some new integration of the two systems is needed to create a more descriptively adequate theory. We will attempt this in chapter 6.

The formal comparison was built on the insight that rule interaction types and constraint interaction types may be fully generalised by reference to the nature of rules and constraints as mathematical relations in the set of representations. This provides a fullness of generality which is not achieved by schematised versions of context-sensitive string-rewriting rules, $A \rightarrow B/X\_Y$ and the like, that persist in general discussion of phonological rules (despite the well-argued theoretical progression in phonology from strings to multi-tiered graphs for phonological representation). A second essential formal insight was the recognition that rule interaction may involve feeding and overapplication simultaneously. This is easily overlooked under the received view of rule interaction that distinguishes feeding, bleeding, counterfeeding and counterbleeding (Kiparsky 1968).