Optimality Theory

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Constraint Interaction in Generative Grammar

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Prefatory Note

This book derives from an informally circulated manuscript which was issued as a Technical Report by the University of Colorado Computer Science Department (CU-CS-696-95) and the Rutgers Center for Cognitive Science (RuCCS-TR-2), eventually coming to repose on the Rutgers Optimality Archive as ROA-537 (http://roa.rutgers.edu).

The current text is content-wise identical to its predecessors, with correction of as many typos, oversights, inconsistencies, and outright errors as we could track down. Footnote and example numbering has been retained. In revising the bibliography, we have tried to reconcile the twin goals of reference: to identify our sources and to provide the reader with usable modes of access to them. Those familiar with an earlier version of the text will not find new notions or notations here, but in various places a certain amount of local rewording has been attempted in the name of clarity.

The authors' names are arranged in lexicographic order.

Alan Prince
Paul Smolensky
January, 2004

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We remember Robert Jeffers with special appreciation for constructing the Rutgers environment that so greatly facilitated the progress of this work.

Everything is possible but not
everything is permitted . . .

– Richard Howard, "The Victor Vanquished"

"It is demonstrated," he said, "that things cannot be otherwise: for, since everything was made for a purpose, everything is necessarily made for the best purpose."

– Candide ou l'Optimisme, ch. I

Chapter 1

Preliminaries

1.1 Background and Overview

As originally conceived, the *Rule* of grammar was to be built from a Structural Description delimiting a class of inputs and a Structural Change specifying the operations that altered the input (e.g. Chomsky 1961). The central thrust of linguistic investigation would therefore be to explicate the system of predicates used to analyze inputs – the possible Structural Descriptions of rules – and to define the operations available for transforming inputs – the possible Structural Changes of rules. This conception has been jolted repeatedly by the discovery that the significant regularities were to be found not in input configurations, nor in the formal details of structure-deforming operations, but rather in the character of the *output* structures, which ought by rights to be nothing more than epiphenomenal. We can trace a path by which "conditions" on well-formedness start out as peripheral annotations guiding the interpretation of re-write rules, and, metamorphosing by stages into constraints on output structure, end up as the central object of linguistic study.

As the theory of representations in syntax ramified, the theory of operations dwindled in content, even to triviality and, for some, nonexistence. The parallel development in phonology and morphology has been underway for a number of years, but the outcome is perhaps less clear – both in the sense that one view has failed to predominate, and in the sense that much work is itself imperfectly articulate on crucial points. What is clear is that any serious theory of phonology must rely heavily on well-formedness constraints; where by 'serious' we mean 'committed to Universal Grammar'. What remains in dispute, or in subformal obscurity, is the character of the interaction among the posited well-formedness constraints, and, equally, the relation between such constraints and whatever derivational rules they are meant to influence. Given the pervasiveness of this unclarity, and the extent to which it impedes understanding even the most basic functioning of the grammar, it is not excessively dramatic to speak of the issues

surrounding the role of well-formedness constraints as involving a kind of conceptual crisis at the center of phonological thought.

Our goal is to develop and explore a theory of the way that representational well-formedness determines the assignment of grammatical structure. We aim therefore to ratify and to extend the results of modern research on the role of constraints in phonological grammar. This body of work is so large and various as to defy concise citation, but we would like to point to such important pieces as Kisseberth 1972, Haiman 1972, Pyle 1972, Hale 1973, Sommerstein 1974, where the basic issues are recognized and addressed; to Wheeler 1981, 1988, Bach and Wheeler 1981, Broselow 1982, Dressler 1985, Singh 1987, Paradis 1988ab, Paradis & Prunet 1991, Noske 1982, Hulst 1984, Kaye & Lowenstamm 1984, Kaye, Lowenstamm, & Vergnaud 1985, Calabrese 1988, Myers 1991, Goldsmith 1991, 1993, Bird 1990, Coleman 1991, Scobbie 1991, which all represent important strands in recent work; as well as to Vennemann 1972, Hooper [Bybee] 1972, 1985, Liberman 1975, Goldsmith 1976, Liberman & Prince 1977, McCarthy 1979, McCarthy & Prince 1986, Selkirk 1980ab, 1981, Kiparsky 1981, 1982, Kaye & Lowenstamm 1981, McCarthy 1981, 1986, Lapointe & Feinstein 1982, Cairns & Feinstein 1982, Steriade 1982, Prince 1983, 1990, Kager & Visch 1984ab, Hayes 1984, Hyman 1985, Wurzel 1985, Borowsky 1986ab, Itô 1986, 1989, Mester 1986, 1992, Halle & Vergnaud 1987, Lakoff 1988, 1993, Yip 1988, Cairns 1988, Kager 1989, Visch 1989, Clements 1990, Legendre, Miyata, & Smolensky 1990bc, Mohanan 1991, 1993, Archangeli & Pulleyblank 1992, Burzio 1992ab, Itô, Kitagawa, & Mester 1992, Itô & Mester 1992 – a sample of work which offers an array of perspectives on the kinds of problems we will be concerned with – some close to, others more distant from our own, and some contributory of fundamental representational notions that will put in appearances throughout this work (for which, see the local references in the text below). Illuminating discussion of fundamental issues and an interesting interpretation of the historical development is found in Goldsmith 1990; Scobbie 1992 reviews further relevant background.

