1   Rules v. Constraints

DAVID ODDEN

1   Background

The goal of a theory of phonology is to elucidate the nature of "phonology" at a conceptual and predictive level. The title of this chapter refers to a comparative evaluation of rules and constraints as successful theories of phonology, which implies having a standard of evaluation, and adequate clarity as to what "rules" and "constraints" refer to. Neither prerequisite is trivial to satisfy.

1.1   The Scope of Inquiry

Certain assumptions about the nature of phonology must be considered, even lacking agreement on which assumptions to make. First and foremost, deciding whether phonology is based on rules or constraints, or a mix of the two, requires having objectively expressible statements of phonologies within different frameworks whose consequences can be compared. Therefore the theories must have a definite form, that is, they must be formalized. The entities which make up a phonological grammar should be expressions, which are finite sequences of elements taken from a specified set, and combined by rules of construction that define well-formed statements of rule or constraint. The value of formalism is its power to make objectively-interpretable statements about the phonology which can be checked against fact. To evaluate rules versus constraints as models, we should then consult the formalisms of the theories, to see whether one theory better passes the test of empirical and aesthetic adequacy.[1] Problems in this area are not trivial; certain theories of constraints or rules are severely under-formalized so that it is hard to know what predictions the theory makes; and a number of

theories are under-applied in the sense that it is impossible to determine from examples how particular phenomena would be analyzed.

Assuming that we are comparing formal theories, we must resolve questions about the scope of phonology, including how much of "phonetics" or "morphology" is phonology, and whether all facts bearing on phonology are the responsibility of the theory. Generative phonology traditionally encompasses a broad range of processes which might be considered phonetic (allophonic) or morphological (rules with lexical or morphological conditions), but the edges of phonology may also be contracted for theoretical purposes, viz. restrictiveness. Thus Webb (1974: 127) excludes metathesis from phonology, stating that "synchronic metathesis is not a phonological process. In the residual cases of metathesis, the rule is always morphologically restricted," enabling the "Weak Metathesis Condition," a restriction against reordering in phonology. If phonology is deemed to be concerned only with biuniquely recoverable surface-true relations between sounds (e.g. allophonic vowel nasalization in English), and abstract phonological alternations are to be described by the formal methods of morphology, a theory designed to account for just surface phonotactics cannot be meaningfully compared to one designed to account for both phonotactics and abstract morphophonemics.[2] A surface-phonotactic view of phonology thus must ignore a substantial portion of research into phonological grammars, on Bedouin Arabic (Al Mozainy 1981), Finnish (McCawley 1963; Harms 1964; Karttunen 1970; Keyser and Kiparsky 1984; Kiparsky 2003a), Chukchi (Krauss 1981), Kimatuumbi (Odden 1995), Klamath (Kisseberth 1973; White 1973), and Ojibwa (Piggott 1980), and numerous other languages.

There are also questions as to the level of explanation demanded of a theory – do we demand formal explanation, or formal and functional explanation? Much of the course of phonological theorizing has involved the increasing absorption of substantive factors into the theory, in an attempt to narrow the gap between prediction and observation. Comparative evaluation of theories implies determining which theory is better at making definite the notion "possible rule" or "possible constraint." The notion "possible" is used in two ways. One sense is theoretical well-formedness, that is, a rule constructible by free combination of elements, according to a theory of the form of rules. In that sense, "A→B/C__D" would be a possible rule, but "→B__/ACD" would not. McCawley (1973: 53) points to a different sense, the metaphysically possible, claiming "One who takes 'excessive power' arguments seriously has as his goal characterizing 'phonological rule' so as to include all and only the phonological rules that the phenomena of a natural language could demand. . . ." This notion of "possible rule" seems to mean what does exist, so *is* attested, or that which we have solid scientific or philosophical reason to conclude *must exist* now or in the past or future, just waiting to be discovered. The latter kind of "possible" depends on metatheoretical expectations, so McCawley intuits that assimilation of nasal to labials alone is not a possible rule (the present author does believe that such a rule is possible, if unlikely).

Whether such a rule is possible is not central to this discussion: what is essential, is distinguishing the undiscovered from that which is impossible by the nature

of language. Expansion of the substantive content of phonological theory narrows the predictive gap, though, complicates the theory and renders it redundant with respect to the extragrammatical physical explanations for the gap. If phonology is only a system of symbolic computations where the syntax of computations defines a broad class of possible rules, and separate aspects of languages referring to substance (perception, acoustics, articulation, language learning, and the transduction between grammar and linguistic behavior) explain why some formally allowed rules have negligible probability of attestation (as argued by Hale and Reiss 2008; Morén 2007), then failure to capture a generalization about substance within the theory of computation is not an argument against the theory of computation. But there is no universal agreement that the object of investigation *is* the computational apparatus rather than the full and undifferentiated panoply of factors influencing linguistic sound.

A second metatheoretical question affecting a comparison is whether phonology describes abstract string collections, or the mental faculty which generates them. If phonology only models strings, then considerations such as the results of psycholinguistic tests or problems regarding infinities in the model – infinite sets of candidate or sub-rules – are irrelevant to theory selection.[3] An example of how different conclusions are reached depending on whether one considers just the strings, versus the strings plus the mechanisms, is Mohanan (2000: 145–146) versus Calabrese (2005: 34). Mohanan contends that a rule [+nasal] → [+voice] is "logically equivalent" to a negative constraint *[+nasal,–voice], while Calabrese contends that rules and constraints are totally different means of implementing a linguistic action and are ontologically different. Mohanan is correct that the rule and the constraint describe the same string classes – are weakly equivalent; Calabrese is right that the imputed mental mechanisms of rules versus constraints are different – are not strongly equivalent.[4]

Even if we presume that phonology should be concerned with a mental faculty as well as the sets of strings, we must also determine whether phonology is concerned with all sound-related behavior, or just that behavior which generates the strings. A mentalist view of phonological grammars would care whether insertion of [i] after a word-final obstruent is regulated by a rule or a constraint, and whether this takes place in a single step or many steps; but a mentalist view of phonological grammars does not automatically care about the behavior of speakers of such a language under certain types of psycholinguistic testing, since a mentalist view of grammar does not automatically hold that all aspects of the mind pertaining to language sound are contained in the phonological component of a grammar.

To properly contrast "rules" versus "constraints" in phonology, we must also determine what these terms refer to, because we want our conclusions about differences between rules and constraints to reflect the concepts themselves, and not quirks of particular theories of rules or constraints. Many definitions of "rule" are offered in the Oxford English Dictionary, but the ones that seem closest to its linguistic use are:

A fact (or the statement of one) which holds generally good; that which is normally the case.

A principle regulating the procedure or method necessary to be observed in the
pursuit or study of some art or science.
(Grammar). A principle regulating or determining the form or position of words
in a sentence. In modern linguistics, usually applied to any one of a system of
rules that can be formulated in such a way that together they describe all the
features of a language.

The closest applicable definition of constraint is

The exercise of force to determine or confine action; coercion, compulsion.

In addition, the terms "principle," "condition," and "convention" are often used
in linguistics to describe what often seems to be the same thing as a constraint,
perhaps with the implication of greater generality or a stronger commitment to
universality.

In other words, the terms "rule" and "constraint" have developed into terms
of art in linguistics, requiring special definition, and the ordinary meanings of
the words only have an approximate correspondence to their linguistic use. The
original formal notion of a "rule" derives from the computational notion of Post
production systems, developed in the 1930s by Emil Post (Post 1943). In genera-
tive grammatical theory, the essential characteristic of a *rule* is that it maps classes
of strings onto other classes of strings in a specific way: the rule encodes the
particular change. Classically, rules in generative grammar also have the Markov
property, that the device or rule refers only to its current state (the input string)
and not some future or past state or string – such a device is "Markovian."[5] Thus
a rule which states "AXB $\rightarrow$ AZB" means "if you find a string analyzable as AXB
(at the current stage of the derivation), it maps to AZB (at the successor stage)."
A non-Markovian rule could refer to facts of a prior stage in a derivation.

Constraints are less well-defined largely due to the fact that their primary
characteristic is "not being a rule."[6] A constraint is essentially a "limit," so the
exact nature of a constraint depends on whether one is constraining a rule, a
derivation, or a representation. Contemporary usage sees constraints as evaluat-
ing structures, but originally, constraints were limits on rules, typically defined
in terms of a string property. The property of "overarching, non-local influence,"
that is, relevance to something more than one rule, is another behavioral charac-
teristic of constraints. Constraints can be either Markovian (morpheme-structure
or surface well-formedness constraints, which state generalizations at one level)
or non-Markovian (transderivational constraints on input-output relations, OT
Correspondence Constraints, the Elsewhere Condition), but are typically not seen
as *holding of* just one rule or step in a derivational mapping, assuming derivations.[7]
The general concept "constraint" does not say whether the mechanics of grammar
allow constraints to be violated, and says nothing about how constraints are
enforced or how potential or actual violations are handled. Constraint-based
theories differ considerably in this respect, some theories (Declarative Phonology)
disallowing violations of constraints, others (famously, OT) allowing them.

To anticipate the results of this investigation, there is no substantial difference between rules and constraints per se in their power to deal with phonological systems. The important differences reside in properties of particular theories of rules and constraints. Different theories of rules and constraints combine simple theoretical properties in many ways. For example, "surface-trueness" is a property sometimes associated with constraints and not rules, but some rule theories require the rules of language to be surface true (Natural Generative Phonology; Equational Grammar, Sanders 1972b), and OT is founded on the idea that constraints can be violated. The most important properties of the formal statements used in rule or constraint systems which we will be watching for are:

Globality: the statement applies "generally" in a language, not just at one point.
(*Language*) *Universality*: the statement pre-exists in UG: is not dependent on exposure to a particular language.
Inviolability: the statement must be true of particular levels of representation.
Negativity: the statement may give conditions that must not hold.
Ordering: the statement interacts with other statements according to language-specific priority.
Multiple Representations: more than one representational string is involved in computing the output form.

1.2   The Seeds of the Rule/Constraint Distinction

While the idea of directly and literally stating all of the facts of the mapping performed by a rule within the formalization of the rule itself would seem to characterize rule-based grammar, such a theory has never existed, and generative grammar has always operated with local rules and global meta-principles of rule interpretation. Nevertheless, the development of the concept "rule" in generative grammar from the most direct and literal statement of string-to-string mapping inevitably gave rise to the separate concept "constraint," when linguists faced recurring linguistic regularities which were not easily expressed in a general-purpose symbol-manipulation algebra. In saying that rules map classes of strings onto classes of strings, we recognize that rules use abbreviatory expressions to reduce classes of objects to compact symbols, for example a symbol to represent "consonant" or "NP." Rules are not written to apply exclusively to particular concretes such as [f] or *the child*. Formal linguistic statements are necessarily written with an abbreviatory notation referring to linguistic objects, and conventions that transcend a specific rule must be established for interpreting rules.

The development of the distinction between rules and constraints began in syntax, and early concepts of phonological constraints were a direct consequence of the prior development of such ideas in syntax – the implicit goal is to develop a theory of grammar. Early generative grammar as exemplified by Chomsky (1957, 1965) depended heavily on rules which explicitly stated the operations performed. Thus the Particle Shift transformation in Chomsky (1957: 112) is stated as "X-V1-Prt-Pronoun → X-V1-Pronoun-Prt," that is, when a particle precedes a pronoun,

the pronoun obligatorily moves to precede the particle: a separate optional rule addresses the situation where the word after the particle is a full non-pronominal NP. In this rule, X is taken by general mathematical convention to be a variable representing "any sub-string." Chomsky considers (p. 76) but does not formalize a generalization to the effect that ordinarily optional Particle Shift is obligatory *if* the post-verbal nominal is a pronoun, setting the stage for higher-order "conditions" on rule application separate from classical string-rewriting rules. Such a generalized version with an "obligatory if pronoun" condition does not follow the simple string-rewriting model, indicating that something in addition to string-rewriting statements are required.

A principle of Chomsky (1964: 931), dubbed in Ross (1967) the "A-over-A principle," gave rise to the first explicit constraints in generative grammar. This principle asserts that "if the phrase X of category A is embedded within a larger phrase ZXW which is also of category A, then no rule applying to the category A applies to X (but only to ZXW)." That is, when category A dominates an A, how is reference to "A" in a rule interpreted with respect to a string – as applying to the higher A or the lower A? According to this principle, interpretation of "A" is limited to just the higher A. A-over-A is not a rule (it does not state a string mapping), and it is global rather than local. It thus had a separate status, as a limitation on grammars, and an autonomous and universal claim about the notion "rule of grammar."

