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Deriving An Implicational Universal In Two Theories of Phonology*

Charles Reiss—Concordia University
(*reiss@alcor.concordia.ca*)

0. Introduction

This paper is divided into four major sections. In section 1 I describe an apparent typological universal concerning the scope of assimilation processes. In section 2 I suggest an explanation of this universal within rule based phonology by appealing to the subset principle of acquisition. In the section 3 I demonstrate that the universal can also be derived from the nature of a relatively simple OT grammar. In section 4, I then use some of the concepts introduced in earlier sections to provide insight into the problem of under and overgeneration in OT, including the counterfeeding problem, and constraints on the set of OT constraints. Section 5 contains a brief conclusion.

1. A Typological Universal

The universal pattern I refer to has the form of an implicational hierarchy which can be intuitively grasped with a simple example.

1.1 Example

A language can have the alternations pn>mn and bn>mn, or pn>pn and bn>mn. That is if p assimilates, then b does too. But it could not be the case that pn>mn and bn>bn. The implication and the impossible pattern appear in (1).

(1) Implication: pn>mn ⇒ bn>mn
Impossible pattern: pn>mn, but bn>bn

This claim is consistent with the evidence from Ancient Greek and Latin. In Latin both stops assimilate:

(2) Labials before /n/ in Latin

- b,p > m /_n
- Labial, [-continuant] > [+voice], [+nasal], [+sonorant]

/sop-/	sop-or 'deep sleep'	som-nus 'sleep'
/ab-/	Ab-ella (name of town)	am-nis 'stream, river'

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In Ancient Greek, however, only the voiced labial /b/ assimilates to a following /n/, while the voiceless /p/ and voiceless aspirated /p^h/ do not:

(3) Labials before /n/ in Ancient Greek

- b > m / __ n
- Labial, [+voice], [-continuant] > [+nasal], [+sonorant]

/seb-/	seb-omai	'feel awe'	sem-nos	'reverend, august'
/hup-/	hupnos	'sleep'		
/ap^h-/	ap^hneios	'wealthy'		

Let's stay with this example—1) why is /b/ the only labial stop to assimilate to /n/ in Greek, and 2) why can no language exist identical to Greek except that it had assimilation of /p/ > /m/ before /n/, but not of /b/? It seems intuitive that the answer to both questions lies in the fact that /b/ is "closer" to /m/ than the voiceless stops are, since /b/ shares more features with /m/. In this section, I will formalize the notion of closeness in such a way as to allow us to answer these questions about Greek and to predict, in general, what factors might constrain assimilation processes universally.

Since assimilation rules are conceived of as spread of a single node in the feature tree, this alternation must actually consist of a two stage rule complex in some instances. The change of /b/ to [m] will merely require the spread of the specification [+nasal] from the /n/ to the labial, with concomitant delinking of the underlying [-nasal] specification.[1] However, the change of /p/ to [m] must involve changing the feature [voice] as well. The change of the two features cannot be expressed as a single process because the first node dominating [voice] and [nasal] is the root node, the spread of which implies complete assimilation, and that is not what we observe. This voicing of underlying /p/ can be accomplished in two ways—either by assimilation to the voicing of the nasal, i.e. by another spreading rule; or by a redundancy or repair rule guaranteeing that all nasals surface as voiced in Latin.

Note that it is possible to apply the rules in either order—nasalize both /p/ and /b/, then voice the voiceless nasal (given in 4a); or voice the /p/, then nasalize underlying and derived /b/ (given in 4b)). In the Latin case the two orders produce indistinguishable output.

[1] I will ignore the automatic change of the feature [sonorant]. In doing so, I am not making a claim about the relationship of [sonorant] to [nasal] vs. that of [voice] and [nasal], though it may be true that the relationship is different in the two cases. However, in the examples under discussion, [+nasal] always implies [+sonorant], so specification of the latter provides only redundant information.

(4) Possible ordering of nasal spread and voicing in Latin

a.	/pn/	/bn/
nasalize labial stops	/m̥n/	/mn/
voice nasals	/mn/	—
output	[mn]	[mn]
b.	/pn/	/bn/
voice stops before nasals	/bn/	—
nasalize labial stops	/mn/	/mn/
output	[mn]	[mn]

However, we can imagine a language with similar rules where the ordering would be crucial. If a language had a rule nasalizing only voiceless stops, followed by a rule voicing nasals (by either of the mechanisms described above) then we would expect to find cases of /pn/ > /mn/, but /bn/ > /bn/. Stated informally, /p/ could bypass /b/ on the way to becoming m.

(5) A hypothetical language—/p/ 'bypasses' /b/ on the way to [m]

	/pn/	/bn/
nasalize voiceless stops	/m̥n/	—
voice nasals	/mn/	—
output	[mn]	[bn]

Note that we do know that nasalization can spread to voiceless stops, as in the voiceless nasals of the Welsh mutations.

It appears that languages with derivations such as (5) do not occur, i.e. if a language exhibits the alternation *pn* > *mn* then it will also exhibit *bn* > *mn*.

In six I have sketched some other attested implicational hierarchies that fall into the same pattern as the Grk and Latin.

(6) Some more examples of implications

- If s>ʂ under some condition, then if the language has ʃ, it is also the case that ʃ>ʂ under the same conditions.
- If a language has alternations of the form *k* > *ŋ* / __*n*, then if the language has /g/, it is also the case that *g* > *ŋ* / __ *n* under the same conditions. If, on the other hand, we only have direct evidence that *g* > *ŋ* / __ *n*, it is not necessarily true that *k* > *ŋ* / __ *n* as well.
- If a language has alternations of the form *a* > *i* / __*i*, then if the language has /e/, it is also the case that *e* > *i* / __ *i* under the same conditions. If, on the other hand, we only have direct evidence that *e* > *i* / __ *i*, it is not necessarily true that *a* > *i* / __ *i* as well.
- If a language has alternations of the form p^b > *m* / __*m*, then if the language has /p/ and /b/, it is also the case that both *p,b* > *m* / __*m* under the same conditions. If, on the other hand, we only have direct evidence that *b* > *m* / __*m*, it is not necessarily

true that either p or p^b > m / __m as well. However, if only one of the two is nasalized it will be /p/.

- If a language has alternations of the form $p > b^b$ / __ d^b, then if the language has a /b/ and a /p^h/, it is also the case that b, $p^b > b^b$ / __ d^b as well. On the other hand, if only one of the labials does not undergo the change, it must be p. (The diacritic ^{b} denotes [+spread glottis].)

1.2 Closeness

Before attempting to explain the observed universal pattern we need to formulate precisely the general case. If we assume that all sounds are represented by feature trees, and here I will assume that these trees are fully specified, then let us define closeness as in (7).