The work of Stampe 1973/79, though framed in a very different way, shares central abstract commitments with our own, particularly in its then-radical conception of substantive universality, which we will assume in a form that makes sense within our proposals. Perhaps more distantly related are chapter 9 of Chomsky & Halle 1968 and Kean 1974. The work of Wertheimer 1923, Lerdahl & Jackendoff 1983 (chs 3 and 12), Jackendoff 1983 (chs 7 and 8), 1987, 1991, though not concerned with phonology at all, provide significant conceptual antecedents in their focus on the role of preference; similarly, the proposals of Chomsky 1986, and especially 1989, 1992, though very different in implementation, have fundamental similarities with our own. Perlmutter 1971, Rizzi 1990, Bittner 1993, Legendre, Raymond, & Smolensky 1993, and Grimshaw 1993, are among works in syntax and semantics that resonate with our particular concerns.

The basic idea we will explore is that Universal Grammar (UG) consists largely of a set of constraints on representational well-formedness, out of which individual grammars are constructed. The representational system we employ, using ideas introduced into generative phonology in the 1970s and 1980s, will be rich

enough to support two fundamental classes of constraints: those that assess output configurations *per se* and those responsible for maintaining the faithful preservation of underlying structures in the output. Departing from the usual view, we do not assume that the constraints in a grammar are mutually consistent, each true of the observable surface or of some level of representation or of the relation between levels of representation. On the contrary: we assert that the constraints operating in a particular language are highly conflicting and make sharply contrary claims about the well-formedness of most representations. The grammar consists of the constraints together with a general means of resolving their conflicts. We argue further that this conception is an essential prerequisite for a substantive theory of UG.

It follows that many of the conditions which define a particular grammar are, of necessity, frequently violated in the actual forms of the language. The licit analyses are those which satisfy the conflicting constraint set *as well as possible*; they constitute the optimal analyses of underlying forms. This, then, is a theory of optimality with respect to a grammatical system rather than of well-formedness with respect to isolated individual constraints.

The heart of the proposal is a means for precisely determining which analysis of an input *best satisfies* – or least violates – a set of conflicting conditions. For most inputs, it will be the case that every possible analysis violates many constraints. The grammar rates all these analyses according to how well they satisfy the whole constraint set and declares any analysis at the top of this list to be *optimal*. Such an analysis is assigned by the grammar as output to that input. The grammatically well-formed structures are exactly those that are optimal in this sense.

How does a grammar determine which analysis of a given input best satisfies a set of inconsistent well-formedness conditions? Optimality Theory relies on a conceptually simple but surprisingly rich notion of constraint interaction whereby the satisfaction of one constraint can be designated to take absolute priority over the satisfaction of another. The means that a grammar uses to resolve conflicts is to rank constraints in a *strict domination hierarchy*. Each constraint has absolute priority over all the constraints lower in the hierarchy.

Such prioritizing is in fact found with surprising frequency in the literature, typically as a subsidiary remark in the presentation of complex constraints.[1] We will show that once the notion of constraint-precedence is brought in from the periphery and foregrounded, it reveals itself to be of remarkably wide generality, the formal engine driving many grammatical interactions. It will follow that much that has been attributed to narrowly specific constructional rules or to highly particularized conditions is actually the responsibility of very general well-formedness constraints. In addition, a diversity of effects, previously understood in terms of the triggering or blocking of rules by constraints (or merely by special conditions), will be seen to emerge from constraint interaction.