The consideration of factoring generalizations out of rules and giving them independent status – the globality property – took on a major role in linguistics with Ross (1967), who argues for the unambiguous necessity of autonomous constraints in grammar, in order to account for the facts covered by A-over-A. Ross argues that greater generality and simplicity can be achieved by removing certain considerations from explicit rule statements, and giving them the status of separate limitations or constraints on grammars. Since a rule is one derivational mapping, the only means of propagating a formal identity across rules in early generative rule theory was via a convention which defines a notation, for example, "X *means* a string of symbols of unbounded length." Ross-constraints change the conception of language because those statements cannot be reasonably construed as "defining the meaning of formal symbols," but they also are not linearly ordered string-rewrite rules.

The first constraint postulated by Ross is S-pruning (p. 26): "delete any embedded node S which does not branch . . . ," motivated by the fact that syntactic theory at that time held, counter-intuitively, that "his" and "yellow" in "his yellow cat" are sentences. Ross comments (emphasis added) "This principle should *not be thought of as a rule* which is stated as one of the ordered rules of any grammar, but *rather as a condition upon the well-formedness* of trees, which is *stated once in linguistic theory*, and applies to delete any non-branching S nodes which occur in any derivations of sentences in any language." In terms of globality and the statement of well-formedness, S-pruning has clear affinities to a constraint, but insofar as it also includes a statement of repair – the principle is not interpreted to mean "block a rule that *would* create such a structure" – S-pruning resembles

a rule. Other constraints such as the Complex NP Constraint – "No element contained in a sentence dominated by a noun phrase with a lexical head noun may be moved out of that noun phrase by a transformation" – exert a blocking influence, preventing wh-movement from generating *"Who does Phineas know a girl who is jealous of."

The constraint-based tactic, best summarized in Ross (1967: 271), is "that many conditions previously thought to be best stated as restrictions on particular rules should instead be regarded as static output conditions, with the rules in question being freed of all restrictions": recurring aspects of multiple rules can be factored out and stated separately, making the formal statements of the rules simpler. Extraposition from NP thus need not explicitly list the content of its right-edge variable, to block the sentence *"That a gun$_i$ went off surprised no one which I had cleaned __$_i$." Instead, this effect is achieved via a rule-independent principle – a constraint – on the content of variables in certain kinds of rules. Constraints might be universal (the Coordinate Structure Constraint was claimed to be universal) or language specific (the Pied-piping constraint is language specific).

Constraints typically had two realizations in early generative grammar, blocking and filtering. The blocking function says that if a particular rule application would contradict some constraint, the rule could not apply. Ross's Coordinate Structure Constraint thus blocks wh-movement from applying to "Bill and who bought biscuits?" The notion of "filtering" is brought out explicitly in Chomsky (1965: 137–139), to explain why the relative clause and higher NP must contain identical nouns, to prevent an unrealizable deep structure [the man [Bill saw the woman]]. Chomsky notes (pp. 138–139) "The transformational rules act as a 'filter' that permits only certain generalized phrase-markers to qualify as deep structures." Blocking and filtering are not particularly distinct when applied to optional rules (as syntactic rules have sometimes been held to be), and blocking an optional rule is string-equivalent to freely applying the rule and then filtering out violations of the constraint. Constraints and filtering achieved greater prominence in such works as Ross (1967), Emonds (1970), Perlmutter (1971), Hankamer (1973), Lakoff (1973), for instance and, as we will see below, a number of works in phonology.

2   Rules in Phonology

The concept of a (synchronic) generative phonological rule was developed in such works as Chomsky (1951), Halle (1959b, 1962, 1964), Chomsky and Halle (1965), Kiparsky (1965), Lightner (1965), McCawley (1965), Schane (1965), Zwicky (1965), Sloat (1966), Harris (1967), culminating in the essential reference work in the theory of generative rules in that era, Chomsky and Halle (1968). In this theory, often called the SPE ("Sound Pattern of English") theory, a grammar is a linearly ordered sequence of rewrite rules mapping an underlying form (the output of the syntax) to the surface representation.

The main theoretical concerns of phonology were the sub-theories of ordering, features, and rule formalism. All three aspects must be considered in evaluating

the theory against its competitors. Representation and rule statement are closely related since rules map between representations. Ordering bears on the question since some constraint-based theories preclude ordered derivational steps, and because a rule implies at least two levels, the input and output.

2.1   Rules and Conventions

A grammar is a linearly ordered sequence of rules, and, as is characteristic of generative formalism at the time, a rule is defined (Chomsky and Halle 1968: 391) as:

> $Z X A Y W \rightarrow Z X B Y W$, where A and B may be φ or any unit; $A \neq B$; X and Y may be matrices; Z or W may be C_i^∞ for some i; Z, X, Y, W may be null; and where these are the only possibilities.

Feature matrices identify sets of segments by conjoining specified features, thus the expression [+high,–voice] refers to the set of all segments which are both *+high* and *–voice*. Since the vast majority of phonological rules operate on just a single segment at a time, rules were usually stated in a format that factors out the non-changing segments, thus B → C / X___Y where X, Y could be any string of matrices, and B and C are a matrix or the null string.[9]

Given this characterization of rule, any mapping from specific string to specific string is possible (meaning, allowed by the syntax of rule construction) – a rule *mowzɪz → mɪdḷtawn* is a possible rule, and so is the following, which refers to classes of string:

(1)   X [+syllabic] [+nasal] Y → X [+syllabic,+nasal] [+nasal] Y

However, not every mapping of string *class* to string *class* is possible. Feature theory defines possible matrices, and given the nature of SPE's feature theory, the set {æ, m, š, ʊ, g} cannot be referenced to the exclusion of {a, n, i, ɪ, u, s, b, p, t, k}, so no rule can effect the mapping:[10]

(2)   {æ, m, š, ʊ, g}$_i$ → {š, ʊ, g, æ, m}$_i$ / {a, n, i, ɪ, u, s, b, p, t, k} ___

That is, even though any rule (as defined above) is possible, not every imaginable mapping of string class to string class is a possible rule in the theory. A rule in SPE is local (not global), not universal, positive (not negative); rules are linearly ordered, there can be multiple representations (a derivation), and while rules are not violated in the immediate output of the rule (modulo lexical exceptionality and optionality), they need not be true of any level.

The notion of "rule" becomes more complex because in SPE, sets of elementary rules can be combined into rule schemata via auxiliary expressions, for the purpose of grammar-evaluation and ordering. The notion of "evaluation" plays a significant role in grammatical theory – the assumption is that children learning a language are faced with multiple competing hypotheses which need to be

evaluated, the best one being the one actually acquired. The claim of the theory is that when rules resemble each other in specific ways, this resemblance is a significant linguistic generalization which needs to be captured. For example, a grammar could contain the following pair of elementary rules:

(3) $[+A] \rightarrow [-D] /$ __ $\begin{bmatrix} +E \\ -F \end{bmatrix}$

   $[+A] \rightarrow [-D] /$ __ $[-G]$

The similarity between these rules can be captured via a notational device, the brace notation, whereby a single statement can express these two elementary rules:

(4) $[+A] \rightarrow [-D] /$ _____ $\left\{ \begin{bmatrix} +E \\ -F \end{bmatrix} \\ [-G] \right\}$

which means "Any segment which is [+A] becomes [–D], when it stands before either a [+E,–F] segment or a [–G] segment." The significance of such abbreviation is two-fold. First, the evaluation metric assigns a greater value to a sequence of rules which can be collapsed via an abbreviatory convention than a similar un-collapsible rule sequence, and second, sub-rules abbreviated with abbreviatory devices apply disjunctively,[11] so only one of the rules in a schema can apply to a given segment. The evaluative function of abbreviatory notations was the most important, because language acquisition was seen as the process of selecting the formally simplest grammar consistent with the data. Abbreviatory devices then say that certain sets of rules are simpler in the sense that their "cost" is a fraction of the cost of the total set of individual rules. The mappings described as {æ, m, š, ʊ, g} → {š, ʊ, g, æ, m} / {a, n, i, ɪ, u, s, b, p, t, k} ___ can only be accomplished via a highly disvalued list of unreducible changes æ → š / a__ ; æ → š / n__ ; m → ʊ / a__ ; etc.

   Other devices were employed to express optional elements, so the context "__([+A])[–C]" means "when the segment precedes something that is [–C], with or without one intervening [+A] segment," and "__[+A]$_0$[–C]" means "before a [–C], with any number of intervening [+A] segments." Another significant device was the feature-coefficient variable, typically expressed with Greek letters α,β,γ . . . which represented the two feature values {–,+}. This notation was widely used to express assimilation processes, such as the following place assimilation for nasals.

(5) $[+\text{nasal}] \rightarrow \begin{bmatrix} \alpha\text{ant} \\ \beta\text{cor} \end{bmatrix} /$ __ $\begin{bmatrix} -\text{syl} \\ \alpha\text{ant} \\ \beta\text{cor} \end{bmatrix}$

This abbreviates the following four rules.

(6)   a. $[\text{+nasal}] \rightarrow \begin{bmatrix} \text{+ant} \\ \text{+cor} \end{bmatrix} / \underline{} \begin{bmatrix} \text{−syl} \\ \text{+ant} \\ \text{+cor} \end{bmatrix}$ c. $[\text{+nasal}] \rightarrow \begin{bmatrix} \text{−ant} \\ \text{+cor} \end{bmatrix} / \underline{} \begin{bmatrix} \text{−syl} \\ \text{−ant} \\ \text{+cor} \end{bmatrix}$

    b. $[\text{+nasal}] \rightarrow \begin{bmatrix} \text{+ant} \\ \text{−cor} \end{bmatrix} / \underline{} \begin{bmatrix} \text{−syl} \\ \text{+ant} \\ \text{−cor} \end{bmatrix}$ d. $[\text{+nasal}] \rightarrow \begin{bmatrix} \text{−ant} \\ \text{−cor} \end{bmatrix} / \underline{} \begin{bmatrix} \text{−syl} \\ \text{−ant} \\ \text{−cor} \end{bmatrix}$

Various aspects of the theory of rule formalism and schemata are set forth in SPE, especially pp. 393–399 for rule schemata, including X_0, X^* and other notations. See also Bach (1968) for the Neighborhood Convention notation.

The complement notation suggested in Zwicky (1970) introduces "negativity" into rule statements which otherwise state what must hold for a rule to apply, since the complement notation refers to "anything but," that is, what must not hold, for a rule to apply. An example of that kind is the *ruki* rule of Sanskrit, where /s/ becomes [ṣ] after the class *r,u,k,i*, provided that the following segment is not /r/. The right-hand context could be expressed "−[+son,−nas,+cor]" or "~[+son,−nas,+cor]" with the complement notation. As Zwicky notes, the complement of a natural class – a feature conjunction – is, by DeMorgan's law for negation of a conjunction, equivalent to a disjunction of negated values $(\neg(A \wedge B) \equiv (\neg A \vee \neg B))$, thus the right-hand condition can be stated as {−son,+nas, −cor}. A simple translation between direct statement of context and complement statement is possible for a single matrix being a blocking context, but not for a segmental sequence. Suppose a rule applies after certain segments but is blocked when immediately followed by [ba]. Simply changing conjunction to disjunction and reversing signs on the right-hand context does not give the desired effect. Such a conversion applied to the expression:

(7) $-\begin{bmatrix} \text{+voice} \\ \text{−cont} \\ \text{−nas} \\ \text{+ant} \\ \text{−cor} \end{bmatrix} \begin{bmatrix} \text{+syl} \\ \text{+low} \end{bmatrix}$

would give:

(8) $\begin{Bmatrix} \text{−voice} \\ \text{+cont} \\ \text{+nas} \\ \text{−ant} \\ \text{+cor} \end{Bmatrix} \begin{Bmatrix} \text{−syl} \\ \text{−low} \end{Bmatrix}$

which means "anything besides [b] followed by anything besides [a]." The difference in the two expressions lies in the fact that with the complement notation, the sequence [bi], [da] on the right would not block the rule, but with the negated

disjunction approach, such sequences would block. This points to an important question about blocking conditions, namely, does blocking ever require the characterization of a sequence of segments, or do blocking effects always involve the complement of a single element? A further point about blocking effects is that the negated disjunction statement presupposes the brace notation, and the validity of the brace notatation in phonology has been called into question, for example, by McCawley (1973). The connection with constraints should be clear, since a rule that applies except when a configuration is present is extensionally equivalent to one subject to an output condition, that is, a constraint against the configuration blocks the rule.