(7) **Closeness**: If the set of identically valued nodes shared by the feature geometry trees representing x and z ($x \cap z$) is a proper subset of the set of nodes shared by the trees representing y and z ($y \cap z$), then y is **closer** to z than x is. We can denote this relationship as one of set containment: "y is closer to z than x is" means that $y \cap z \supset x \cap z$.

For example, b is closer to m than p is, using standard feature values. This can be seen by comparing shared valued features in (8).

(8) Standard:/m/—candidates:/p,b/: /b/ is closer to /m/ than /p/ is

/p/	/b/		/m/
[-voice]	[+voice]		[+voice]
[-cont]	[-cont]		[-cont]
[-nasal]	[-nasal]		[+nasal]
[-son]	[-son]		[+son]

We can see in (9) that the closeness relation is not always defined. Neither of the candidates /p/ and /m/ is closer to /b/ than the other.

(9)Standard:/b/—candidates:/p,m/: Neither candidate is closer to the standard.

/p/	/m/		/b/
[-voice]	[+voice]		[+voice]
[-cont]	[-cont]		[-cont]
[-nasal]	[+nasal]		[-nasal]
[-son]	[+son]		[-son]

This example shows that mere feature counting is insufficient to determine relative closeness; a strict subset relationship is necessary.

1.3 General Case

With this definition of closeness we can now state the general form of the implicational hierarchies illustrated above.

(10) **Target-Output Closeness** (TOC): Suppose that in a language *L* there is a phonological process (a rule or set of rules) *P*, by which a segment *x* becomes *z*. If a segment *y* is closer to *z* than *x* is, *y* will also be a target of *P* in *L* and also become *z*.

The TOC can be seen to be consistent with the examples given so far: b∩m ⊃ p∩m, g∩ŋ ⊃ k∩ŋ, etc.

1.4 What the TOC is not

It is useful to distinguish the TOC from a similar principle which has been proposed in the literature, but which can be shown to have exceptions. The **principle of similarity**[2] basically claims that segments which share more features should assimilate more than segments share fewer. Note, however, that the voiced dental stop /d/ does not assimilate to a following /n/ in Greek (*hedna* 'bride price').

(11)Gk. *hedna* 'bride price'.

This may appear to contradict the TOC, but in fact it does not, since the TOC examines closeness to the *output* of an observed alternation to make predictions about potential assimilation in other feature complexes. A /d/ is clearly closer to /n/ than /b/ is. However, given a rule *b>m/__n*, the segment /d/ is not implicated as an additional target for assimilation if we follow the TOC algorithm established above in (10). Greater closeness to the rule trigger is not a sufficient condition for a TOC prediction, as shown by *hedna*. It is worth pointing out that geminate *nn* does surface in Greek..

(12) Geminate [nn] in Greek: *ennea* 'nine'

If, on the other hand, /b/ not only nasalized, but also lost its place features in a hypothetical rule (*b>n/ __ n*), then the change would necessarily apply to /d/ as well, since /d/ is clearly closer to an output /n/ than /b/ is.

(13) Hypothetical language consistent with TOC: bn>nn⇒dn>nn.

The Greek facts illustrate that closeness is not a trivial notion. It is **not** the case that the assimilation of target *x* to trigger *w* implies the assimilation of *y* to *w* whenever *y* is closer to *w* than *x* is. The TOC requires that an implied target be closer to the *output* of an observed target, not just closer to the trigger. It is sometimes necessary to stipulate that a target *x* have certain features which are in no obvious way related to the spreading features, as in this case of nasalization of /b/, but not of /d/ in Greek.

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[2] Cf. Hutcheson 1973. Other relevant works are Cho 1989, Kenstowicz 1970, and Foley 1977.

1.5 Narrow range of TOC

It is perhaps instructive to point out that in many typical assimilation processes the TOC is not violated, but it allows no predictions to be made. This occurs whenever assimilation involves just the creation of allophones, but no neutralization of underlying contrasts. For example, in certain Swedish dialects all coronal non-continuants /t, d, l, n/ are retroflexed by a preceding /r/ (and in many cases the only surface manifestation of the /r/ is the retroflexion on the following coronal). Assume that retroflexion involves a change of [+anterior] to [-anterior] for these sounds. Since each coronal surfaces as a retroflexed allophone of its UR, there will be no other underlying coronal which is closer to this allophone than its own UR. For example, a retroflexed /d/ will surface as [ɖ], and there is no underlying segment *x*, such that *x* is closer to [ɖ] than /d/ is. So the observation of these individual retroflexion cases in Swedish does not allow us to predict that the process actually affects a class of sounds.

(14) Swedish retroflexion: /t, d, l, n / > [-anterior]/ r __

Consider now the retroflexion of the underlying coronal fricatives /s, ʃ/.

(15) Retroflexion of sibilants in Swedish

a. hon [s]er honom 'she sees him'	var [ʂ]er hon honom 'where does she see him?'
b. hon [ʃ]öper det 'she buys it'	var [ʂ]öper hon det 'where does she buy it?'

(16) Swedish sibilants

	s	ʃ	ʂ
anterior	+	-	-
distributed	+	+	-

Assume that /s/ is represented as having a coronal node that dominates the terminal nodes [+distributed] and [+anterior]. A retroflex [ʂ] is both [-distributed] and [-anterior]. Obviously, the palato-alveolar fricative /ʃ/, which is [+distributed] but [-anterior] is closer to the retroflex [ʂ] than /s/ is. Therefore, if we know that /s/ is retroflexed by /r/, we can predict that /ʃ/ is as well, since the retroflexion rule neutralizes the two underlyingly distinct segments. The forms in (15) show that this is indeed the case.

An obvious consideration concerning the scope of the TOC is the fact that a descriptive grammar may appear to contain counterexamples to the TOC. For example, the Australian language Mara is described by Heath 1981 as having the following rule (where L is any liquid):

(17) Mara u-lowering

u > a / a L __

The TCC predicts that /o/ should also be affected by such a rule, since /o/ is closer to the output /a/ than /u/ is. However, Mara has basically a three vowel system, /i,u,a/. No occurrence of /o/ exists in the proper environment, so the TOC is not contra-

dicted. Therefore, the proper statement of the rule of vowel lowering should refer the class of targets as any back vowel.

I now turn to a discussion of possible explanations for the TOC.

2. An Explanation in Derivational Phonology

2.1 Why a problem

The TOC appears to be universally valid[3], and its validity is probably tacitly accepted by most phonologists. However, it is not obvious how to account for the TOC since it is trivial to write a grammar which contradicts it. It seems unlikely and undesirable that closeness should be a primitive element of grammar. Stating a generalization such as TOC as a global constraint which applies throughout the course of a derivation is undesirable because this requires that rules have the ability to look back or ahead to insure conformity with the predictions of closeness. As noted above, the TOC cannot reflect a simple constraint on the SD of rules because the nasalization of stops in Latin is actually a two step process. The constraint would have to require that voiceless stops alone not get nasalized if a later rule is going to voice them.