[1] One work that uses ranking as a systematic part of the analysis is Cole 1992; thanks to Robert Kirchner for bringing this to our attention.

Although we do not draw on the formal tools of connectionism in constructing Optimality Theory, we will establish a high-level conceptual rapport between the mode of functioning of grammars and that of certain kinds of connectionist networks: what Smolensky (1983, 1986) has called 'Harmony maximization', the passage to an output state with the maximal attainable consistency between constraints bearing on a given input, where the level of consistency is determined exactly by a measure derived from statistical physics. The degree to which a possible analysis of an input satisfies a set of conflicting well-formedness constraints will be referred to as the *Harmony* of that analysis. We thereby respect the absoluteness of the term 'well-formed', avoiding terminological confusion and at the same time emphasizing the abstract relation between Optimality Theory and Harmony-theoretic network analysis. In these terms, a grammar is precisely a means of determining which of a pair of structural descriptions is more *harmonic*. Via pair-wise comparison of alternative analyses, the grammar imposes a harmonic order on the entire set of possible analyses of a given underlying form. The actual output is the most harmonic analysis of all, the optimal one. A structural description is well-formed if and only if the grammar determines it to be an optimal analysis of the corresponding underlying form.

With an improved understanding of constraint interaction, a far more ambitious goal becomes accessible: to build individual grammars directly from universal principles of well-formedness, much as Stampe 1973/79 and Bach 1965 envisioned, in the context of rule theories, building grammars from a universal vocabulary of rules. (This is clearly impossible if we imagine that constraints or rules must be surface- or level-true and hence non-interactive.) The goal is to attain a significant increase in the predictiveness and explanatory force of grammatical theory. The conception we pursue can be stated, in its purest form, as follows: Universal Grammar provides a set of highly general constraints. These often conflicting constraints are *all* operative in individual languages. Languages differ primarily in the way they resolve the conflicts: in how they rank these universal constraints in strict domination hierarchies that determine the circumstances under which constraints are violated. A language-particular grammar *is* a means of resolving the conflicts among universal constraints.

On this view, Universal Grammar provides not only the formal mechanisms for constructing particular grammars, but also the very substance that grammars are built from. Although we shall be entirely concerned in this work with phonology and morphology, we note the implications for syntax and semantics.

1.2 Optimality

The standard phonological rule aims to encode grammatical generalizations in this format:

(1) $A \rightarrow B \ / \ C\text{—}D$

The rule scans potential inputs for structures CAD and performs the change on them that is explicitly spelled out in the rule: the unit denoted by A takes on property B. For this format to be worth pursuing, there must be an interesting theory which defines the class of possible predicates CAD (Structural Descriptions) and another theory which defines the class of possible operations A → B (Structural Changes). If these theories are loose and uninformative, as indeed they have proved to be in reality, we must entertain one of two conclusions:

(i) phonology itself simply doesn't have much content, is mostly 'periphery' rather than 'core', is just a technique for data-compression, with aspirations to depth subverted by the inevitable idiosyncrasies of history and lexicon; or
(ii) the locus of explanatory action is elsewhere.

We suspect the latter.

The explanatory burden can of course be distributed quite differently than in the re-write rule theory. Suppose that the input–output relation is governed by conditions on the well-formedness of the *output*, 'markedness constraints', and by conditions asking for the *exact preservation of the input* in the output along various dimensions, 'faithfulness constraints'. In this case, the inputs falling under the influence of a constraint need share no input-specifiable structure (CAD), nor need there be a single determinate transformation (A→B) that affects them. Rather, we generate (or admit) a set of candidate outputs, perhaps by very general conditions indeed, and then we assess the candidates, seeking the one that best satisfies the relevant constraints. Many possibilities are open to contemplation, but some well-defined measure of value excludes all but the best.[2] The process can be schematically represented like this:

(2) **Structure of Optimality-Theoretic Grammar**
(a) Gen (In_k) → {Out_1, Out_2, . . . }
(b) H-eval (Out_i, $1 \leq i \leq \infty$) → Out_{real}