The SPE-era abbreviatory conventions were received skeptically: see McCawley (1973) for discussion. An important question raised there is whether the notations do, as claimed in SPE, represent sets of independently-existing sub-rules – the various sub-rules actually exist in the grammar and are simply evaluated as a single unit – or are the notations first-order concepts? The notations which abbreviate infinite set (X^* and X_0) cannot represent the collapsing of sets of rules in a grammar at least under a "model of the mind" view of grammar since a mental grammar cannot contain an infinity, so some of the SPE notational conventions must be primitive and not abbreviatory.

McCawley proposes, regarding feature variables, that the notion of feature identity should be a first-order concept in rule theory, so that a rule assimilating the coronality value of segment 1 to that of segment 2 would encode this as "coronal(1) $\rightarrow$ coronal(2)," meaning "the value of coronal for 1 becomes whatever it is for 2." The significance of this change to the theory is that it narrows the gap between observation and formal prediction, ruling out a large class of rules which are expressible in the SPE notation, such as:

$$(9) \quad [+\text{syl}] \rightarrow \begin{bmatrix} \alpha\text{hi} \\ \beta\text{low} \\ \gamma\text{back} \\ \delta\text{round} \end{bmatrix} / \underline{\quad} \begin{bmatrix} +\text{syl} \\ \delta\text{hi} \\ \alpha\text{low} \\ \beta\text{back} \\ \gamma\text{round} \end{bmatrix}$$

where features and values are mismatched. See Reiss (2003) and Section 2.4 for further discussion.

The main objection to the abbreviatory devices proposed in SPE is that large classes of non-generalizations could be expressed. The "dash-factoring" notation (p. 338):

$$(10) \quad X \rightarrow Y / \begin{bmatrix} \underline{\quad} \\ Z \end{bmatrix} Q$$

which means "Before Q, anything that is X becomes Y when it is also Z" was also little-used, and was seen as a spurious economization, being extensionally equivalent to the expression "anything that is both X and Y." Apart from being

a capricious "use it if you want" device, this device was used to coerce collapsibility in rules that could not otherwise be formally collapsed, such as the SPE Tensing rules (Chomsky and Halle: 241).

The star-parenthesis notation was motivated in that it was used to express a fact of language, but was supplanted by the theory of rule iteration (Howard 1972; Jensen and Stong-Jensen 1973, Kenstowicz and Kisseberth 1977). Angled brackets were employed for various purposes, primarily structure-preserving side-effects (e.g. in Slavic velar palatalizations where *k* becomes [č] but /g/ becomes [ž] and not [ǰ]). The brace notation was also viewed with skepticism, especially since the majority of recurring uses pertained to syllable structure and typically involved finding a way to make {C,#} be a natural class. The parenthesis, subscript-zero and variable feature notations were fairly well motivated in that phenomena which the devices were predominantly used for are not easily deniable. These notations still posed significant predictive problems. For example, factoring a string into units of two for stress purposes was not difficult (see (11a)) and appropriately so because binary stress units are well attested, but it was no harder to factor strings into groups of seven, thus the formal theory overgenerates.

(11) a. $V \rightarrow$ [+stress] /# C_0 $((VC_0)_2^2)_0$ ___
     b. $V \rightarrow$ [+stress] /# C_0 $((VC_0)_7^7)_0$ ___

Nasal place assimilation (5) is evaluated the same as the unattested rule (12).

(12) [+nasal] $\rightarrow \begin{bmatrix} \alpha\text{ant} \\ \beta\text{cor} \end{bmatrix} / \underline{\quad} \begin{bmatrix} -\text{syl} \\ \beta\text{ant} \\ \alpha\text{cor} \end{bmatrix}$

The class of attested rules of natural languages that motivate feature-variable notation seems to be a small fraction of the set of predicted rules, which is quite problematic if the theory is held responsible for distinguishing "actual languages" from "non-languages." The advent of nonlinear phonology seemed to eliminate the motivation and need for these notations (though see below), where a different theory of representations resulted in the possibility of expressing the facts at least as well. A similar trade-off between representational richness and statement-impoverishment is to be found in certain constraint-only theories, including Candidate Chains in OT and Declarative Phonology.

2.2 *Blocking and Repairing Conventions*

While the SPE theory with abbreviatory notations does a remarkable job, by comparison to previous formal theories of phonology, in characterizing possible versus impossible grammars and matching that to attested languages the theory mispredicted the possibility or probability of phenomena. Some of this stems from the substance-free nature of formalism, which counter-intuitively puts palatalization before back vowels and palatalization before front vowels on an equal footing.

On the assumption that this should be addressed by the formal theory, SPE introduced a major departure from strict rule theory, via a set of universal "rules" (not part of a grammar: p. 403), namely the markedness rules which encode aspects of phonetic substance. Given the device of linking, these rules automatically and globally modify the immediate output of rules. This introduces the notions of automatic repair and persistent rule, which played a major rule in the operation of non-linear phonology.

Under the markedness and linking proposal, lexical representations may have the values "u" (unmarked) or "m" (marked), which map to plus and minus by universal rules such as [$u$low] → [–low], [$u$del.rel] → [+del.rel]/[__–ant,+cor] (pp. 419–435). These rules also apply to the output of phonological rules, so given a rule changing F, a feature G whose unmarked value depends on F may be reassigned by a markedness rule. In Slavic, the rule [–ant] → [–back] / ___ [–cons, –back] derives /k g x/ → [č ǰ š]. Without markedness rules, this would only result in *[k^y g^y x^y]. A direct statement of the actual change requires more complex formulation with angled brackets (which encode discontinuous dependency not expressible via parentheses):

$$(13) \quad \begin{bmatrix} -\text{ant} \\ <-\text{cont}> \end{bmatrix} \rightarrow \begin{bmatrix} -\text{back} \\ +\text{cor} \\ +\text{strid} \\ <+\text{del.rel.}> \end{bmatrix} / \text{---} \begin{bmatrix} -\text{cons} \\ -\text{back} \end{bmatrix}$$

The change [–back] links to the coronal marking convention, where the unmarked value is [+cor] in [–back,–ant] consonants (it is [–cor] in [+back,–ant] segments). Markedness rules are linked in sequence, so the immediate result of applying coronal markedness triggers a change in the value of del.rel. to plus (because of the changed value of coronal), and finally a change in stridency. To block this chain of secondary feature modifications and allow the output to be [k^y g^y x^y], the rule simply needs to explicitly specify that [coronal] is not changed:

$$(14) \quad [-\text{ant}] \rightarrow \begin{bmatrix} -\text{back} \\ -\text{cor} \end{bmatrix} / \text{---} \begin{bmatrix} -\text{cons} \\ -\text{back} \end{bmatrix}$$

Because reassignment of the value of coronal is preempted with such a formulation, further changes to the segments do not arise. The added complexity of the latter rule predicts that [k^y g^y x^y] will be a less common form of velar palatalization. Stanley (1967: 404) similarly proposes that the output of any rule is subject to the segment structure rules of the language, so if a segment structure rule requires non-low back vowels to be round, then any rule inserting a non-low back vowel automatically undergoes the roundness redundancy rule.

Other limitations on rule operation were proposed, with researchers seeking a way to capture recurring and potentially universal generalizations while maintaining simple notation. An example of such a rule-external constraint is the Crossover Constraint (COC) (Howard 1972), which limits the interpretation of

variables in phonology.[12] Given the adoption of rule iteration, the star-parenthesis notation became superfluous, and was suspicious insofar as it was only used to express the notion "any number of possible rule foci." Elimination of the notation allowed a constraint on material appearing between the target (focus) and trigger (determinant) in a rule: "No segment may be matched with an element other than the focus or determinant of a rule if that segment meets the internal requirements of the focus of the rule."

The Crossover Constraint was seen as a constraint on string-to-rule matching, and not on possible rule statements. This allows a simple statement of the Menomini vowel raising rule with no mention of intervening features, which affects all long mid vowels and intentionally skips over all vowels, but extensionally does not skip long mid vowels:[13]

$$(15) \quad \begin{bmatrix} +\text{syl} \\ -\text{low} \\ +\text{long} \end{bmatrix} \rightarrow [+\text{high}] / \underline{\quad} C_0 \ (VC_0)_0 \ C \begin{bmatrix} -\text{cons} \\ +\text{high} \end{bmatrix}$$

The effect "anything besides a long mid vowel" is determined by universal principle.

A related constraint is the Relevancy Condition (RC) (Jensen 1974):

> Only IRRELEVANT segments may intervene between focus and determinant in phonological rules. The class of segments defined by the features common to the input and determinant of a rule is the class of segments RELEVANT to that rule, provided at least one of the common features is a major class feature. If there is no common major class feature, then ALL segments are relevant.

This constraint operates in the context of a theory which (apparently) only had a generalized variable X and no infinite abbreviatory expressions. See Odden (1977, 1980), Jensen and Stong-Jensen (1979) for discussion.

Guerssel (1978) proposes the Adjacency-Identity Constraint (AIC):

> Given a string A_1A_2 where $A_1=A_2$, a rule alters the adjacency of A_1A_2 if and only if it alters the identity of A_1A_2.

The purpose of this constraint was to explain why certain rules did not affect geminate segments: for example, vowel epenthesis is blocked from splitting up geminate clusters.

Another constraint of the era, governing whether a rule could apply, was the Revised Alternation Condition (RAC) (Kiparsky 1973), a global constraint which states that "Non-automatic neutralization processes only apply to derived forms." The purpose of this constraint is to block application of rules such as assibilation in Finnish, which do not apply to lexical /ti/ sequences in [äiti] 'mother' but does apply to derived sequences, for example, [vesi] ← /vete/ 'water', [halusi] ← /halut+i/ 'wanted'.

The above constraints had "active" consequences, forcing a particular inter-pretation of the notation (interpretation of variables with RC, COC; causing non-specified changes via linking; blocking rule application with RAC and AIC), but some constraints simply state universal properties of rules. The Marked-ness Constraint of Houlihan and Iverson (1977: 61), conceptually related to SPE linking, requires that "Phonologically-conditioned neutralization rules convert relatively marked segments into relatively unmarked segments." Although their discussion does not provide explicit formulations of the rules under discussion, they do not suggest that this constraint results in any changes in how rules are stated or applied. Rather, this constraint expresses a well-formedness requirement on phonological grammars.[14]

Apart from such global constraints on rules which were held to be universal, holding of all languages and operations, there were also language-specific con-straints applicable to single rules – that is, unformalizable conditions on rule application. One example is the blocking condition on Ojibwa T-palatalization (Kaye and Piggott 1973: 360, note). This rule is blocked when a sibilant follows, and Kaye and Piggott do not formalize the condition, stating "We are uncertain as to the formal status of this effect. It is our opinion that it does not form part of the T-Palatalization rule proper but rather is a condition ancillary to that rule." Kiparsky (1982b: 147) formulates English Trisyllabic Shortening as:

(16) $V \rightarrow [-long] / \_\_\_ C_0 V_i V_0 V_j$ where V_i is not metrically strong

Glover (1988: 225) formulates the epenthesis rule of Muscat Arabic as:

(17) $\emptyset \rightarrow V$ $/ C_i \_\_ C_j] (C_k V..)]_{Nominal}$
          $[+high]$
          Conditions: 1) Rule is optional when C_j is a fricative.
                               2) $C_i C_j$ do not form a sonorant-obstruent sequence.
                               3) C_i is not identical to C_j.

Combined with the notion of phonotactic constraint, Newman (1968: 513) proposes the following schwa-deletion rule in Tera:

(18) $\vartheta \rightarrow \emptyset / \_\_\_ X$ (where X is not #)
                    Condition: Rule void where not permitted by phonotactic rules.