2.2 The subset principle

It appears to be unnecessary to posit the TOC as a principle of UG since it can be derived from some very simple, independently motivated principles of acquisition, especially the subset principle. The subset principle is based on the premise that children first create restricted grammars and expand their generative capacity upon exposure to positive evidence. For our purposes, we must determine how children go about constructing phonological rules without overapplying them. As illustrated above, a child learning Greek must not hypothesize that the presence of an alternation bn>mn in the PLD implies that all labial stops get nasalized before /n/, since /p/ does not. Similarly, the child must not hypothesize that all voiced stops get nasalized before /n/, since /d/ does not. The child must know that certain features of the target may be stipulated as prerequisites for the application of the rule. If this were not the case, the child might nasalize /p/ or /d/ before /n/ as well, and would require negative evidence to correct this overgeneralization. So our task is to discover what the structural description of a rule looks like in order to generate observed alternations, but not overgenerate.

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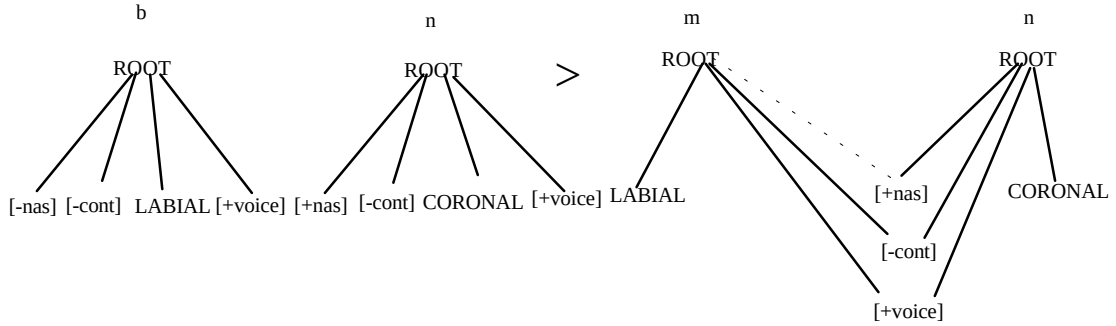
[3] The only counterexamples I have come across are cases that can be analyzed as delinking of the root node and reassociation of the mora which had been associated with the delinked material. For example, sn> nn in Greek ***hennumi*** 'to put on clothing.' This should imply tn>nn and dn> nn by the TOC. However, if the only apparent counterexamples are cases of apparent total assimilation, then we may be justified in assuming that they are not assimilation at all. We probably do not want to treat deletion of a consonant with compensatory lengthening of the preceding vowel as assimilation either. (I am currently working on this. I may need to revert to my earlier formulation of the TOC as only applying in assimilation. This poses an interesting challenge for OT which I have begun to work out. Since OT cannot distinguish total assimilation from delinking and spreading in a single OT level, this case can be taken as an argument for a phonetic level in OT phonology—details forthcoming...).

In order to posit the existence of a rule like bn>mn, the child must know the underlying forms of the concatenated morphemes. The principle of acquisition in (18) is sufficient to assure that children acquire grammars which are consistent with the TOC.

(18)**Principle of rule acquisition**: Any underlying feature specification which changes in an alternation must be absent from the structural description of all rules which contribute to that alternation. (And all other feature specifications on target and trigger are assumed to be prerequisites for the rules which compose the alternation, until there is evidence to the contrary.)

Imagine a learner is confronted with an alternation /bn/ > [mn], as represented in(19), we derive the rule in (20).

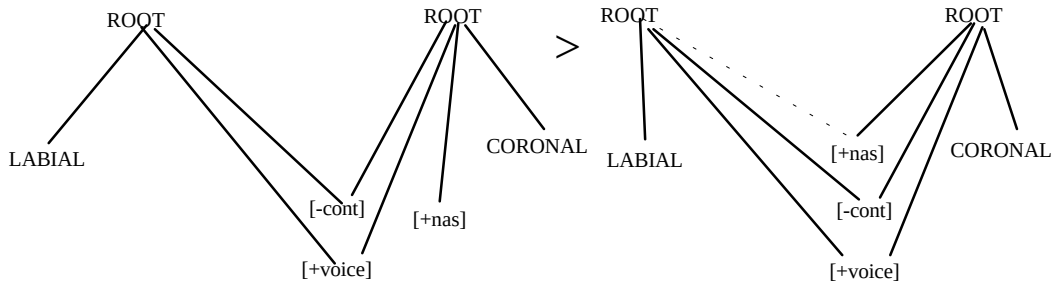
(19) The ALTERNATION bn > mn



Since the process changes the value of nasal associated with underlying /b/, this feature is absent from the SD of the rule in (20). Since the specification of [voice] on underlying /b/ has not changed, this feature is assumed to be a prerequisite for the change. I have represented the [+voice] nodes of the target and trigger as linked before the application of nasal spread, but this is not crucial to the argument.

(20) The RULE responsible for bn > mn

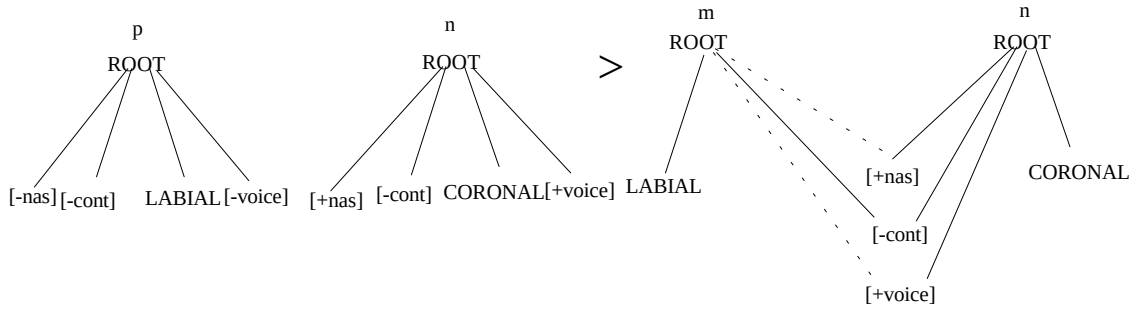
spread [+nasal] from voiced coronal nasal to voiced labial stop



Note that the rule in (20) leads to no predictions about the behavior of the sequence /pn/. This is consistent with the predictions of TOC.