The grammar must define a pairing of underlying and surface forms, ($input_i$, $output_j$). Each input is associated with a candidate set of possible analyses by the function Gen (short for 'generator'), a fixed part of Universal Grammar. In the rich representational system employed below, an output form retains its input as a subrepresentation, so that departures from faithfulness may be detected by scrutiny of output forms alone. A 'candidate' is an input–output pair, here formally encoded in what is called 'Out_i' in (2). Gen contains information about the representational primitives and their universally irrevocable relations: for example, that the node σ may dominate a node *Onset* or a node μ (implementing some

[2] This kind of reasoning is familiar at the level of grammar selection in the form of the Evaluation Metric (Chomsky 1951, 1965). On this view, the resources of UG define many grammars that generate the same language; the members of that set are evaluated, and the optimal grammar is the real one.

theory of syllable structure), but never vice versa. Gen will also determine such matters as whether every segment must be syllabified – we assume not, below, following McCarthy 1979 *et seq.* – and whether every node of syllable structure must dominate segmental material – again, we will assume not, following Itô 1986, 1989. The function H-eval evaluates the relative Harmony of the candidates, imposing an order on the entire set. An optimal output is at the top of the harmonic order on the candidate set; by definition, it best satisfies the constraint system. Though Gen has a role to play, the burden of explanation falls principally on the function H-eval, a construction built from well-formedness constraints, and the account of interlinguistic differences is entirely tied to the different ways the constraint-system H-eval can be put together, given UG.

H-eval must be constructible in a general way if the theory is to be worth pursuing. There are really two notions of generality involved here: general with respect to UG, and therefore cross-linguistically; and general with respect to the language at hand, and therefore across constructions, categories, descriptive generalizations, etc. These are logically independent, and success along either dimension of generality would count as an argument in favor of the optimality approach. But the strongest argument, the one that is most consonant with the work in the area, and the one that will be pursued here, breaches the distinction, seeking a formulation of H-eval that is built from maximally universal constraints which apply with maximal breadth over an entire language. It is in this set of constraints, Con, that the substantive universals revealed by the theory lie.

Optimality Theory, in common with much previous work, shifts the burden from the theory of operations (Gen) to the theory of well-formedness (H-eval). To the degree that the theory of well-formedness can be put generally, the theory will fulfill the basic goals of generative grammar. To the extent that operation-based theories cannot be so put, they must be rejected.

Among possible developments of the optimality idea, it is useful to distinguish some basic architectural variants. Perhaps nearest to the familiar derivational conceptions of grammar is what we might call 'harmonic serialism', by which Gen provides a set of candidate analyses for an input, which are harmonically evaluated; the optimal form is then fed back into Gen, which produces another set of analyses, which are then evaluated; and so on until no further improvement in representational Harmony is possible. Here Gen might mean: 'do any *one* thing: advance all candidates which differ in one respect from the input.' The Gen $\rightleftarrows$ H-eval loop would iterate until there was nothing left to be done or, better, until nothing that could be done would result in increased Harmony. A significant proposal of roughly this character is the *Theory of Constraints and Repair Strategies* of Paradis 1988ab, with a couple of caveats: the *constraints* involved are a set of parochial level-true phonotactic statements, rather than being universal and violable, as we insist; and the *repair strategies* are quite narrowly specifiable in terms of structural description and structural change rather than being of the general 'do-something-to-α' variety. Paradis confronts the central complexity implicit in the notion 'repair': what to do when applying a repair strategy to satisfy one constraint results in violation of another constraint (i.e. at an intermediate level of derivation). Paradis refers to such situations as 'constraint conflicts'

and although these are not conflicts in our sense of the term – they cannot be, as Robert Kirchner has pointed out to us, since all of her constraints are surface- or level-true and therefore never disagree among themselves in the assessment of output well-formedness – her work is of unique importance in addressing and shedding light on fundamental complexities in the idea of well-formedness-driven rule-application. The 'persistent rule' theory of Myers 1991 can similarly be related to the notion of Harmony-governed serialism. The program for *Harmonic Phonology* in Goldsmith 1991, 1993, is even more strongly of this character; within its lexical levels, all rules are constrained to apply harmonically. Here again, however, the rules are conceived of as being pretty much of the familiar sort, *triggered* if they increase Harmony, and Harmony itself is to be defined in specifically phonotactic terms. A subtheory which is very much in the mold of harmonic serialism, using a general procedure to produce candidates, is the 'Move-x' theory of rhythmic adjustment (Prince 1983, Hayes 1991/95).[3]