The relevant phonotactic rules (constraints) are that words are minimally CV and cannot end in a voiced obstruent or a cluster.[15]

Global rule conditions in general escaped formalization. For example, Kisseberth (1973) argues for a global condition on vowel shortening in Klamath which short-ens long vowels either after V:C_0, or after two consonants when not followed by CV. This shortening only applies to long vowels deriving from vocalization of vowel+glide sequences, a condition which could not be formalized. Similarly, Miller (1975) posits a global condition on West Greenlandic assibilation, that it

changes /t/ to [s] after [i] before another vowel, but only when the preceding [i] is underlying /i/, not derived by epenthesis (epenthesis is shown to be ordered before assibilation) – this global condition is also not formalized. Thus despite best efforts, a number of factors determining rule applicability remained outside the scope of a fully formal theory of rules lacking recourse to plain-English restrictions.

The upshot of this section is that classical generative rule theory is characterized primarily by string-rewrite rules augmented by notational conventions referring to string classes, but there are also global limitations on the actions performed by rules – constraints. The constraint might trigger a repair (as in linking) or, more commonly, block rule application. The main characteristic of these constraints is that they are often held to be universal and global. As universals, the question of how these statements are formalized in a grammar need not arise, because the constraints are not part of a grammar. Such constraints were typically stated in prose (markedness and linking conventions were actually formalized). Most problematic were unformalizable language-specific constraints, undermining the concept "formal theory."

2.3   *Evaluative Constraints*

Evaluative constraints, as distinct from string-changing rules and ones guiding rule application, became particularly relevant in phonology via morpheme-structure conditions (Stanley 1967). The purpose of MSCs is to recognize redundancy in underlying forms: for example, English morpheme-initial nasals cannot be followed by a consonant. Previous work such as Halle (1959) would assume a zero specification for [consonantal] in the dictionary, and rules fill in a surface value.

Stanley showed how blank-specification undermined feature binarity and argued that phonology operates on fully-specified matrices, proposing that blank specifications be restricted to so-called "dictionary matrices." MS rules – rebranded as MS conditions (Stanley 1967: 424ff.) – are seen as statements of redundancy. Conditions either accept or reject matrices according to whether they satisfy or contradict the condition; conditions can be positive, negative, or "if-then." The latter type of constraint plays a significant rule in constraint-driven phonology, since it allows encoding cause and effect directly, for instance the if-then constraint "[−cons] ⊃ [+voice,+cont,−strid]" rules out vowels which are voiceless, stop, or strident, and fixes the locus of repair on the features *voice*, *cont*, *strid*, saying that vowels receive these three values.

Following research on derivational constraints pursued by Lakoff (1970, 1971), Kisseberth applies the notion of derivational constraint in his 1970 paper on phonological conspiracies. He argues that generalizations are missed in the standard account of Yawelmani:

> There are rather heavy constraints in Yawelmani phonetic representations on the clustering of consonants and of vowels. No vowel-vowel sequences are permitted. Words may neither end nor begin with consonant clusters. Nowhere in a word may more than two consonants occur in a sequence. (p. 294)

Specific rules of the language such as vowel epenthesis, syncope, consonant dele-tion, final Apocope, and a requirement on underlying representations regarding the presence of "protective vowels," appear to conspire to guarantee what we now understand to be the lack of branching onsets and rhymes. The formalism at the time provided no means of extracting this generalization and reducing it to notation. Note also that the concept "syllable" (restrictions on whose structure covers these generalizations quite simply) had no status in the formal theory at the time: see Goldsmith (this volume) for an overview of the syllable. Kisseberth argues that the evaluation metric *should* recognize the value of functionally related rules, even without the structural similarity required to bring them under the purview of abbreviatory notations. Fleshing out the formal details of the idea, especially how to express the notion "functional relatedness" is left for future research (p. 303). One part of Kisseberth's account posits derivational constraints against the sequences CCC, #CC and CC#. If a rule can only apply when "the output string would not be in violation of the derivational constraint," syncope can simply be stated as deleting a short vowel between two consonants, and the further fact that the consonants must be *single* consonants follows from the fact that if there were two consonants to the left or right, a forbidden triconsonantal sequence arises. Syncope can thus be simplified.

Shibatani (1973) argues for surface structure constraints, analogous to Stanley's MSCs. He argues that German must have a constraint requiring word-final obstruents to be unvoiced. This contrasts with the orthodox view that SSCs are redundant, because the facts which they cover are already explained by MSCs and the phonological rules of the language, wherefrom any SSCs can be deduced. Shibatani's argument emphasizes the fact of "independent psychological reality," the claim that SSCs are things that speakers "know" and therefore must be expressed as such in the grammar. Without a constraint to reflect the knowledge that *[bund] is not possible in German, speakers would have to not only look at existing words but also every imaginable word and apply the rules to these underlying forms to arrive at the conclusion that *[bund] would have no source in the language (could not come from /bundə/ or /bundö/): the procedure for evaluating "possible derivability" would be very complex.

Shibatani argues that rules are (often) redundant (p. 100) so the German devoicing rule [−sonorant] → [−voi] / __ ## is "identical" to his SPC2 which is stated as:

(19)   IF: [−sonorant] ##
                ↓
    THEN   [−voiced]

Similar to SPE linking, Shibatani notes that SPCs encode repairs. Given the if-then format, he proposes "The convention further entails the imposition of the features given in the THEN-part of A/SPCs onto all the forms that meet the IF-part of the same constraints." The imposition of "then"-features localizes the constraint and the repair, so that both word-final regressive voicing agreement (20a) and progres-sive voicing agreement (20b) can be derived from SPCs.

(20) a. IF: [−sonorant] [−sonorant, αvoiced] ##

                        ↓

            THEN [αvoiced]

      b. IF: [−sonorant, αvoiced] [−sonorant]##

                                          ↓

            THEN   [αvoiced]

This is a significant step towards elimination of rules, or at least demonstrating a significant level of interchangeability between rules and constraints.

   Sommerstein (1974) proposes a more formal implementation of Kisseberth's idea of conspiracy, where a rule can be marked to apply only if it improves harmony (in the sense of compliance with phonotactic statements) with respect to the motivating constraint, thus "A rule, or sub-case of a conspiracy, positively motivated by phonotactic constraint C does not apply unless its application will remove or alleviate a violation or violations of C" (p. 75). When connected to a constraint prohibiting final consonants, a language might delete final voiceless consonants and insert schwa after voiced consonants; under Sommerstein's proposal, these rules can be simplified by linking them to insertion and deletion rules, which can be stated as "delete voiceless" and "insert schwa," since phonotactically motivated rules only apply when violation of a constraint is alleviated. The choice of the word "alleviate" is also noteworthy: in his view, constraint satisfaction could be partial, presaging the OT view of relative harmony and gradient constraint violation.

2.4   Nonlinear Representations and Rules v. Constraints

The introduction of Autosegmental Phonology in Goldsmith (1976) gave substantial impetus to the expansion of constraints in phonology. Essential to Goldsmith's theory is the Well-formedness Condition, which states "All vowels are associated with at least one tone; all tones are associated with at least one vowel; Association lines do not cross." In line with the prevailing "trigger repairs when violations arise" viewpoint, Goldsmith states:

> Note that the Well-formedness Condition is in the indicative, not the imperative. A derivation containing a representation that violates the Well-formedness Condition is not thereby marked as ill-formed; rather, the condition is interpreted so as to change the representation minimally by addition or deletion of association lines so as to meet the Condition maximally. (p. 27)

The tune-to-text mapping in (21) occurs automatically, not by specific rule, to satisfy the WFC.

(21)   *   *

      archipelago   archipelago

                    →

         H*L   H*   L

Similarly (p. 50), an argument for the autosegmental model "comes from the phenomenon of bidirectional spreading and, we would suggest, its *un*governed nature in these cases – that is, the spreading is not due to a specific phonological rule, but rather to the geometry of autosegmental representations, and its Well-formedness Condition. . . ."

The necessity of general conditions on structures, rather than explicit rules implementing an effect, is particularly compelling given the wide-spread phenomenon of tone preservation. As Goldsmith argues (p. 31), the alternative (proposed by Spa 1973) is a global rule that when a segment with H tone deletes, the H transfers to the nearest syllabic segment: but this constitutes a new formal object outside the purview of ordered rules. The significance of the WFCs is that they not only prevent certain relations, such as line-crossing but, like Shibatani's interpretation of SPCs, *demand* others, for instance that toneless vowels are prohibited – so if there is a toneless vowel, some tone must spread to that vowel. Goldsmith's account had a significantly lower dependence on explicit rule statements, and a higher use of representational possibilities interacting with general constraints.

The logic of autosegmental representation makes expansion of the role of constraints mandatory. In the theory of linear representations, especially with fully-specified underlying forms, it is easy to satisfy that aspect of the Naturalness Condition (Postal 1968: 61–62) which requires dictionary representations to map to some phonetic form without applying rules of a grammar – requiring only the application of universal conventions – because there was no such thing as a representation without an interpretation, all features being present in all segments.[16] Autosegmentalization meant that a representation might contain segments lacking a specification of voicing. For representations to be interpretable, and not simply due to the good graces of a particular rule but always interpretable in any language, universal conventions would be necessary to link up features or guarantee specifications when missing.

Research in the autosegmental paradigm was not univocal in seeking a shift in the direction of universal representational constraints. The version of autosegmental phonology proposed in Haraguchi (1975), also pursued by Clements and Ford (1979), Halle and Vergnaud (1982), and Pulleyblank (1986), depends more on language-specific rules to accomplish tone-to-TBU mapping. The first step in tonal mapping is an Initial Tone Association Rule; as characterized by Clements and Ford (1979: 181), "Initial tone association results from the application of rules which are language-specific, but drawn from a narrowly-defined set of rule schemata." The WFCs of Haraguchi and Clements and Ford are persistent and universal, and perform a 1-to-1 tone-to-vowel mapping. Other mappings are language-specific rules, so association of free tones to a vowel already bearing tone is mediated by a specific rule (Clements and Ford 1979: 191).

Halle and Vergnaud (1982) pursue an even more rule-driven account without a Well-formedness Condition, thus spread of linked tone (p. 73) is accomplished by a Mapping Rule applying only to free tones.[17] Because Halle and Vergnaud distinguish autosegmental versus "phonemic core" tone specification, where

autosegmental specification overrides core specification, autosegmentally toneless vowels are allowed on the surface without spreading being needed to fill in tone. Pulleyblank (1986) conjectures that the association conventions only apply at the beginning of a derivation, leaving derived 1-to-1 free tone/V configuration alone, to be repaired only by specific rule. Pulleyblank also relies on default specification as opposed to "phonemic core" specifications, but also dispenses with automatic spreading. Default specification has the flavor of both rules and constraints. Like markedness rules, default rules seem to be universal, but like rules, they "apply" at a particular point in the derivation – what that point is was a matter of discussion in underspecification theory; see especially Archangeli (1984).

The conflict between rule vs. convention-based grammar was also evident in syllable theory. The approach to syllabification in Kahn (1976) largely eschewed representational constraints. Syllabic analogs to Goldsmith's Well-formedness Conditions are proposed, so each [+syl] segment is associated with exactly one syllable, each [−syl] segment is associated with at least one syllable, and lines cannot cross. Kahn's tack, though, is to have explicit rules which achieve a well-formed state, hence he proposes Rule I, which states that [+syl] links to a syllable, and he does not appeal to action via universal convention. The language-specific rule-governed nature of Kahn's syllabification algorithm is especially made clear in his discussion of consonant clustering options in syllables:

> The system of rules assigning syllable structure to strings of segments, as envisioned here, does not refer back to some general set of constraints on possible word-initial and -final clusters which is pervasive throughout the phonology. It is rather in the syllable-structure assignment rules themselves that these constraints are found. Furthermore the constraints are not referred to by any other rules of the phonology. (p. 25)

The implicit assumption is that the syllabification rule would directly state that an onset could be [sp] but not [ksp]. Undermining this presumption is the fact that no rule was given to encode the restrictions. The reason why onset restrictions of English cannot reduce to well-formedness constraints in the sense employed in autosegmental tonology is that the required constraints are not universal across languages, or even within English – onset stop clusters which are not allowed via core syllabification (*[ptɛrədæktl̩]) arise in the output of later vowel deletion rules ([pətéɾo] → [ptéɾo]) "potato."[18]

Clements and Keyser (1983) pursue a more constraint-dependent approach to syllabification, exploiting positive conditions which license certain kinds of onset clusters (admitting [sp,st,sk] and [pl,pr,kr] etc. onsets), and negative conditions, which filter out a subset of positively licensed clusters (eliminating *[tl, pw] and various other more specific clusters). Rather than positing language-specific ordered rules to construct syllables, the Clements and Keyser approach posits general principles which are universal (with the parametric choices "delete syllable initial C" and "insert syllable final C" as well as allowing sequences of vowels and consonants, pp. 28–30), persistent, and which interact with language-specific

admissibility conditions. A general "grouping" process is constrained (p. 37) by the Onset First Principle:

(a)   syllable-initial consonants are maximized to the extent possible with the syllable-structure conditions of the language in question,
(b)   Subsequently, syllable-final consonants are maximized to the extent consistent with the syllable-structure conditions of the language in question.