Now suppose the child is exposed to an [m-n] sequence which can be assumed, on the basis of alternations, to be derived from /p-n/. The observed alternation can be assigned the following representation:

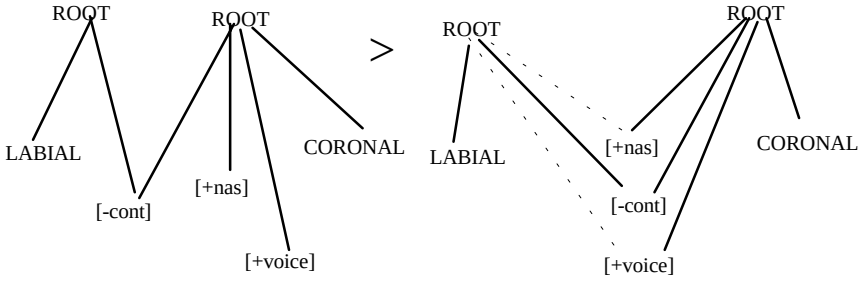
(21) The ALTERNATION pn > mn



In this case, the identically valued [-continuant] specification is assumed to be a pre-requisite for the assimilation. Since the two segments do not start out with the same value for [voice], this feature is assumed to be irrelevant to the application of the rule.

The observed alternation is thus assumed to represent one instantiation of a process represented as in (22).

(22) The RULE COMPLEX responsible for pn > mn



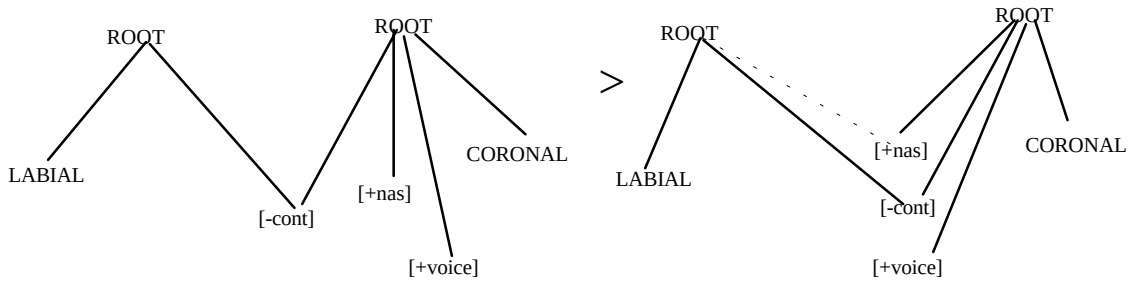
So we see that the rule complex derived in this case will apply equally to /p/ and /b/ since [voice] is irrelevant to the class of targets. Given standard assumptions about the nature of assimilation, such as that in (23) the process in (22) must be broken down into two rules, one which spreads [+voice] and another which spreads [+nasal].

(23) Clements and Hume (1993, 5): Phonological rules perform single operations only.

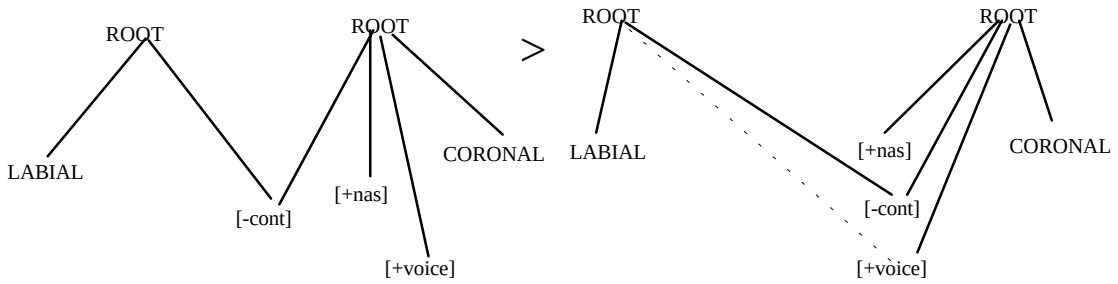
The two rules are given in (24ab).

(24) The two RULES comprising the RULE COMPLEX in (22)

a. spread [+nasal] from voiced coronal nasal to labial stop



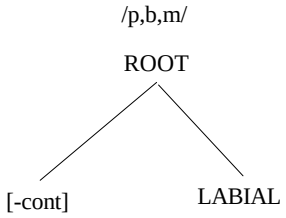
b. spread [+voice] from voiced coronal nasal to labial stop



Since the two rules have exactly the same conditions on their targets and triggers, and since neither rule changes these conditions, no extrinsic ordering is necessary. Each rule spread a valued feature ([+voice] or [+nasal]) from a coronal nasal to a labial, as long as both are [-continuant].

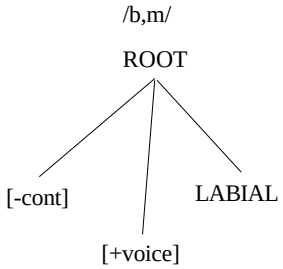
The set of targets defined by the rules which make up the rule complex in (22) are defined by the structural description in (25).

(25) Targets of rules defined by (22)



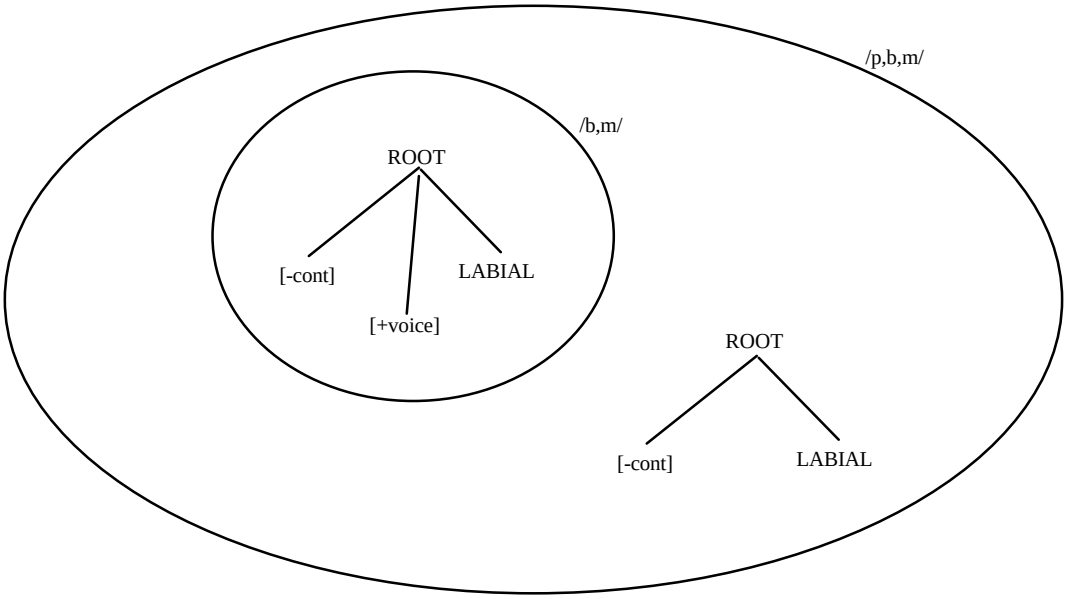
The set of targets defined by the rule in (20) has the structural description in (26).