A contrasting view would hold that the *Input* → *Output* map has no internal structure: all possible variants are produced by Gen in one step and evaluated in parallel. In the course of this work, we will see instances of both kinds of analysis, though we will focus predominantly on developing the parallel idea, finding strong support for it, as do McCarthy & Prince 1993a. Definitive adjudication between parallel and serial conceptions, not to mention hybrids of various kinds, is a challenge of considerable subtlety, as indeed the debate over the necessity of serial Move-α illustrates plentifully (e.g. Aoun 1986, Browning 1991, Chomsky 1981), and the matter can be sensibly addressed only after much well-founded analytical work and theoretical exploration.

Optimality Theory abandons two key presuppositions of earlier work. First, that grammatical theory allows individual grammars to narrowly and parochially specify the Structural Description and Structural Change of rules. In place of this is Gen, which defines for any given input a large space of candidate analyses by freely exercising the basic structural resources of the representational theory. The idea is that the desired output lies somewhere in this space, and the constraint system is strong enough to single it out. Second, Optimality Theory abandons the widely held view that constraints are language-particular statements of phonotactic truth. In its place is the assertion that the constraints of Con are universal and of very general formulation, with great potential for disagreement over the well-formedness of analyses; an individual grammar consists of a ranking of these constraints, which resolves any conflict in favor of the higher-ranked constraint. The constraints provided by Universal Grammar must be simple and general; interlinguistic differences arise from the permutations of constraint-ranking; typology is the study of the range of systems that re-ranking permits.

[3] An interesting variant is what we might call 'anharmonic serialism', in which Gen produces the candidate set by a nondeterministic sequence of constrained procedures ('do one thing; do another one') which are themselves not subject to harmonic evaluation. The candidate set is derived by running through every possible sequence of such actions; harmonic evaluation looks at this candidate set. To a large extent, classical Move-α theories (Chomsky 1981) work like this.

Because they are ranked, constraints are regularly violated in the grammatical forms of a language. Violability has significant consequences not only for the mechanics of description, but also for the process of theory construction: a new class of predicates becomes usable in the formal theory, with a concomitant shift in what we can think the actual generalizations are. We cannot expect the world to stay the same when we change our way of describing it.

1.3 Overall Structure of the Argument

This work falls into three parts. Part I develops the basic groundwork, theoretical and empirical, and illustrates the characteristic kinds of analytical results that can be gotten from the theory. Part II propounds a theory of universal syllable typology at two levels of idealization, drawing on and then advancing beyond various constraints introduced in Part I. The syllable structure typology provides the basis for a full-scale analysis of the rich system of prosodically conditioned alternations in the Lardil nominal paradigm. Part III begins with an investigation of the way that inventories are delimited both in UG and in particular grammars. A variety of issues are then explored which have to do with the conceptual structure of the theory and with its relation to other work along the same general lines. We conclude with an Appendix containing proofs of some theorems stated in the text proper and other material of interest.

The argument ranges over a variety of issues, problems, generalizations, and theoretical constructions. Some are treated rapidly, with the aim of extracting a general point, others are pursued in detail; sometimes the treatment is informal, at other times it is necessary to formalize carefully so that nonobvious results can be established by explicit proof. We have tried to segregate and modularize as much as possible, but the reader should feel free on first reading to tunnel through bits that do not appeal: the formalist can surely find another formal patch up ahead, the connoisseur of generalizations another generalization. We have tried to sign-post the way in the text.

If the reader's interest is piqued by the present contents, the following works, which make use of Optimality Theory in various ways and are roughly contemporary with its first inklings and exposures, may be of interest (full citations may be found in the References):

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The full range of research is well represented in the extensive bibliography of McCarthy 2002. Many contributors have made their work universally available at the Rutgers Optimality Archive, http://roa.rutgers.edu. Its search facilities provide a convenient route to the main avenues of development, analysis, and controversy that Optimality Theory has led to.