Onset First has a mixed status qua principle/constraint versus rule. It is termed a principle, and it is not subject to the standard linear ordering requirements of rules – but, Clements and Keyser also refer to these principles as rules. For example, (p. 54) the Resyllabification Convention states "The output of every rule is resyllabified according to the syllable-structure rules examined up to that point in the derivation," which asserts that these are rules, but attributes to them a property of constraints, namely everywhere-applicability. One rule-like property of syllabification is that it can have a derivational "endpoint," that is, at a certain step in derivations, it ceases to function (p. 55): "We propose, then, that individual grammars may specify a point in the set of ordered rules at which the Resyllabification Convention becomes inoperative . . ."

In addition to the aforementioned principles governing basic autosegmental associations, the repertoire of constraints includes the Twin Sister convention prohibiting adjacent identical feature values on a single feature-bearing unit (Clements and Keyser 1983), the Linking constraint (Hayes 1986: 331) which states "Association lines in structural descriptions are interpreted as exhaustive"; the Shared Features Convention (Steriade 1982) which forces merger of identical feature values under certain conditions, in response to the application of a rule. Other constraints on phonology were widely employed in this era, such as the Strict Cycle Condition, the notion of structure preservation, and the ideas of structure-building versus structure-changing rules, especially the related notions feature-changing vs. filling, which allowed rule theory to avoid explicit reference to zero.

While the role of independent constraints and interpretive conventions expanded considerably in the autosegmental era, attention was also paid to the theory of rule formulation. Pulleyblank (1983: 55–56) advances a standard symbolic notation for expressing rules operations where in addition to the notational standards introduced in Goldsmith (1976b), a line to Y means "is linked,"[19] a circle around Y means "is not linked" and a line to Y followed by a line from Y to "x" means "rightmost," that is, "a link not followed by another link." The notion of features being organized into constituents (Clements 1985; Sagey 1986) made possible the single-node characterization of rules (Clements 1985: 244), "assimilation processes only involve single nodes in tree structure," or more generally, rules operate on only one object. McCarthy and Prince (1981: 1) claim "a rule may fix on one specified element and examine a structurally adjacent element and no other," limiting the class of well-formed rules significantly (a proposal in part made plausible by expanding the class of "elements").

Discussion of constraints and rules in the context of autosegmental phonology would be incomplete without mention of the Obligatory Contour Principle: see Leben (1973), Goldsmith (1976), Singler (1980), McCarthy (1986), Odden (1986, 1988), and Yip (1988) inter alia. The basic statement of the OCP is "Adjacent identical elements are prohibited," thus two adjacent H tones would be prohibited, two adjacent identical specifications for voicing would be prohibited; generalizing the original version of the OCP somewhat, the principle could also rule out adjacent identical segments (identity with respect to the whole set of features) or adjacent homorganic segments (identity with respect to a subset of features).

One view of the OCP, advanced in McCarthy (1986), is that it is an absolute representational universal; a competing view set forth in Odden (1986, 1988) is that it is not directly part of linguistic theory but is a formal accident resulting from an interaction between language learning and representational theory, and is only formally instantiated as a language-specific rule. The problem for the representational universal view is that the highly variable naure of the OCP – its effect, viz. limiting underlying contrasts, triggering a process, blocking a process; what unit it applies to (tones, place of articulation, major articulators only, laryngeal features, whole sets of features); the degree of adjacency (strictly adjacent segments, in adjacent syllables, within the same word); even whether it is obeyed or simply ignored. All of these considerations point away from the idea of a hard universal, analogous to the No-Crossing constraint. Such parochiality was typically seen as evidence for rule status whereas the concept "constraint" was traditionally reserved for hard universals; nevertheless, within Optimality Theory, the OCP, once joined with "constraint family" and "violable constraint," remains a universal constraint. Reiss (2003) on the other hand draws a different formal conclusion, that rule theory requires variables, quantifiers, and equality computations.[20] As Reiss points out, homorganic syncope ("anti-antigemination") in Yapese and Koya, where C_iVC_i and only C_iVC_i syncopates to C_iC_i, cannot be explained by appeal to sharing of a place node, so some reference to identity of values is needed, and OCP effects are easily subsumed under a general theory that includes feature identity.[21] See also Baković (2005) for related quantificational analysis within OT.

To summarize the course of rule theory, there has been a steady progression of ideas, from minimal reliance on the guiding hand of UG and more emphasis on explicit statement of directly interpreted operations, to a greater reliance on conditions, some language specific but in the mainstream view universal, which are stated independent of the rules that control derivations. The main difficulty facing the theory is the assumption that rules are language-specific whereas constraints (conditions, principles) are true of rules in general, and yet hard and fast constraints turned out to be difficult to come by. Many putative conditions required specific assumptions about representations which were highly controversial. The OCP debate highlights both of these problems, in that manifestations of the OCP are sufficiently common across languages that it cannot be dismissed as a coincidence; and yet it is not an absolute representational universal.

3 Parametric Rules

If rules are non-recurring parochial statements of the mapping from input to output, and grammars contain just rules and representations which rules act on, then generalizations which recur within a language or across languages are expected only to the extent that they might arise more than once by random combinations of symbols into rules, according to a theory of rule formalism. Thus we expect rules of regressive nasal assimilation or voicing assimilation because such rules are possible in rule theory, and we do not expect the mapping /p,l,i/ → [r,o,t] / __[s,p,e] which is not a rule in phonetic feature-based rule theory. But within possible rules, there is a significant disparity between observed frequency of rules and their combinatoric probability, given the free combination of elements according to a syntax of rule formulation. Nasal place assimilation and post-nasal voicing are common, but post-nasal devoicing and "continuancy assimilation" (e.g. /xt/ → [kt], /ks/ → [xs]) are extremely rare and possibly non-existent. Formally speaking, there is no basis for this, since continuancy assimilation is the same operation as place assimilation, simply applied to a different node in the representation, and post-nasal devoicing is expressible as dissimilatory delinking, a known process in language. The frequency of consonantal homorganicity conditions on rules and the rarity of analogous laryngeal identity conditions cannot be formally explained just on the basis of formal properties of rules. From OCP investigations, we know that these tendencies cannot be hard universals – there is no absolute requirement that nasals *must always* agree in place with the following consonant.

The idea of a "parameter" is well suited to resolve recurrency with violability. A parameter is a fixed choice given by UG, which narrows the degree of freedom to less than that given by free combination of symbols, but still provides a degree of freedom greater than zero. The notion of "parameter" is introduced in Chomsky (1964: 315), who states:

> Even if conditions are language- or rule-particular, there are limits to the possible diversity of grammar. Thus, such conditions can be regarded as parameters that have to be fixed (for the language, or for particular rules, in the worst case), in language learning . . . It has often been supposed that conditions on application of rules must be quite general, even universal, to be significant, but that need not be the case if establishing a "parametric" condition permits us to substantially reduce the class of possible rules.

This approach particularly flourished in syntax in work emanating from Chomsky (1981).

Parameter-like theories of phonology were pursued in Natural Phonology (Stampe 1972), which posits that humans are endowed with a list of innate, substantive phonological processes, some of which must be suppressed in the course of language acquisition. The theory of Atomic Phonology posits that the core of phonological systems is a collection of given basic processes (such as palatalization,

vowel nasalization, etc.), termed "atomic rules," and "complements"[22] of the atomic rules present in particular grammars. Dinnsen (1979: 31) thus posits that "The theory of atomic phonology maintains that all linguistic variation requiring distinctly varied formulation of phonological rules is predictable from a set of atomic rules and universal principles of grammar." The atomic rule of final devoicing is:

(22) $\begin{bmatrix} -\text{son} \\ -\text{cont} \end{bmatrix} \rightarrow [-\text{voice}] \ / \ \_\_ \ \#$

Any language with final devoicing must have *at least* this form of the rule – a language with just "velar stop devoicing" or "fricative devoicing" would be impossible since those rules are (by hypothesis) not atomic rules. Restricted sets of options are made universally available, but they may be overridden – the process may be suppressed, the atomic rule may not be selected, or a complement rule may be selected, as long as the atomic rule is.

Non-linear phonology in the 1980s also saw an increased reliance on rule construction with formal and substantive parameters. As discussed above, core syllabification in Clements and Keyser (1983) invoked consonant insertion and deletion parameters. Hayes (1980) proposes "that the characteristic stress rules which occur in language after language are all derivable using a fairly simple rule schema, in which a number of parameters may be set independently of one another." While arguing for an absolute, inviolable universal interpretation of the OCP, McCarthy (1986: 256) also allows that "The alternative and, I think, the best way to account for any nonuniversality in the OCP, if clear violations arise that are not susceptible to reanalysis, is to consider the OCP a parameter of Universal Grammar whose unmarked value is 'on'." Substantial use of OCP parameters in rules is found in Yip (1988); parameters play a major role in certain typological studies, such as Cho (1990) for consonant assimilation and Hayes (1995a) for stress. Universally fixed choices for adjacency conditions are discussed in Odden (1996), and Calabrese (1988) proposes a rule-based theory augmented with parametrically-selected negative filters on segments and universal clean-up rules.

The fundamental work in parametric rule theory is Archangeli and Pulleyblank (1994), which articulates a general parametric theory of rules, Grounded Phonology, combining absolute conditions and universal choices for rule formulation. See also Davis (1995) for an application of the theory to rule statement in Palestinian Arabic. The concept of a constraint or condition is strong, according to Archangeli and Pulleyblank (1994: 14): "Wellformedness encodes the requirement that no representation may be allowed, even temporarily, to violate conditions," thus (p. 14) "Given an input representation of a particular type, a *convention* predicts a single related output representation." The theory defines rules in terms of conditions in fixed boxes including *function, type, direction, iteration*.

Rules specify an argument (the focus in traditional terminology), so a rule spreading [–ATR] has the argument [–ATR], and can have structure requirements on argument and target (whether they must be unassociated or not). Finally, rules have an "other requirements" box for context conditions, such as whether

a rule applies only to certain morphemes or string properties like "word finally if preceded by L," or the Menomini target condition μμ (p. 379) which states that only long vowels can undergo ATR harmony. This much of the theory essentially re-states aspects of standard non-linear rule theory.

The most significant difference from standard rule theory resides in the substantive "grounding conditions" on argument and target, which specify phonetically motivated if-then relations between features in a path. An example is ATR/LO, which states that if a vowel is [+ATR], it should be [–low]. Imposed as a target condition, only non-low vowels could undergo an ATR spreading rule (a common restriction on ATR spread), and as an argument condition it states that [ATR] spreads only from a non-low vowel. The theory presumes specific sets of feature relations, thus six $\alpha F_i \supset \beta F_j$ relationships between ±ATR, ±hi and ±low are postulated as exhausting the range of phonetically grounded conditions. This listing precludes combinatorially possible relations such as "if [+hi] then [–ATR]"; evidence for such a condition would be a case where [–ATR] spreads only to a high vowel or from a high vowel (see Poliquin 2006 for an example from Canadian French).

The question will naturally arise whether there is a substantial difference between the parametric rule approach of Grounded Phonology and similar works, and the Principles and Parameters account of Halle and Vergnaud (1987), or Paradis discussed in the next section. Hayes (1995: 55) aptly characterizes the matter as follows:

> An interesting problem within parametric metrical theory is to what extent the parameters characterize rules versus grammars. Here, we will conservatively assume that parameters characterize rules. However, the possibility that they have more general scope, as suggested by HV [Halle and Vergnaud 1987: DO], is an appealing one: for example, it predicts that when more than one rule creates feet, the feet created should be the same.