(26) Targets of rules defined by (20)



These two sets of targets are in a subset relation, as shown in the Venn diagram in (27).

(27) Targets of (22) and (20)



We can now see that the reason for the hypothesis in (18) is that it will produce a grammar in which the scope of assimilation is more restricted, thus preventing the child from overgeneralizing. Once the child receives evidence of the more general rule, in other words if s/he is exposed to Latin, rather than Greek, s/he can loosen the restriction by paring away structure from the SD of the rule.

3. Implications in OT

I turn now to a discussion of Optimality Theory.

3.1 Deriving TOC

McCarthy (1995) suggests that all OT constraints should fall into two classes:

(28) McCarthy 1995 on types of constraints

> Optimality Theory (Prince and Smolensky 1993) deals with constraints on surface forms. Yet it also depends crucially on constraints that regulate the **faithfulness** of the surface form to the lexical structure.

I now wish to demonstrate that a version of OT which makes use of only these two constraint types is able to generate the languages in (36) but cannot generate the impossible language sketched in (5). In other words, the TOC follows from the nature of an OT grammar which makes use of only well-formedness constraints (constraints that refer only to output structure) and faithfulness or correspondence constraints (constraints that refer only to identity of features in morphologically related forms) in the sense that a grammar which contradicts the TOC is unstatable. This is clearly a good result for OT.

In (31)-(34) I list two faithfulness constraints and two well-formedness constraints which can be used to generate the relevant patterns. The actual formulation of the constraints is irrelevant, as long as the well-formedness constraints refer only to output strings. Faithfulness constraints have taken a variety of forms in the literature, including the suggestion that each one be divided in two. Kiparsky (1995) has suggested having two faithfulness constraints for each feature, one referring to the feature regardless of value and one referring to the marked value only.

(29)Kiparsky's (1995) faithfulness constraints

a. Be faithful to underlying [F]

b. Be faithful to underlying [αF], where α is the marked value of [F]

Pater (1995) has suggested one referring to [αF] and one referring to [-αF] for each feature.

(30)Pater's (1995) faithfulness constraints

a. Be faithful to underlying [+F]

b. Be faithful to underlying [-F]

As far as I can tell, these suggestions do not bear on the examples I will consider, except for an aspect of Kiparsky's proposal I will return to below.

Following McCarthy and Prince (1994), we can call the constraint that favors faithfulness between input (UR) and output (optimal candidate) with respect to the feature [nasal] Feat_{IO}[nasal].

(31) [nasal] faithfulness—FEAT_{IO}[nasal]

Correspondent segments in input and output must have identical values for the feature [nasal].

A constraint that favors faithfulness with respect to [voice] is FEAT_{IO}[voice].

(32) [voice] faithfulness—FEAT_{IO}[voice]

Correspondent segments in input and output must have identical values for the feature [voice].

The surface well-formedness constraints I adopt have the effect of demanding that adjacent segments share certain features. The constraint in (33) is a ban on sequences which agree in voicing, but not in nasality, which I will call "voice link implies nasal link" (VOI/NAS).

(33) Voice link implies nasal link (VOI/NAS)

Adjacent segments which agree in voicing must agree in nasality.

To account for voicing assimilation between nasals and stops let's assume that the relevant condition is that adjacent non-continuants must share the same [voice] node.

(34) [-continuant] link implies [voice] link—-CON/VOI

Adjacent non-continuants must agree in voicing.

Note that we will be able to use these two constraints to effect nasalization of a voiceless stop without positing a new constraint that demands that adjacent non-continuants agree in nasality. Adding this extra constraint will not effect the argument, so I will follow the more conservative approach.

3.1.1 Some definitions

It will prove useful to the following discussion to introduce the conventions and definitions given in (35).

(35) Some conventions and definitions
Suppose x,y,z. are distinct segments and F,G,H are features.

Definition: F(x) is the value which segment x has for feature F (+ or -).

Since the three segments are distinct, for any two segments x and y, there is always a feature F such that F(x)= -F(y).

Definition: y is closer to z than x is iff

- F(x)= $-\alpha$ and F(y)=α and F(z)=α, that is -F(x)=F(y)=F(z) for some F (y and z agree with each other but not with x)
- and there is no G s.t. G(x)=β and G(y)= $-\beta$ and G(z)=β (there is no G such that x and z agree with each other but not with y)

This is equivalent to the definition in (7).

For any feature, either all three segments agree, only x and y agree, or only y and z agree. It is never that case that x and z agree to the exclusion of y. The table below illustrates the three possible feature relations if y is closer to z than x is.

	x	y	z
F	+	-	-
G	+	+	+
H	+	+	-

3.1.2 Attested Grammars

I will now provide a sketch of how such a grammar can generate languages like those in (36).

(36) Treatments of /pn/ and /bn/

a) /pn/ > [pn] and /bn/ > [bn] (no assimilation)
b) /pn/ > [pn] and /bn/ > [mn] (assimilation of /b/ only)
c) /pn/ > [mn] and /bn/ > [mn] (assimilation of both)

In the following paragraphs I provide relevant constraint tableaux, followed by a summary of what they show, and then a characterization of the general case represented by each language.

3.1.2.1 Language (36a)

(37) Language (36a)—CON-VOI and VOI/NAS not crucially ranked

/pn/	$FEAT_{IO}$[voice]	$FEAT_{IO}$[nasal]	VOI/NAS	-CON-VOI
☞[pn]	✓	✓	✓	*
[bn]	*!	✓	*	✓
[mn]	*!	*	✓	✓

/bn/	$FEAT_{IO}$[voice]	$FEAT_{IO}$[nasal]	VOI/NAS	-CON-VOI
[pn]	*!	✓	✓	*
☞[bn]	✓	✓	*	✓
[mn]	✓	*!	✓	✓

(38) pn>pn bn>bn —Language (36a)
Faithfulness constraints are not outranked by any well-formedness constraint.

(39) For all features F, s.t. F(x) = -F(y) = -F(z) and G s.t. G(x) = G(y) = -F(z)the constraint which maintains output faithfulness to F or G is ranked higher than any well-formedness constraint that could result in changing F or G.

3.1.2.2 Language (36b)

(40) Language (36b)

/pn/	VOI/NAS	$FEAT_{IO}$[voice]	$FEAT_{IO}$[nasal]	-CON-VOI
☞[pn]	✓	✓	✓	*
[bn]	✓	*!	✓	✓
[mn]	✓	*!	*!	✓

/bn/	VOI/NAS	$FEAT_{IO}$[voice]	$FEAT_{IO}$[nasal]	-CON-VOI
[pn]	✓	*!	✓	*
[bn]	*!	✓	✓	✓
☞[mn]	✓	✓	*	✓

(41) pn>pn bn>mn—Language (36b)
Faith to [-voice] outranks the well-formedness constraint driving b>m.