A pure-parameter approach would say that the scope of the parameter is the particular representational object, and the prediction is that a language should not have multiple rules spreading or deleting a given feature, except if a parameter holds only of one lexical level. In a parametric rule approach, the scope of a parameter is the given rule, which allows more than one rule focusing on a particular feature such as nasal or H tone. Odden (1981) argues that Karanga has over a half-dozen each of partially similar rules raising L after H and lowering H after H, differentiated by subtle contextual properties, but perhaps with a highly articulated theory of level, these rules could be reduced to single parameter settings.
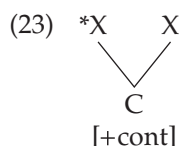
4   Constraints-Only

Given the expanding role of constraints in phonology, it would seem a hindsight-obvious simplifying move to attempt a theory without rules. As discussed in

Section 5, it is unclear which theories are "constraint-only" since there is no clear characterization of "constraint" as distinct from "rule," and naming conventions are variable, for example Karttunen's (1993) paper is about "Finite State Constraints," but also talks about these constraints as "rules." A characteristic of the rule-based approaches of the preceding section is positing that the engine underlying phonology is a set of string-changing rules. Constraint-based theories deny this, and may deny that there is any string changing at all (Declarative Phonology) or view string changes as automatic responses to representational requirements (TCRS and OT). This section considers four approaches that can reasonably be considered constraint-only: TCRS and similar Principles and Parameters (P&P) theories; the fixed-level approaches of Goldsmith, Lakoff and Karttunen; Declarative Phonology; and OT.

4.1   *Principles and Parameters*

The main representative of P&P phonology is the Theory of Constraints and Repair Strategies (TCRS), articulated in Paradis (1987, 1988), building on work by Singh (1987) and Piggott and Singh (1985). The essential difference between strict P&P phonology and parametric rules is that the latter theory has a linearly orderable grammatical object, but the P&P approach only states conditions on representations, and derivational steps are given automatically by the theory.

Paradis (1987, 1988) argues for a repair driven model, based on the contention that phonological rules are "contextual and arbitrary" but repair strategies are context-free and "motivated," the context and motivation of the repair being found in the constraints. In TCRS, constraints can be universal ("principles") or language-specific. Examples of presumed universals are the OCP and Prosodic Licensing (all units must belong to higher prosodic structure). Constraints have either a blocking effect or, if blocking is impossible, they trigger a repair – "insert," "delete," or "change." The theory has a number of particular parameters, such as "Spread Nasal," so if "Spread Nasal" is set "on" for a language, then nasal must spread. Other parameters accept/reject particular sequences, for example sequences of non-high vowels may be accepted in some languages, but are generally rejected due to a parameter setting. Parameters may also be set according to lexical phonology domain (similar to Goldsmith's Harmonic approach). An important feature of Paradis' constraints (found also in Shibatani's account) is that constraints have a focus. The Fula constraint:

(23)   *X   X
          \   /
           C
        [+cont]

has a segmental focus on the feature [+cont]. The locus of a repair would be that feature, and in Fula, would-be geminate continuants change to stops (rather than degeminating).

Paradis also points to the "many effects from one constraint" argument made by conspiracy theorists, an example in Guere being the constraint against non-high vowel sequences, which not only limits underlying forms (there are no non-high vowel sequences within morphemes – an MSC), but it also triggers vowel raising and vowel deletion. Similarly, OCP-labial causes both hardening ($w\upsilon \rightarrow g\upsilon$) and deletion ($kwu \rightarrow ku$).

TCRS separates morphophonology and automatic phonology. Paradis (1988: 5) notes "I do not claim, then, that there are no rules but rather that these are morphologically conditioned processes." It is not clear whether such processes would be in a separate grammatical module, though the disposition of morphophonology in Singh's theory (1987: 282) is clearer: it "cannot work without giving up what has seemed to be the non-negotiable heart of generative phonology: the assumption that even non-automatic morphophonology is a part of phonology." An example of a phonological rule consigned to morphology mentioned by Singh is English Trisyllabic Laxing (accounting for the alternation *serene ~ serenity*). This would be an example of how precluding classes of phenomena may allow a formally more constrained theory, while making comparison of theories (standard rule theory versus P&P phonology) meaningless because they are theories about different things.

4.2   *Fixed-level Accounts*

Another approach to stating phonological regularities, arising from work in computational linguistics, especially Koskenniemi (1983), relies on directly stating relationships between input and output (or some similar fixed set of levels). One of the main concerns of fixed-level approaches is elimination of extrinsic rule ordering, also a goal of the Unordered Rule Hypothesis (URH: Koutsoudas, Sanders, and Noll 1974). Early implementations of unordered rules failed because the claim of persistent reapplication of rules was falsified by counter-feeding relationships, and direct mapping theories (Kenstowicz and Kisseberth 1977 291 ff.) were falsified[23] by feeding relationships. The problem for direct mapping is that if rules can only refer to what is present in underlying forms, cases such as Lardil are impossible to express without redundant recapitulation of the conditions in Apocope. In the Lardil derivation /tjumputjumpu/ → *tjumputjump* → *tjumputju*, where Apocope feeds non-apical deletion, the conditions for consonant deletion are not present in the underlying form and, in light of the fact that /kuŋka/ → [kuŋka] without Apocope (because of a word-minimality restriction), an elaboration of non-apical deletion which allowed deletion of intervocalic consonants must repeat the conditions for Apocope.

In the version of Karttunen (1993) (see also Karttunen, Koskenniemi, and Kaplan 1987), a phonology is modeled as correspondences between input and output. Rather than producing the required output from a set of rules which modify an input, the constraints accept (or reject) pre-existing pairings of input and output, based on the properties of the input and output – which means that the constraint has simultaneous access to the input and the output (not possible under the

Markovian conception of rule). In Karttunen's notation, "u:" means "lexical u," ":u" means "surface u," and "⇔" expresses the input/output relation "is realized as . . . in the context . . . and nowhere else." Examples from Finnish which are relevant in accounting for the mapping in Finnish *kaNpan:kamman* are as follows.[24]

(24)   N:m ⇔ ___p:
       p:m ⇔ :m __

This means "input *N* is realized as *m* only before underlying /p/" and "input *p* is realized as *m* only after surface *m*." For the problem of Lardil Apocope and non-apical deletion, non-apical deletion could be stated as:

(25)   [non-apical]:∅ ⇔ __:∅* :#

that is, an input non-apical must map to an output null before an output word boundary, disregarding deleted segments.

   An alternative graphic representation of these relations is adopted by Lakoff (1993) and Goldsmith (1993a), who recognize three levels of structure,[25] the M(orphophonemic), W(ord) and P(honetic) levels. These levels describe respectively a description of phonological properties of the morpheme, the word (with minimal redundant information), and the phonetic output. Goldsmith's Harmonic Phonology constraints (Goldsmith 1993a) for vowel lowering and Apocope in Lardil are as follows:

(26)   M   [V]]$_{word}$ M   VCVCV]]$_{word}$
       ↕ | ↕ |
       W̄   [-hi]   W̄   ∅

   Goldsmith's Harmonic Phonology addresses the well-known rule ordering relationships, by distinguishing intralevel and cross-level rules. Intralevel rules are held to be "harmonic," that is, the string is modified to the point that no further increase in harmony (satisfaction of target condition) results, thus *tjumputjump* loses final consonants until the perfectly harmonic string [tjumputju] results. This is analogous to the repeated application of rules in the URH which allowed feeding relations (but was falsified because of the existence of counter-feeding).[26] Cross-level rules, on the other hand, can be harmonic or non-harmonic, the latter meaning that there is a single evaluation of the relationship between levels. The relationship illustrated by the mapping /tjumputjumpu/ → [tjumputju] with respect to vowel lowering and Apocope (*[tjumputja], *[tjumpu]) exemplifies how cross-level rules can accommodate counter-feeding as a function of the rule itself: the rule only demands that a vowel which is word-final at the M-level correspond to zero (or a non-high vowel) at the W-level, and the last vowel of [tjumputju] is not word-final at the M-level. With three levels, five classes of rules are defined (three which describe properties of representations at the level and two which describe the relationship between adjacent levels), and the empirical claim is that this suffices to handling all rule ordering effects.

4.3   *Declarative Phonology*

Declarative phonology explicitly shares theoretical assumptions with the declarative syntactic theories HPSG (Pollard and Sag 1994) and LFG (Bresnan 1982), and like HPSG is, according to Bird, Coleman, Pierrehumbert and Scobbie (1992: 1), "an attempt to do away with the ordered derivations and the concomitant feature-changing rules of traditional generative phonology." The declarative paradigm is committed to non-algorithmically describing static properties of linguistic strings by continuous elaboration of a description where, as characterized by Levine and Meurers (2006: 377), "all representations which play a role in licensing a particular string are simultaneously and completely part of the model of the linguistic object being licensed." All statements in a declarative account must be true, that is, there can be no exceptions from any source to rules, and constraints cannot be violated.

The DP view is that a phonological representation is a "description of a class of utterances" (Bird and Klein 1994: 456), which refers to a narrower class of utterances when the description is more fully articulated, or a broader class of utterances when it is less fully articulated. For instance, English *p* can be described without mentioning aspiration or glottalization, in which case all *p*s would be subsumed under that description, or it could be described as "aspirated," in which case only the syllable-initial ones are being described. Descriptions of linguistic objects are said to be partial in that they do not specify every detail of an utterance – they are descriptions of *classes* of utterances, so the details distinguishing one utterance from another within the class will not be part of the class description. Questions of formal representation become paramount in a declarative phonology, and representations can be rather complex. Other examples of DP research are Bird (1995), Scobbie (1997), Coleman (1998, 2006), and Hoehle (1999). A very similar partial-description approach to phonology, relying on the notion of property-percolation and eliminating all feature-changing in favor of lexical allomorph selection is proposed in what appears to be the first generative constraint-only theory, Guerssel (1979), though DP does not appear to a have been influenced by that work.

Allophony is straightforward for DP, which like American Structuralism sees the phoneme as a descriptive device for subsuming a class of phonetic realizations. Little information is available on how DP treats neutralizing processes, which pose a problem for the non-destructiveness requirement of the theory. The German root-object meaning "federal" manifested in attributive *bund-ə* must be distinct from the root-object meaning "colorful" manifested in attributive *bunt-ə*, but the two root-objects are pronounced the same in uninflected [bunt] "federal; colorful." The standard feature-changing account is impossible since underlying information would not be present in all instances of the object being modeled (the root "federal"). Based on analyses by Bird in Bird (1995) and especially Bird, Coleman, Pierrehumbert and Scobbie (1992), it seems that this problem could be reduced to disjunctive allomorph selection as practiced by Trubetzkoy, Item-and-Arrangement morphologists (Hockett 1954) and Natural Generative Phonology (Hudson 1975; Hooper 1976). The representation would be enriched so that [bunt] "federal" could be /bunT{+voice,∅}/ and [bunt] "colorful" could

be /bunT{−voice,∅}/. Another approach to the problem is to deny the existence of neutralizations.[27]

4.4   *Optimality Theory*

While Optimality Theory relies on constraints, as McCarthy (2002) points out, it is a theory of constraint *interaction*, not constraint substance. OT has no necessary position on whether there is a constraint Onset requiring syllables to have onsets, and no necessary position on banning a constraint Coda obligating syllables to have a coda, or *Onset prohibiting onsets (p. 46, Note 13).

An OT constraint is a requirement which should be true for forms, but unlike most constraint-based theories, violations of constraints are possible, indeed unavoidable. For any violation a mark is assigned, and the output of the system is determined based on a computation over the set of marks. It is hard to say what syntactic form constraints have, since the theory does not hold to any particular idea of the syntax of constraints. Rules were held to be constructed on the basis of experience, using universally-defined primitives combined according to a particular syntax of rules. OT constraints are claimed to be entirely universal, so it would make little sense to talk of "constructing" constraints according to systematic principles. The fact that there is a constraint *NÇ does not imply that there is also a constraint *NZ (although there probably has to be such a constraint in OT), *SÇ, *N[sonorant], or any other pairing of two consonants. OT constraints being universal, it would be difficult to pin down matters of actual form, since they are invariant across languages. In plain English, the Onset constraint can be stated positively as "A syllable begins with an Onset," or negatively as "no syllable may begin with a vowel." Constraints can also be stated symbolically, in which case they are usually stated negatively – *NÇ or *[σV. Often constraints are simply named, for example, *Complex, when the function of the constraint is presumably obvious. As in Atomic Phonology, the set of constraints needs to be discovered.