(42) For a feature F, such that F(x) = -F(y) = -F(z), the constraint C1 which requires faithfulness to F outranks any well-formedness constraint C2 that would favor changing the value of F. Since F(y) = F (z) changing y>z does not violate faithfulness to F. **C1>>C2**.

3.1.2.3 Language (36c)

(43) Language (36c)—-CON/VOI and VOI/NAS not crucially ranked

/pn/	-CON/VOI	VOI/NAS	$FEAT_{IO}$[voice]	$FEAT_{IO}$[nasal]
[pn]	*!	✓	*	✓
[bn]	✓	*!	✓	✓
☞[mn]	✓	✓	*	*

/bn/	-CON/VOI	VOI/NAS	$FEAT_{IO}$[voice]	$FEAT_{IO}$[nasal]
[pn]	*!	✓	*	✓
[bn]	✓	*!	✓	✓
☞[mn]	✓	✓	✓	*

(44)pn>mn bn>mn—Language (36c)
Well-formedness constraints outrank faithfulness to the changed features.

(45) For any F such that F(x) = -F(y) = -F(z) the well-formedness constraint requiring a change in the value of F(x), C2, outranks faithfulness to F, C1. Since F(y) = F(z), the faithfulness and well-formedness constraints favor the same candidates for underlying /y/.
i. **C2>>C1**.
For any H such that H(x) = H(y) = -H(z) the well-formedness constraint, C4, favoring a change in H(x) and H(y) outranks faithfulness to H, C3.
ii. **C4>>C3**.

3.1.3 An Impossible Grammar

It appears impossible to write an OT grammar which will generate the pattern in (5), that is, one which will select [mn] as the optimal candidate for underlying /pn/ and also select [bn] as the optimal candidate for underlying /bn/. In other words, we cannot write the OT equivalent of the rule-based grammar in (5) whose output violates the TOC. This is clearly a desirable result for OT, since it means that it will not overgenerate in one respect.

Consider the string [mn] as a candidate for the UR /pn/. There are several possible rankings that will generate [mn] as the optimal candidate for /pn/, given in (46)—the

two faithfulness constraints must be ranked lowest, and the other two constraints must be ranked highest. Ordering is not crucial among the pairs. Note that if either faithfulness constraint is ranked above one of the other two the candidate [mn] will not be chosen.

(46) To choose [mn] as optimal candidate for /pn/

/pn/	-CON/VOI	VOI/NAS	$FEAT_{IO}$[voice]	$FEAT_{IO}$[nasal]
[pn]	*!	✓	*	✓
[bn]	✓	*!	✓	✓
☞[mn]	✓	✓	*	*

However, note that no possible rankings represented in (46) will select [bn] to be the optimal candidate for /bn/, as shown in (47). These grammars all select [mn] as the output of /bn/.

(47) The four rankings in (46) evaluating candidates of /bn/

a. /bn/	VOI/NAS	-CON/VOI	$FEAT_{IO}$[nasal]	$FEAT_{IO}$[voice]
[pn]	✓	*!	✓	*
[bn]	*!	✓	✓	✓
☞[mn]	✓	✓	*	✓

b. /bn/	VOI/NAS	-CON/VOI	$FEAT_{IO}$[voice]	$FEAT_{IO}$[nasal]
[pn]	✓	*!	*	✓
[bn]	*!	✓	✓	✓
☞[mn]	✓	✓	✓	*

c. /bn/	-CON/VOI	VOI/NAS	$FEAT_{IO}$[nasal]	$FEAT_{IO}$[voice]
[pn]	*!	✓	✓	*
[bn]	✓	*!	✓	✓
☞[mn]	✓	✓	*	✓

d. /bn/	-CON/VOI	VOI/NAS	$FEAT_{IO}$[voice]	$FEAT_{IO}$[nasal]
[pn]	*!	✓	*	✓
[bn]	✓	*!	✓	✓
☞[mn]	✓	✓	✓	*

(48) pn>mn bn>bn—Impossible language (5)

The first alternation (pn>mn) tells us that

i)respecting faithfulness to [-voice] is not as important as a well-formedness condition demanding that the labial be voiced

ii)respecting faithfulness to [-nasal] is less important than (lower ranked than) a well-formedness condition demanding that the labial be nasalized

The second alternation (bn>bn) tells us that

iii)respecting faithfulness to [-nasal] is more important than (higher ranked than) a well-formedness condition demanding that the labial be nasalized

Since ii and iii constitute a ranking paradox they cannot be part of the same grammar.

Therefore the TOC follows from the nature of an OT grammar containing only these two types of constraint.

(49)General case for TOC

To prove: Using only well-formedness constraints and faithfulness constraints it can never be the case that /x/>[z] and /y/>[y] if y is closer to z than x is.

By definition of closeness there exists features F and H such that F(x) = -F(z) and H(x) = -H(z). Therefore x>z means that F(x) > -F(x) and H(x) > -H(x).

So the well-formedness constraint C2 driving the change in F is ranked higher than faithfulness to the underlying value of F, C1.

i. **C2>>C1**

And the well-formedness constraint C4 driving the change in H is ranked higher than faithfulness to the underlying value of H, C3.

ii. **C4>>C3**

However, y>y means that faithfulness to F, C1, outranks any well-formedness constraint that would change the value of F, including C2.

iii. **C1>>C2**

And y>y also means that faithfulness to H, C3 outranks any well-formedness constraint that would change the value of H, including C4.

iv. **C3>>C4**.

But since i. and iii. are contradictory they cannot be in the same grammar. And since ii. and iv. are contradictory, they also cannot be in the same grammar.

So the surface forms of the language in (5) cannot be produced by an OT grammar using these constraints. It appears that changing the constraints will not allow a different result, as long as faithfulness to the UR is valued by some constraints, and there are no constraints which value just unfaithfulness to the UR—again, if we assume that all constraints are either faithfulness or surface well-formedness constraints.

The general form of the TOC can be stated in OT as follows (in our example, x=p, y=b and z=m).

(50) The TOC in OT terms

> Suppose that three segments x, y and z stand in the following closeness relationship: $y \cap z \supset x \cap z$ (y is closer to z than x is). If z is the optimal surface form of x, then z is also the optimal surface form of y in a given context.

It appears, then, that a language like that described by the ordered rules in (5) cannot be stated in OT terms, as long as there exist faithfulness constraints, and no unfaithfulness constraints other than well-formedness constraints.

4. Counterfeeding and constraining OT

I now turn to consideration of a class of chain shift which can be captured in terms of closeness. For ease of exposition, I invoke forms containing the same segments as the Greek and Latin cases discussed above, but it should be clear that any set of segments will do, as long as the set relations of their feature specifications stand in a closeness relation.