Nevertheless, systematic aspects of constraints have been proposed, in the form of constraint schemata. For instance, OCP seems to represent a family of constraints, probably applicable to any feature or node; there seems to be a class of related constraints on identity with different adjacency requirements (see, for example, Bickmore 2000 for distinct rankings of adjacent vs. general Uniformity violations), or relativization to different morphosyntactic levels such as "stem" or "word"; constraints can subdivide into various positional versions. Another systematic form of constraint is the class of alignment constraints, which follow a general formally defined template Align (Edge, Category, Edge, Category).

In OT, constraints are ordered (ranked) and violable – ranking is relevant only to regulate conflicts arising from the impossibility of satisfying every constraint, and ranking makes violability possible. Unlike TCRS or DP, constraints can be violated. OT constraints somewhat resemble parameters in TCRS, which are not enforced in all languages but are potentially available in all languages, thus

allowing unenforced universals. However, in TCRS, if a parameter is set "on," then it is on and enforced throughout the language (or, the lexical level where it is on). The entire content of a grammar is the ranking of these constraints.

The original version of OT, without faithfulness conditions and obeying Containment – "the input is literally contained in the output, with no losses" (Prince and Smolensky 1993: 111) – was effectively monostratal, that is, constraint violation was determined only by inspecting the properties of the output. The advent of Correspondence theory moved OT into the realm of being at least a two-level theory like Kimmo morphology, since constraint satisfaction required inspection of both the input and the candidate itself. The advent of inter-candidate correspondence (Output-Output constraints and Sympathy constraints, inter alia) continues the representational enrichment of OT. In a recent development in OT, the theory of candidate chains (McCarthy 2007), the mapping in Yawelmani from /c'u:m-hin/ to [c'omhun] involves selecting the winning candidate which is a chain of forms <c'u:mhin, c'u:mhun, c'o:mhun, c'omhun>, having as many virtual levels as steps in a rule-based derivation.

5   Interchangeability of Constraints and Rules

The main difficulty in deciding between rules and constraints as the best model of language is the varying metaphysical implications (but not necessarily entailments) of these concepts. Does the concept "rule" entail a real physical operation in time; is a constraint a Platonic requirement that is instantaneously "somehow true?" Is it a disadvantage for a theory to have "productions?" Is it meaningful for a theory to talk as though forms already exist, waiting to be evaluated?

Linguists have, to a considerable extent, been willing to set aside strong commitment to particular metaphysical interpretations of theories, and disputes tend to center on the weak generative capacity of theories. The idea of interchangeability of methods has a venerable tradition in generative grammar, owing in no small part to the results of Chomsky and Miller (1958). The Chomsky hierarchy of production rules in formal language theory has a mathematical equivalence to automata said to "accept" certain languages, whereby Turing machines accept Type 0 languages (the languages produced by unrestricted rewrite systems), linear bounded automata accept context-sensitive languages, pushdown automata accept context-free languages, and finite state automata accept regular languages. A grammar producing a given class of strings is weakly equivalent to some machine that only accepts that class of string and rejects all others. This fact gives rise to the appearance of interchangeability of rules and constraints.

McCawley (1968) advocates a non-production oriented interpretation of base rules, which are understood to state admissible mother-daughter node relations where NP may dominate *det* and *N*, rather than stating how the object NP is converted into a sequence of objects, *det* and *N*. Lakoff (1970: 627–628) provides an insight into the notions "constraint" and "rule," suggesting that they are not very different objects.

> phrase-structure and transformational rules . . . are local; they define well-formedness conditions on individual phrase-markers and on pairs of successive phrase-markers in a derivation . . . *Transformations are essentially local derivational constraints, in that they filter out those pairs of successive trees which are transformationally related from those which are not.* (emphasis added)

Dinnsen (1972: 2) similarly notes that "phonological rules thus establish grammatical relationships between adjacent lines in a derivation."

Stanley (1967: 393) states that ". . . a morpheme structure rule can be interpreted both as a statement of a constraint on phoneme sequences and as an algorithm for predicting redundant feature values in phoneme sequences. The morpheme-structure rule itself is neutral as regards its interpretation." This again points to the recurring observation that string-rewrite rules and string-evaluation statements may be notational variants, from the perspective of the classes of strings that they describe. Finally, in comparing parallel and sequential descriptions, Karttunen (1993: 174) says "One important lesson that has been learned about the two styles of description is that in phonology they are formally equivalent." Thus the Finnish constraint regulating the $p \sim m$ alternation stated in Two-Level Morphology as "p:m $\Leftrightarrow$:m __" means "accept an input p matched with output m just in case output m precedes," the rule "p→m/ m__" means "change p into m when m precedes," and the input-output relationships are the same whether you interpret the generalization as a well-formedness constraint or a production rule.

Translation between OT constraints and production rules may be straightforward,[28] since the proposition asserted by a constraint has an analog to some aspect of a production rule. The rule [+syl] → [+hi]/ __[+nasal] $_\sigma$] can be re-expressed as well-formedness constraints addressing the structural description, such as *[+syl,–hi] [+nasal] $_\sigma$], with limitations on repair strategies via faithfulness and markedness referring to the complement of the changing features (e.g. Faith(+syl), Faith(nas), which prevent denasalization or resyllabification as repairs) – in general, keep all things the same, except that which changes. It is very likely that such a translation could be automated, though hand-coding the markedness and faithfulness relations could lead to a more streamlined characterization of the constraints relevant to a process, just as hand-coding the composition of rules in two-level phonology can lead to simpler sets of regular expressions.

In short, if we are committed to neutrality as to metaphysical interpretation (and we are *not* all committed to such neutrality), a theory describing language as a system of operations replacing objects with other objects in real time is extensionally indistinguishable from a theory describing language in terms of separating wheat from chaff, in a pre-existing set of language objects. It is more productive to focus on properties of specific rule versus constraint theories and ask, which properties do phonological systems have? Some property can always be identified as defining the "line in the sand," sacrificing other considerations in its defense. As is well known, there is a trade-off between statement-simplicity and ordering – simplicity can be purchased at the cost of imposing order on processes (either derivational rule ordering or constraint ranking). Is simplicity and generality of statement so important that ordering is tolerable? Put the other

way, is ordering so repugnant that massive rule complication is actually preferable? Why is no-ordering intrinsically superior to simplicity (or the converse)? How much complication is needed to avoid derivational steps and ordering? Simplicity of the metatheory itself is also a consideration in theory selection. Is there validity in the Occam's Razor argument that constraints-only is conceptually simpler than rules plus constraints? Is that simplicity negated by the fact that OT also requires adding Gen and Eval algorithms to grammar? Because such philosophical questions are hard to answer decisively, it may be more fruitful to look for empirical answers, but even then, compelling and unequivocal evidence is hard to find.

5.1   Globality

A supposed difference between rules and constraints is globality and the conspiratorial nature of constraints. Rules are linearly ordered and constraints are classically unordered requirements on representations having numerous sources, so finding conspiracies would seem to support constraints over rules. However, it has long been known that rule ordering is not strictly linear because of the cycle; furthermore, it has been proposed in the rule-based context (Chafe 1968; Halle and Vergnaud 1987) that there are unordered "persistent rules." Some constraint theories have ordered domains (Paradis 1988; Kiparsky 2008a), and constraints in Harmonic Phonology fall into three ordered levels with two rule-governed transitions. P&P phonology allows constraints to have a "cutoff" within the derivation, and insofar as parametric rule theories such as Grounded Phonology are at heart a fusion of the notions "independent constraint" and "particular rules," constraints can be quite localized. Thus conspiracies do not automatically argue for constraints over rules, any more than "opacity" automatically argues for rules over constraints.

Since constraint and rule theories have resources for expressing globality, the productive question to raise is, what kinds of properties seem to be global? Rules and constraints alike operate on possible representations and either modify them or say something about them (whether they are "allowed"). Language is a system where symbols can be defined in terms of other things (symbols or perhaps physical properties). A universal syntax of representations for defining these symbols therefore establishes a baseline of globality: if an imaginable combination of primitives is not within the scope of linguistic representation – the would-be symbol is undefined – then rules will obviously show the effect of that fact. It is a fairly well supported hypothesis, at least in generative theories, that languages include (27a) but not (27b).

(27)   a.   Foot   b.   σ

           | |

           σ   Foot

           | |

           μ   μ
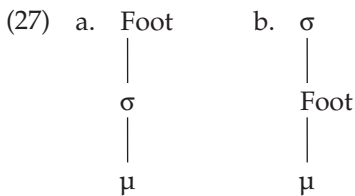
The need for representational constraints on defined linguistic objects can hardly be questioned – there are feet, and they have a specifically defined nature which then limits (constrains) what a foot can be: but it is debatable what those representational objects are, and whether definitions are universal or can also be language-specific. The vowel objects [æ] and [ɑ] are both defined (generated) and used in English and Finnish, but the object [æ] is not defined in Italian. Global structure-preserving effects which limit the operation of rules to only deal with defined symbols would be one source of global effects in rule theory. Another kind of symbolic object that requires definition would be a prosodic constituent – onset, coda, foot. If "onset" is defined in some language as "sonority-decreasing sequence of consonants," then a sequence *rp* will not be an onset, and as long as phonological rules are restricted to producing defined outputs (and assuming that prosodic licensing is a requirement of representations), conspiracies regarding constituent makeup are expected.

A requirement for creating only defined objects is expected to result in conspiracies – segmental and prosodic structure-preservation effects – but simple concatenation of objects would not, by the same logic, lead to conspiracies. A linear segment sequence coronal+labial might be precluded by a constraint, and such a limit would not be due to the definition of a specific segmental or prosodic object. Multiple references to the exclusion of such a sequence in a rule system could then be an argument for the notion of "conspiracy" extrinsic to the system of rules, and thus an argument for the autonomous constraint. A case for including constraints in the theory of grammar would come from a language with multiple rules defined on concatenations of segments, having an evidently unified teleology but a disunified collection of structural changes, at least presuming that the similarity must be captured in the grammar. One example could be the fact that in Karanga, over a half-dozen rules lowering H tone to L after H are motivated, and given the various subtle differences in morphosyntactic requirements and other phonological conditions on the rules, it cannot be maintained that there is just one rule H→L/H__.

A second type of conspiracy, one that is fairly widely attested, is the grammar with multiple rules eliminating vowel sequences – glide formation, vowel deletion, and vowel fusions. Odden (1996) analyzes Kimatuumbi's vowel hiatus-resolution processes in terms of six specific rules, without explicit encoding of a common teleology behind these rules in the grammar. The constraint-based criticism might be that this leaves uncaptured a unifying generalization expressed through a motivating constraint against V-V sequences. The rule-based response would be that this is not a generalization needing to be captured in the grammar, and that expressing the generalization via a handful of separate rules is appropriate, since V-V hiatus resolution is fairly idiosyncratic and does not reflect a general fact of Kimatuumbi which, unlike Luganda, is rather tolerant of vowel hiatus, which is resolved in only around half of the contexts where it arises. The methodological question underlying the conspiracy argument is whether a grammar should directly encode all imaginable descriptive generalizations about the language. Just as it would be invalid to argue against a constraint-based account of phonological

processes on the grounds that it requires multiple constraints to fully express them, it is also invalid to argue against rule-based phonology by *presuming* that a grammar must contain single constraints that directly state teleological goals and then criticizing rule-based grammar for not having constraints.

5.2   Derivation-like Properties

Two main characteristics give a "derivational" character to theories, namely time invariance and multiple representations. Time invariance is a concept from signal processing, where a system is time-invariant in case all orders of application of functions yield the same output from an input, thus $F_i(F_j(x))=F_j(F_i(x))$, which is to say, the computation of one function does not depend on the results of the computation of another function. For numeric functions, $|1/x|=1/|x|$ so a system with "absolute value" and "multiplicative inverse" is time-invariant, but $succ(\sqrt{x})\neq\sqrt{succ(x)}$, thus "successor" and "square root" form a time-variant system. The notion of time invariance can be interpreted to refer to real time, but can also be viewed abstractly as referring to logical priority. N-stratality refers to the number of representations involved in computing a form. Most phonological theories are at least bi-stratal, having input and output representations, although DP seems not to have an input representation, thus would be monostratal.[29] Classical OT, Kimmo-style two-level phonology, and the DMH would appear to be bistratal, having just input and output representations. Two-level phonology might also be considered to have one representation with two aspects, the input and the output, thus Finnish *kammat* could be a single representation *kaMpat:kammat* where the substring to the right of the colon is what is pronounced. In like fashion, the Yawelmani OT candidate-chain <c'u:mhin, c'u:mhun, c'o:mhun, c'omhun> could be considered a single representation, only the last part of which is pronounced, but it is a representation with at least as many parts as a standard rule-based derivation. Without a clear definition of what constitutes a single representation, it is easy to achieve monostratality by conjoining derivational steps into one complex representational object.

Some constraint-based theories have a small fixed number of representations greater than two in the computation of an output, for example Harmonic Phonology which has three levels of representation. Polystratal theories can be subdivided into those with automatic and non-automatic strata: P&P and the URH are polystratal because their computations have multiple representations and the theories are time-variant (there is a correct vs. incorrect sequence of application of functions in the theory), but the sequence in which functions are applied is theoretically given automatically. Derivational phonology is generally non-automatically polystratal, so in a grammar with K rules, there are K representations, although there have been attempts to proscribe explicit ordering in certain cases, for example in Lexical Phonology to ascribe properties to the lexical vs. post-lexical modules. In OT, the selection of an optimal form is time-variant because the results of computing the winner from the sequence of marks {**,{*}} is not the same as computing the winner from the sequence of marks {*,{**}}.

While representational enrichment potentially translates multi-step derivations into multi-aspect representations, two- and three-level theories such as Kimmo Morphology and Harmonic Phonology seem to depend minimally on representational embellishment to eliminate steps in the production of outputs, and thus stand as the clearest alternatives to rule theory, with respect to the derivationality issue. One reason for concern over ordering mentioned by Goldsmith (1993b: 6) is the "100-step limitation," which refers to the fact that neural activity is not infinitely fast, so there may in principle be a maximal number of ordered steps in a derivation. This would be a concern for a theory aspiring to modeling an actual mental process, but not all theories have such aspirations.

5.3   *Universality, Negativity*

While universality was, historically speaking, seen as having a tight connection to constraints, no such connection is logically mandated. The connection between constraint (vs. rule) and universality has the dubious status of a question-begging presumption in generative grammar – *by definition*, constraints ought to be universals. In classical rule theory, the substance from which rules are constructed is drawn from a universal alphabet, combined into rules according to universal principles of rule construction, and sometimes with parameters which are universally available choices. Certain specific rules may be pre-supplied in a form, such as in atomic rules. At the same time, some theories assume that constraints are universally provided, but P&P phonology also allows language-specific constraints, and there seems to be little implication that constraints in a DP grammar are all universal. There is likewise little evidence that fixed-level constraint theories actually hold that constraints are pre-given by UG.

Universality is unlikely to be a valid argument for constraints over rules for two reasons. First, whether one uses rules or constraints, if one subscribes to the idea that there is some version of Universal Grammar, that entails a universal machinery and vocabulary, be it syntactic forms or lists, rules, or constraints. So if grammar is based on rules and UG states what the form of rules is, then *of course* there will be universals in the formulation of rules; equally, if grammar is based on constraints and UG states what the form of constraints is, then *of course* there will be universals in constraints formulation. Second, repeatedly observed phonological facts which defy reduction to a property of rule syntax – the fact that nasalization is vastly more common than denasalization, post-nasal voicing is vastly more common than post-nasal devoicing, and languages seem eager to give onsets to syllables and not so eager to get rid of onsets – may be at a probabilistic advantage from the perspective of sound change (see Hale and Reiss 2008), without reflecting on the grammatical faculty.

Similarly, the historical association between constraints and negative expressions vs. rules and positive expressions may be reinforced by the ordinary language association between constraint = negative command, vs. instruction = positive command, but without a well-justified theory of the form of constraints/rules and propositions that they depend on, any instruction to act one way when certain

conditions hold can almost trivially be translated into a prohibition against action any other way when those conditions do not hold. More interesting questions to ask would be: Are all/any features two-valued or monovalent? Should structural descriptions include disjunction as well as conjunction?

6   Conclusions

One firm conclusion that can be reached regarding rules vs. constraints as a model of phonology is that it is easy to be distracted by non-essential details of a particular theoretical package. The general ideas of rule-based and constraint-based grammar are sufficiently open-ended that neither can be per se reasonably judged superior to the other. A detailed and extensive comparison of a specific rule-based theory and a specific constraint-based theory could be productive, but is not the purpose of this chapter. Such a comparison must start from explicit metaphysical commitments – whether we are modeling sets of data presumed to already exist, or processes that generate complex data from simple parts; what facts are to be explained (low-level phonetic detail, neutralizing processes, lexically and morphologically governed processes); and whether the theory of phonology is held to account for the effect of grammar-independent factors of perception, production, and learning.

ACKNOWLEDGMENTS

NOTES

1   The notion of empirical adequacy is straightforward: either a theory can handle the facts of language, or it cannot. The criteria for aesthetic adequacy are not well studied in linguistics: it corresponds to the difference between "explaining the facts" versus "merely grinding out the forms."

2   Natural Generative Phonology and Declarative Phonology share such a commitment to surface-true generalizations. See Hudson (1975), Hooper (1976) for basic NGP and the suppletive treatment of surface-opaque phonological alternations. In summarizing the essentials of Declarative Phonology, which strictly requires all statements to be surface true, Scobbie, Coleman, and Bird (1996: 703) claim "In particular, by arguing that would-be phonological transformations are in fact suppletive or phonetic, the one-level view of phonology is made tenable," and see pp. 694, 696 for hypothetical

examples of deletion and counter-feeding. Suppletive lexical listing is required in order to adhere to the "non-destructiveness" requirement of declarative theories: see Section 4.

3   Certain arguments for surface structure constraints in Shibatani (1973) were based on speaker-behavior facts which are outside grammar, and have no value in theory-selection phonology accounting for grammatical data patterns rather than mental states. McCarthy (2002: 10) rejects the Bromberger and Halle (1997) criticism of OT as entailing the impossibility of sorting an infinite set in finite time, on the grounds that such a consideration is external to competence, being properly part of a performance model in his opinion.

4   See Hale and Reiss (2008) for general discussion of these two perspectives.

5   However, transformational rules are (originally) taken to be non-Markovian in a limited way – see Chomsky (1956, 1957) – because reference to "NP" is a non-Markovian reference to the fact that a certain terminal substring such as "The little dog" derives from applying the rule NP $\rightarrow$ Det Adj N.

6   In a number of works, the term "rule" is also used to refer to what we would now identify as a well-formedness constraint, for example in parts of Stanley (1967).

7   There have been proposals to connect constraints to specific rules, for example the proposal of Sommerstein (1974) that rules may be "motivated by," and thus refer to, constraints, the parametric approach of Archangeli and Pulleyblank (1994), or Yip's (1988) use of the OCP as a force guiding rules.

8   C refers to category, for example, "noun," "noun phrase," "sentence."

9   Grammatical boundaries such as + and # had the formal status of matrices assigned the value [–segment,±word boundary,±formative boundary] – Chomsky and Halle (1968: 364 ff.).

10 The subscript on the braces indicates that the segments on the left become respectively the segments on the right, and that the changes are not random and unordered.

11 Whether braces themselves abbreviate conjunctively or disjunctively applied sub-rules is unclear. The Ordering Hypothesis (Chomsky and Halle 1968: 396) asserts that the sub-rules of a rule schema are applied disjunctively, but the following text fails to explicitly list braces as inducing disjunctivity. Chomsky (1965: 121) explicitly claims that braces abbreviate conjunctively-applied sub-rules.

12 It was a matter of some controversy whether the theory should allow general variables of the form X, or only abbreviatory expressions such as $(C_0V_0)_0$. See Odden (1977, 1980).

13 Since Howard (1972), questions have arisen as to the nature of the facts: see Archangeli and Pulleyblank (1994), Nevins (2004).

14 The caveat "phonologically-conditioned" also raises the possibility that phonological rules with non-phonological conditions may be subject to different principles.

15 This could be stated in standard notation as /VC [–voice]__ X, except that sonorants, which are voiced, also allow deletion of schwa.

16 This is not to say that all practitioners adhered to the principle that matrices should be fully specified: see for example Ringen (1975).

17 This rule must apply simultaneously: in an iterative model, the "free tone" condition would be invalidated after the first application of the rule. This is one of many cases of the critical interdependence of ideas in phonological theorizing, where the validity of one theory depends on the validity of an auxiliary proposition, which the competing theory does not depend on.

18 It should be noted that no argument has ever been given that there is categorical vowel deletion in *potato*, and the conclusion is based on the fact that in fast speech, there is

not usually any voicing on the vowel between voiceless stops. This is analogous to the problem of high-vowel vowel devoicing/deletion in Japanese, see Vance (1987).

19 This allows expression of the condition "is linked to something," where prior usage had required explicit specification of the two things linked.

20 Reiss proposes that both universal and existential quantifiers are required, to formulate the Non-Identity Condition – $\exists F_i \in G$ s.t $[(\alpha F_i)_1] \neq [(\beta F_i)_2]$ – and the Identity Condition – $\forall F_i \in G$ s.t. $[(\alpha F_i)_1] = [(\beta F_i)_2]$. This formalism predicts two unattested conditions, Variable Partial Identity – $\exists F_i \in G$ s.t $[(\alpha F_i)_1] = [(\beta F_i)_2]$ where at least one feature must be the same – and Complete Non-Identity – $\forall F_i \in G$ s.t. $[(\alpha F_i)_1] \neq [(\beta F_i)_2]$ where all features must be non-identical. Reiss proposes a functional explanation for the nonexistence of the latter two classes. It is worth pointing out that this can also be formally explained. Exploiting DeMorgan's Laws, the Identity Condition can be equivalently expressed as $\neg \forall F_i \in G$ s.t. $[(\alpha F_i)_1] = [(\beta F_i)_2]$. Given that, Identity and Non-Identity are a single proposition $\forall F_i \in G$ s.t. $[(\alpha F_i)_1] = [(\beta F_i)_2]$ or its negation. If the formal theory only employs the notion of feature Identity, not Non-Identity, and only employs universal quantifiers, not existential quantifiers, then all and only the attested classes of identity conditions can be formalized.

21 It is not inconceivable that homorganic syncope could be reduced to "syncopate only if an OCP violation results," but that would be counter to the general trend on constraint-driven approaches that rules are triggered by constraints only if the rule increases harmony, not exacerbates constraint violation. The problem of refining the degree of identity remains, since identity effects variably ignore features which are structurally subordinate to the presumed shared node, such as voicing or retroflexion.

22 Rules A and B are complements iff the extension of the intersection of the structural descriptions is equivalent to the union of the extensions of the two structural descriptions.

23 Strictly speaking, the DMH probably cannot be falsified since in the worst case one could simply list all of the input-output pairs of a language; but it can be shown that the rule system entailed by the theory is intolerable, in that it misses major generalizations. A test case might be possible which involved the phrasal phonology of actually unbounded clauses, of the type discussed in Odden (2000): such rules are very rare.

24 Karttunen has no discussion of the remainder of the conditioning environment, viz. "when in the onset of a closed syllable."

25 These are seen as co-existing levels of representation.

26 This is modeled in Goldsmith's approach through a connectionist-type equation involving inherent activations and lateral inhibitions.

27 See Port and O'Dell (1985) for arguments that some claimed neutralizing rules of phonology are not actually neutralizing. See Liphola (2001) for experimental evidence confirming that Makonde vowel reduction is acoustically and perceptually neutralizing.

28 With respect to expressing a single rule in terms of a set of constraints: a derivational grammar includes not just rules, but also ordering statements, which are not the topic of this chapter.

29 Whether this is actually so depends on how "single representation" is defined – see below – and for DP, how neutralizing processes are formally handled.