Many languages show a patterns of 'stepwise' assimilation, exemplified by the following forms from the Italian dialect of Servigliano (Camilli 1929). Stepwise processes are chain-shifts of the form x>y and y>z, where y is closer to z than x is.

(51) Stepwise assimilation in Servigliano

a. /lu patre/ >[lupatre] 'the father' /lu bardaššu/>[lubardaššu] 'the boy'
b. /un patre/>[umbatre] 'a father' /un bardaššu/>[ummardaššu] 'a boy'

The voiceless stop /p/ changes to the voiced stop [b] after a nasal, and the underlying voiced stop /b/ changes to a nasal after a nasal. (The original nasal also assimilates to the place of articulation of the following consonant. This change will not concern us.) In a system of ordered rules, it is clear that the change of voiced stop to nasal (/b/ > [m]) must precede the change of voiceless stop to voiced stop (/p/ > [b]). In other words, the rules are in a counterfeeding order. The two orders are shown in (52), without a formal statement of the relevant rules.

(52) Possible orderings of nasal spread and voicing in Servigliano (w/o place assimilation)

a. **correct order**	/np/	/nb/
1. nasalize voiced stop	--	/nm/
2. voice voiceless stop	/nb/	--
output	[nb]	[nm]

b. **incorrect order**	/np/	/nb/
1. voice voiceless stop	/nb/	--
2. nasalize voiced stop	/nm/	/nm/
output	*[nm]	[nm]

We have already shown that b is closer to m than p is.

Now consider the problem of generating the forms in (51) in an Optimality Theoretic grammar. Despite the fact that the segments appear in the opposite order here

from the cases discussed above, we can use the same constraints as before, since it is their effect, rather than their exact formulation which is important. The fact that the sequence /nb/ surfaces as [nm] implies that VOI/NAS outranks faithfulness to the underlying value of [nasal].

So far we have two constraints and they must be ranked as in (53).

(53) Relative ranking of VOI/NAS and $FEAT_{IO}$[nasal]

/nb/	VOI/NAS	$FEAT_{IO}$[nasal]
[nb]	*!	✓
☞ [nm]	✓	*

Now consider the constraints needed to assure that the optimal candidate for the UR /np/ be [nb]. This requires that CON-VOI outrank $FEAT_{IO}$[voice]:

(54) Relative ranking of -CON/VOI and $FEAT_{IO}$[voice]

/np/	-CON/VOI	$FEAT_{IO}$[voice]
[np]	*!	✓
☞ [nb]	✓	*

Now consider the relative ranking of the four constraints we have posited. There are twenty-four (4!) possible rankings of four constraints. However, we have already ruled out any ranking in which $FEAT_{IO}$[nasal] dominates VOI/NAS (half of all possible rankings), and we have also ruled out any ranking in which $FEAT_{IO}$[voice] dominates -CON/VOI (another half of the remaining rankings). This leaves us with only six remaining rankings available, which define the grammars (55a-f). We can examine all six in turn.

(55) The six grammars consistent with the rankings in (53) and (54).

a. /np/	-CON/VOI	$FEAT_{IO}$[voice]	VOI/NAS	$FEAT_{IO}$[nasal]
[np]	*!	✓	✓	✓
[nb]	✓	*	*!	✓
☞ [nm]	✓	*	✓	*
/nb/	-CON/VOI	$FEAT_{IO}$[voice]	VOI/NAS	$FEAT_{IO}$[nasal]
[np]	*!	*	✓	✓
[nb]	✓	✓	*!	✓
☞ [nm]	✓	✓	✓	*

b. /np/	-CON/VOI	VOI/NAS	$FEAT_{IO}$[voice]	$FEAT_{IO}$[nasal]
[np]	*!	✓	✓	✓
[nb]	✓	*!	*	✓
☞ [nm]	✓	✓	*	*
/nb/	-CON/VOI	VOI/NAS	$FEAT_{IO}$[voice]	$FEAT_{IO}$[nasal]
[np]	*!	✓	*	✓
[nb]	✓	*!	✓	✓
☞ [nm]	✓	✓	✓	*

c. /np/	-CON/VOI	VOI/NAS	$FEAT_{IO}$[nasal]	$FEAT_{IO}$[voice]
[np]	*!	✓	✓	✓
[nb]	✓	*!	✓	*
☞ [nm]	✓	✓	*	*
/nb/	-CON/VOI	VOI/NAS	$FEAT_{IO}$[nasal]	$FEAT_{IO}$[voice]
[np]	*!	✓	✓	*
[nb]	✓	*!	✓	✓
☞ [nm]	✓	✓	*!	✓

d. /np/	VOI/NAS	-CON/VOI	$FEAT_{IO}$[voice]	$FEAT_{IO}$[nasal]
[np]	✓	*!	✓	✓
[nb]	*!	✓	*	✓
☞ [nm]	✓	✓	*	*
/nb/	VOI/NAS	-CON/VOI	$FEAT_{IO}$[voice]	$FEAT_{IO}$[nasal]
[np]	✓	*!	*	✓
[nb]	*!	✓	✓	✓
☞ [nm]	✓	✓	✓	*

e. /np/	VOI/NAS	-CON/VOI	$FEAT_{IO}$[nasal]	$FEAT_{IO}$[voice]
[np]	✓	*!	✓	✓
[nb]	*!	✓	✓	*
☞ [nm]	✓	✓	*	*
/nb/	VOI/NAS	-CON/VOI	$FEAT_{IO}$[nasal]	$FEAT_{IO}$[voice]
[np]	✓	*!	✓	*
[nb]	*!	✓	✓	✓
☞ [nm]	✓	✓	*	✓

f. /np/	VOI/NAS	$FEAT_{IO}$[nasal]	-CON/VOI	$FEAT_{IO}$[voice]
☞ [np]	✓	✓	*	✓
[nb]	*!	✓	✓	*
[nm]	✓	*!	✓	*
/nb/	VOI/NAS	$FEAT_{IO}$[nasal]	-CON/VOI	$FEAT_{IO}$[voice]
☞ [np]	✓	✓	*	*
[nb]	*!	✓	✓	✓
[nm]	✓	*	✓	✓

We can see that only two patterns of assimilation are generated by these rankings. In grammars (55a-e) the optimal candidate for both sequences is [nm]. This is the mirror-image of the Latin case. In grammar (55f) the optimal candidate for both candidates is [np].

Another way to look at the impossibility of generating the Italian dialect data is the following. If the optimal candidate for the UR /np/ is [nb], and our OT grammar values faithfulness to the UR, then [nb] should also be the optimal candidate for the UR /nb/. On the other hand, if there exists a highly-ranked constraint that favors [nm] as the optimal output of /nb/ then the requirement that nasality spread outranks the requirement that output be faithful to the UR. If this is the case, then [nm] will also be the optimal output of the UR /np/.

(56) pn>bn bn>mn—Counterfeeding case like (51)

The second alternation (bn>mn) shows that

i) the well-formedness constraint driving nasal assimilation outranks faith to [-nasal].

The first alternation (pn>bn) shows that

ii) the wellformedness constraint requiring voice assimilation outranks faith to [-voice] AND

iii) faith to [-nasal] the outranks the well-formedness constraint requiring nasal assimilation.

But i and iii are contradictory. They say **A>>B** and **B>>A**. Therefore they cannot both be true in a single grammar.

In case it is felt that this argument is too dependent on the particluar processes invoked, I now provide a general proof that applies to all chain shifts characterized by the closeness relation. It can be applied to the nasalization cases or to any other chain shift such as, for example, a process which turns voiced stops into fricatives and voices voiceless stops, as in Welsh lenition.

(57) Welsh lenition: b>v p>b

(58) General case for counterfeeding

To prove: Using only well-formedness (w.f.) constraints and faithfulness constraints it can never be the case that /x/>[y] and /y/>[z] if y is closer to z than x is.

If y>z then there is a feature H such that H(y) = γ and H(z) = -γ (since y and z are distinct).

Therefore, the w.f. constraint C2 demanding y>z demands /γH/>[-γH]. So this w.f. constraint C2 must be ranked higher than a constraint demanding faithfulness to [γH], C1.

i. **C2>>C1**

If x>y then there is a feature F such that F(x) = β and F(y) = -β.
Therefore, the w.f. constraint C4 demanding x>y demands βF> -βF.
and so C4 must be ranked above a constraint demanding faithfulness to [βF], C3.

ii. **C4>>C3**

Since H(y) = γ, and H(z) = -γ, it follows that H(x) =γ. (**Otherwise y would not be closer to z than x is**.) The constraint ensuring that x does not surface as z demands faithfulness to [γH], C1. This constraint must be ranked higher than the w.f. constraint demanding /γH/>[-γH], C2.

iii. **C1>>C2**

But i and iii cannot both be true in a given grammar.

We can now see that the exact formulation of the constraints is irrelevant as long as all the constraints fit into one of the two categories discussed above.

4.1 Solution in OT—Constraint disjunction and constraints on constraints

So we now have shown that a version of OT which is restricted to faithfulness constraints and well-formedness constraints fails to overgenerate in certain cases (it won't generate TOC violations), yet undergenerates in others (it won't get stepwise processes). The challenge now is to extend the class of constraints enough to get stepwise processes, but not so much that the TOC is lost.

A clear example of the wrong approach is to posit constraints such as "underlying /b/ surfaces as /m/" and "underlying /p/ surfaces as /b/" in a given context. Note that these are neither surface well formedness nor simple faithfulness constraints. The problem with such an approach is two-fold. First of all, such constraints amount to nothing more than a restatement of the data. With such constraints any type of relationship between UR and surface form is possible: "underlying /p/ surfaces as [a]" would be a valid constraint. A related problem is that allowing the grammar such power would

also remove our ability to account for what appear to be real constraints on output such as the TOC. In other words, no principle would rule out a grammar with the constraints "underlying /pn/ surfaces as [mn]" and "underlying /bn/ surfaces as [bn]" which contradicts the TOC.

A more subtle example of a constraint that will lead to TOC violations is a context dependent faithfulness constraint. Such constraints can be stated in a variety of ways, two of which are given in (59).

(59) Undesirable constraints

a. If a candidate is faithful to the underlying value of [voice], then it should be faithful to the underlying value of [continuant] (This constraint can be used to generate p>v and b>f!)
b. Voiced segments must be faithful to underlying [nasal]. (This constraint can be used to generate stepwise processes like the Servigliano p>b and b>m, but also p>m and b>b, contra TOC).

My argument to this point has been tacitly assuming that faithfulness constraints cannot be stated in the form of those in (59). Now, it is important to realize that surface well-formedness constraints are often context sensitive. For example, a constraint banning voiceless nasals expresses something like the statement in (60).

(60) [+nasal] segments must be [+voice]—a context sensitive constraint.

Following a suggestion of Mark Hale (p.c.), I tentatively propose that the tacit assumption to this point has been that faithfulness and well-formedness constraints differ in that the former can refer to only a single feature.

(61) Faithfulness constraints refer to single features.

If we do not accept (61) we will find that our OT grammar massively overgenerates. Mark Hale has also pointed out that if it is correct, this condition raises a problem for Kiparsky's view of faithfulness constraints. If, as Kiparsky proposes, faithfulness constraints can refer to marked values, then they are inherently context sensitive, since the marked value of a given feature is dependent on context. For example, [+voice] is marked in stops, but [-voice] is marked in sonorants.

I still have not dealt with the counterfeeding problem. Bruce Hayes (p.c.) has pointed out that the operation of constraint disjunction can produce counterfeeding results. Under disjunction we assume that candidates will not incur a violation of a complex constraint consisting of two simple constraints if they satisfy **at least one** of its component constraints.

The complex constraint "be faithful to at least one of [voice] or [continuant]" in (62), along with two well-formedness constraints favoring voiced segments and continuants, respectively, can generate a chainshift as shown in (63). For simplicity I have chosen a chainshift of the form b>v and p>b (in an unspecified environment, say between vowels).

(62) Complex constraint

Be faithful to **at least one** of [voice] and [continuant]

(63) Chainshift using constraint disconjunction

/p/	*[-voice]	$FEAT_{IO}$[voice] OR $FEAT_{IO}$[cont]	*[-cont]
[p]	*!	✓	*
☞ [b]	✓	✓	*
[v]	✓	*!	✓

/b/	*[-voice]	$FEAT_{IO}$[voice] OR $FEAT_{IO}$[cont]	*[-cont]
[p]	*	*	*
[b]	✓	✓	*
☞ [v]	✓	✓	✓

These complex constraints are obviously very powerful. However they do allow us to generate the counterfeeding data and perhaps must be accepted as part of an OT which can account for well-attested processes. Fortunately, such disjunctive constraints will not lead to TOC violations.

5. Conclusions

In conclusion I would like to suggest that simple surface generalizations like the TOC can be extremely useful for studying the computational properties of grammars. This is because the definition of the TOC can be made explicit using basical logical notions like set and containment. The discussion of derivational phonology proposes that phonological acquisition can be characterized in ways parallel to syntactic acquisition, e.g. by appeal to the subset principle. The discussion of OT illustrates how we might narrow the search for necessary constraints on the set of constraints by explicitly characterizing upper and lower bounds on desired generative capacity—we need enough power to get chains shifts, but not so much that we violate the TOC.

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